European
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SCIENCE, RESEARCH AND INNOVATION PERFORMANCE OF THE EU

2020

A fair, green and digital Europe

Research and Innovation

Science, Research and Innovation Performance of the EU 2020
A fair, green and digital Europe

European Commission
Directorate-General for Research and Innovation
Directorate A — Policy & Programming Centre
Unit A1 — R&I Strategy and Foresight

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SCIENCE, RESEARCH AND INNOVATION PERFORMANCE OF THE EU

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A fair, green and digital Europe

Foreword

Research, innovation and education are critical for Europe to lead on the twin transitions towards climate neutrality and digital leadership. Europe's industry, economy and society are changing at the speed of light. This creates not only an urgent challenge beyond the means of individual Member States, but also provides a unique opportunity to transform the EU into a fair and prosperous society, with a modern, resource-efficient and competitive economy that works for people.

In order to live up to European citizens' expectations, we also need to anticipate, react quickly and effectively to unexpected events of global magnitude, as it is now the case of the Covid19 pandemic. Europe is demonstrating clearly that science, research, innovation and education are fundamental, not only to tackle the pandemic and protect citizens, but also to exit the crisis as strong as before, and to be prepared for similar situation in the future. Protecting citizens and delivering solutions that meet their needs is vital, and is the European Commission priority.

Research, innovation and education are also key drivers for Europe's sustainable and inclusive recovery, boosting the resilience of our production sectors, the competitiveness of our economies and the transformation of our socio-economic systems. It goes without saying that in times of looming economic and social activity, strong investments in research, innovation and education remain indispensable. Within the EU's long-term budget, the new framework programme for research and innovation, Horizon Europe, is called upon to play a very strong role in support of the EU's competitive sustainability. The time has come to boldly turn Europe's frontier research and cutting-edge technology into solutions addressing societal challenges. Working together will make us worldwide innovation leaders and frontrunners in sustainability.

I am proud to present this edition of our “SRIP 2020” flagship report, which includes contributions from leading scholars and international organisations. This European Commission report investigates relevant global trends and provides an in-depth analysis of Europe’s performance in science, research and innovation over the past years. In addition, the SRIP 2020 offers extensive evidence and “deep dives” into emerging trends. It also captures the very complex reality in which research and innovation are operating nowadays, and their interaction with other crucial policies such as education and skills.

Mariya Gabriel,
European Commissioner for Innovation, Research, Culture, Education and Youth

SRIP Co-creation

The authors of this report gratefully acknowledge the policy steering by the Director-General for Research & Innovation (R&I), Jean-Eric Paquet, and the Director “Policy and Programming Centre” in the Directorate-General for R&I, Julien Guerrier. They also warmly welcome the generous support by Kurt Vandenberghe and Renzo Tomellini, as former senior management staff in the Directorate.

The 2020 edition of the SRIP Report is a result of a genuine co-creation process under the guidance of Román Arjona, Chief Economist and Head of Unit “R&I Strategy and Foresight” of DG Research and Innovation, and Jessica Larsson, Deputy Head of Unit. Julien Ravet was in charge of overall editing, coordination and steering, including the drafting of the Report, managing a number of working groups feeding into the process, and providing support to contributors (within the European Commission services and external experts and contractors).

Lukas Borunsky, Ana Correia, Roberto Martino, Tiago Pereira, Heiko Prange-Gstöhl, Ruzica Rakic, Julien Ravet, Katarzyna Szkuta and Marta Truco are lead authors of the Part 1 of the Report. The statistics for the Part 1 were collected and analysed by Tiago Pereira.

Part 2 of this Report was prepared by colleagues across the Commission, Sara Amoroso, Gaetano D’Adamo, Roberto Martino, Nikolaos Kastrinos, Ewelina Pysklo and Julien Ravet, as well as by the following external experts: Sara Calligaris, Chiara Criscuolo, Nicolas Gonne and Rudy Verlhac (OECD), Peter Cappelli (University of Pennsylvania), Frank Geels (University of Manchester), Andrés Rodríguez-Pose (London School of Economics), Désirée Rückert and Christoph Weiss (European Investment Bank), and Reinhilde Veugelers (Bruegel, CERP and KU Leuven).

Ignacio Baleztena and Ana Correia led all communication aspects related to the production and dissemination of the Report. Tonia Jímenez, Petros Malecos and Alexandra Ruete provided support with communication activities, especially the SRIP website. ESN supported the team with the graphic design of the communication deliverables.

The members of the SRIP 2020 Sounding Board were Peter Dröll (Chair), Bruno Lanvin (INSEAD/ ICANN), Martina Larkin (World Economic Forum), Irene Mia (The Economist Group), Manuel Muñiz (formerly Harvard University/ IE), William Maloney (World Bank), Dirk Pilat (OECD), Pawel Swieboda (formerly IDEA) and Ward Ziarko (BELSPO), who played an essential role in assessing the analysis and key policy implications of the Report.

Particular thanks go to our colleagues Irina Reyes (co-author of Chapter 7), Matija Matoković (author of Box 1-3), Martina Kadunc (author of Box 6.3-1), Laurent Obresse (author of Box 6.3-2) and Lars de Nul (author of Boxes 7-4 and 7-5).

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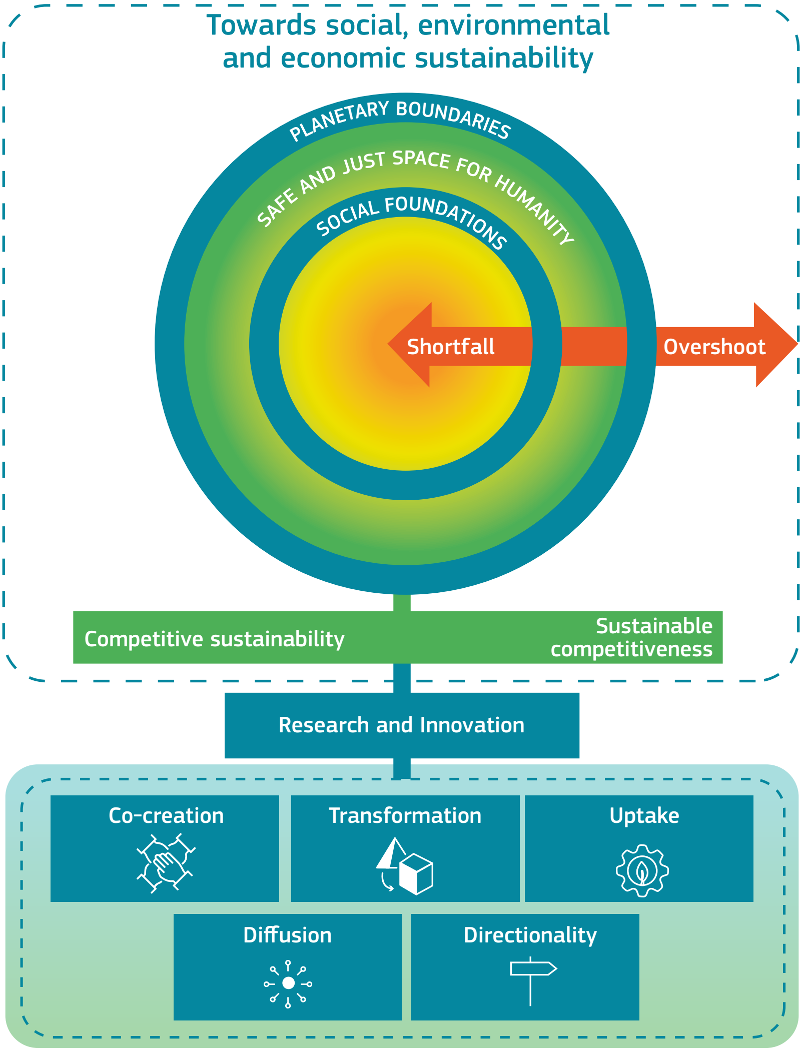
Table of contents

CHAPTER
0

Executive Summary

TOWARDS A FAIR, CLIMATE-NEUTRAL, DIGITAL EUROPE: IMPLICATIONS FOR R&I POLICY AND BEYOND



Source: DG Research and Innovation
Note: Doughnut visualisation based on Kate Raworth's work on the Doughnut Economics.

Research and innovation (R&I) are key for the future we want. They enable and drive the transition to a green and sustainable Europe tomorrow. They help us to better understand our world and provide solutions for the challenges ahead. While the COVID-19 pandemic (Box 0-1) has recently been disrupting our society, Europe has been facing global forces in the longer term and our planet has reached a tipping point.. Climate change poses an existential threat: one of the 8 million species on earth is at risk of being lost[1], and forests and oceans are being polluted and destroyed. At the same time, no one should fall short on life's essentials, such as food, housing, health and education. In this context, R&I helps us to build a safe and just

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[1] Global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (2019).

space for humanity, which avoids the overshoot of our planetary boundaries and preserves our social foundations. At the same time, the digital transformation of our economy and society, empowered by artificial intelligence (AI), blockchain and quantum computing, is revolutionising the way we live, work and innovate at an unprecedented speed.

Hence, Europe must address the *twin challenge* of the green and digital transitions to become a modern, resource-efficient and competitive economy. This means that our R&I policy will need to adapt to ensure that R&I contributes to an ample concept of sustainability – social, environmental and economic – while driving EU competitiveness. Europe's competitiveness should build on a framework of institutions, policies and factors that ensure sustainability in the long term (sustainable competitiveness), and sustainability should become a key driver of Europe's competitiveness and growth (competitive sustainability). To achieve this, EU R&I policy should be guided by the following principles (see also Chapter 1):

- **co-creation**, working and acting together for a better society;
- **diffusion**, sharing knowledge across society, territories and people;
- **uptake**, turning research into sustainable solutions with social and economic value;
- **transformation**, changing the way we consume and produce; and
- **directionality**, with R&I leading the way.

The evidence presented in this report leads to **11 policy headlines** to support our people, planet and prosperity. These include, but are not limited to, messages for EU R&I policy:

R&I FOR A SAFE AND JUST SPACE FOR HUMANITY

#1. As an overarching policy message: **the European Green Deal requires a shift towards a transformative innovation policy.**

#2. Making sure that growth **does not leave anyone behind** ... people, regions, countries and firms.

#3. Equipping Europeans with the **skills to navigate the changing world**.

#4. Fast-forwarding to **gender equality** in and through R&I.

R&I FOR GLOBAL LEADERSHIP

#5. Shaping Europe's **competitive edge in the global race for technology**.

#6. Modernising R&I policy to make it **fit for purpose in the digital age**.

#7. Ensuring **scientific leadership** and stimulating **knowledge flows** within the EU.

#8. Building a **vibrant and resilient R&I ecosystem** in the post-Siemens-Alstom era.

R&I FOR ECONOMIC AND SOCIETAL IMPACT

#9. **Maximising the value of R&I results** for society, the economy and policy.

#10. Making the EU's **regulation** innovation-friendly and forward-looking.

#11. Anticipating the future world through better **evidence for policy**.

BOX 0-1 COVID-19

The COVID-19 crisis is unprecedented and the world has been struggling to contain the pandemic. It has disrupted our lives, economy and society and stopped almost all economies worldwide from fully functioning. This crisis has demonstrated how our intimately connected world has contributed to a global pandemic causing widespread sickness and casualties and disrupting people's personal and professional lives and economies on a global scale. The crisis shows how our citizens' health and well-being, our economy and our society in general are closely interlinked.

The situation demonstrates more than ever how an anticipative, rapid and effective R&I response is crucial. R&I is an essential part of the coordinated EU response to the threat to public health from COVID-19. EU actions for R&I are focusing on:

- funding and financing R&I in virology, vaccine development, treatments and diagnostics, and wider social and economic impacts;
- speeding up research by optimising framework conditions such as research infrastructures, platforms to share information, and taking ethical issues into account;
- translating research findings into public health policy to mitigate the impacts and improve crisis preparedness;
- internal and external coordination; and
- citizen outreach and communication.

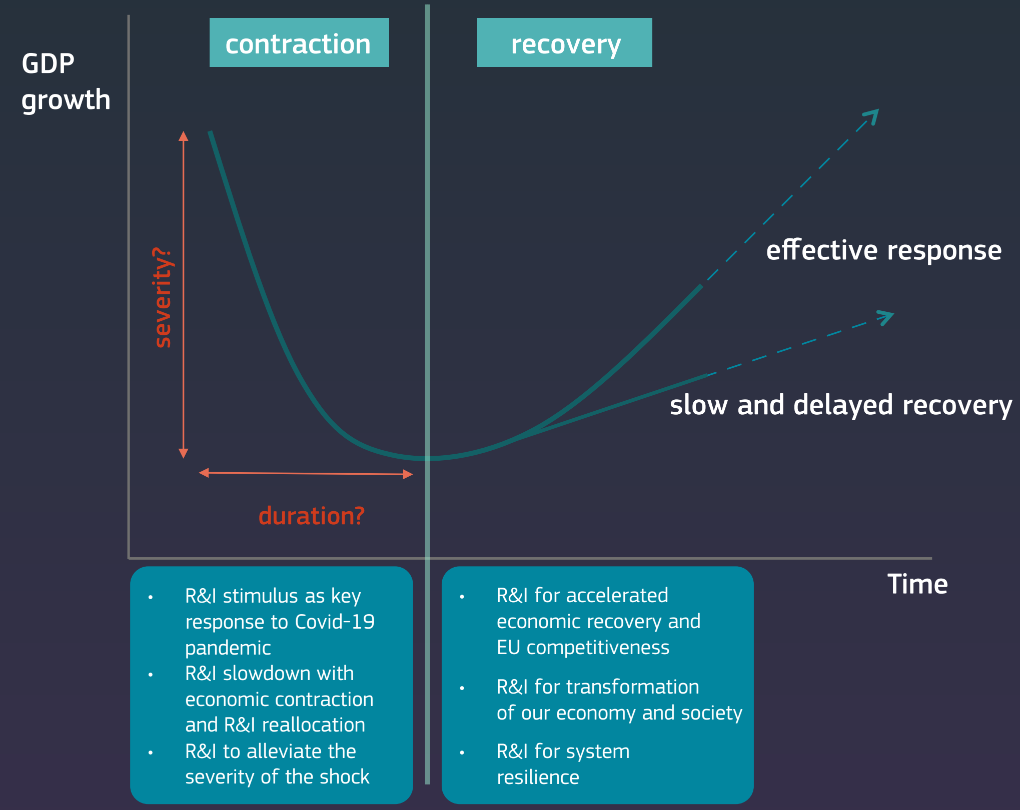
In global emergencies, such as this pandemic, it is essential to remove all obstacles to the free flow of data, researchers and ideas. AI and other digital technologies can also help to track the spread of the virus and speed up the process of diagnosis, detection and monitoring.

Moreover, while R&I is at the core of the response to the pandemic itself, it will also be crucial in the economic recovery from the crisis, not only to spur economic activity, but also to accelerate the transitions our planet and society need – a new economy for health and well-being in a broad sense (physical, mental, skills, social, environmental and economic aspects).

Hence, R&I can directly contribute to a recovery that delivers on the European Green Deal. Europe should strive to make its economic recovery truly transformative by investing massively in science-driven and innovative solutions that accelerate the transitions both our planet and society need. R&I will thus be fundamental to underpinning the shift towards a circular and low-carbon economy and securing a path to net-zero emissions by 2050.

R&I can also help to build system-wide resilience. Technologies are already helping to alleviate, at least partially, the severity of the current economic shock, with digital technologies at the core of business continuity in several sectors. It is of paramount importance to invest in making our society and economy stronger, more resilient and capable of a rapid and integrated response by drawing on the latest scientific discoveries and ensuring equal access to healthcare across the EU.

Figure 0-1 R&I and economic recovery from the COVID-19 crisis



- R&I stimulus as key response to Covid-19 pandemic
- R&I slowdown with economic contraction and R&I reallocation
- R&I to alleviate the severity of the shock

- R&I for accelerated economic recovery and EU competitiveness
- R&I for transformation of our economy and society
- R&I for system resilience

Source: DG Research and Innovation

R&I FOR A SAFE AND JUST SPACE FOR HUMANITY

#1 As an overarching policy message: the European Green Deal requires a shift to a transformative innovation policy

- 100 % increase in greenhouse gas emissions since 1980
- Twice as many Europeans aged 80+ by 2100
- 45 % of global wealth owned by the richest 1 %

Our climate and environment, economy and society are experiencing profound changes that will fundamentally alter our current way of life. R&I activities, and R&I policy, are taking place in a context where global and long-term forces are influencing our needs, including climate change, loss of biodiversity, an ageing population, and growing inequalities. Against this backdrop, the way we both produce and consume is not sustainable: currently, no country in the world seems able to meet its citizens' basic needs at a globally sustainable level of resource use.

R&I contributes to address these challenges and is key to delivering on the Sustainable Development Goals (SDGs). R&I can provide solutions[2] to overcome the challenges we face, enable us to better understand our world and make our society more resilient in the long term. In the context of accelerating digitalisation, R&I solutions are also needed to mitigate the environmental footprint of ICT and AI, improving, for example, the energy efficiency of data centres and high-performance computers, and telecommunications infrastructure. The EU is already performing strongly in several areas, leading technological progress in the fields of energy, climate, environment, food and the bioeconomy. It is crucial that the EU maintains and reinforces leadership in key areas to successfully deliver on the SDGs.

The interconnection between social, economic and environmental issues calls for a profound transformation of our systems, in particular agro-food, energy and transport. This sustainability transformation is an unprecedented governance challenge at all levels, from local to global. It results from the combined effects of the urgency, the scale of the necessary transformations, the complexity, and the interdependence of issues in a context of fragility and unpredictability. The **European Green Deal** provides a strategy to make the EU economy sustainable by turning climate and environmental challenges into opportunities across all policy areas. However, the Deal will only be possible by means of a highly ambitious agenda linking research, innovation and investments with reforms and regulation that can mobilise a collective response across Commission services, Member States, regions, companies of all sizes, academia and the public.

To deliver on the Green Deal, EU R&I policy should shift to a transformative policy which sets the direction in investments, reforms and regulation

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[2] These can include science-driven and deep-tech innovations as well as social innovations and non-research-based innovations

(see Box 0-2) to stimulate the emergence and diffusion of knowledge and (radical) solutions for the transformation towards sustainability. A transformative innovation policy can become a compass to help the EU to navigate the complexities of our world and co-create a common direction, as a key enabler of the European process for SDG policy coordination. However, this is not an easy task: a transformative innovation policy involves several policy challenges, such as **synergies** between policies, **co-creation**, involving a wider set of actors, and ensuring the dissemination of radical innovation across the market and society. **Horizon Europe**, the EU's R&I Framework Programme for 2021-2027, is a key part of EU transformative policy. It will continue to create new knowledge and solutions to achieve the SDGs and will provide increased directionality through its **mission-oriented approach** (on, for example, climate change, healthy oceans, climate-neutral and smart cities, and soil health and food) and European partnerships.

BOX 0-2 Instruments for an EU R&I policy

Actions to deliver on EU R&I policy can be regrouped under three main categories – investment, regulation and reforms – in combination with a co-creation approach across the entire Commission agenda and joining up capacity with and across the Member States through the European Research Area (see Box 0-3).

Investment

Several EU initiatives aim to step up investment in R&I capacity. Among them, the EU's R&I Framework Programmes are its main instruments for investing in R&I and directing investment towards EU political priorities.

Horizon Europe, covering the period 2021-2027, will be the EU's largest ever R&I Framework Programme, and will presents different novelties compared to its predecessor, Horizon 2020, which has covered the period 2014-2020.

- EU-wide **missions** are an important new feature of Horizon Europe. They will focus on a handful of ambitious but time-bound and achievable high-visibility goals. They are an R&I tool but offer the scope to support much broader aims to deliver European public goods on issues that really matter, such as fighting cancer, preserving our citizens' health from all kinds of pollution, ensuring food security and restoring land, and protecting our seas and oceans.
- The **European Innovation Council** (EIC) is another major novelty in Horizon Europe. It aims to put Europe on top of the next wave of breakthrough, market-creating innovation at the intersection of digital/AI and deep tech. It will be the one-stop shop for innovation, delivering on EU objectives to enable more innovators to bring breakthrough technologies to market and making it easier for small businesses to become large innovators.
- The next generation of R&I European **partnerships** also aims to respond to the needs of all EU Member States and stakeholders (citizens, industry including small and medium-sized enterprises (SMEs) and civil society) in line with agreed EU strategic priorities.

Smart specialisation strategies under the **EU Structural Funds** are another key initiative to support R&I. During 2014-2020, the European Regional Development Fund has contributed more than EUR 40 billion to the development of R&I strategies by Member States and regions a Europe.

In the coming years, the Commission will aim to ensure access to affordable finance and mobilise private funds for R&I through different instruments, such as a dedicated window under the **InvestEU Fund** that relies on financial instruments and budgetary guarantees, and **VentureEU**, which has the potential to double the total venture capital investment in Europe. The **European Investment Fund** also provides risk financing for SMEs and small mid-caps.

Regulation

The impact of these investment instruments will be greater if policy and regulation actively stimulate innovation. By applying this **innovation principle**, the Commission can help ensure that innovative activities by European entrepreneurs, researchers, business and civil society are aligned with the broader social, environmental and economic objectives and that innovation realises these objectives better and more quickly. The acceleration of technological development also calls for less traditional approaches to regulation and policy, such as **regulatory sandboxes and policy experimentation** (see also message #10).

Reforms

Most of the public budget and policies for R&I are in the hands of the Member States. This is why there is a need to encourage national policy reforms. A **European Semester** integrating the SDGs supports Member States in making effective reforms of their national and regional policies and systems. Notably, this involves linking up the necessary reforms with an appropriate synergy of investments from the relevant programmes in the Multiannual Financial Framework (e.g. European Structural and Investment Funds (ESIF), European Social Fund (ESF), Horizon Europe). This will support the alignment of efforts at the national and EU levels to address the ecological, economic and social transitions. The European Semester is reflected and reinforced by the **European Research Area** (see Box 0-3) and complemented by specific R&I assessment and governance. The **Policy Support Facility** (PSF) is an instrument to encourage Member States to improve their R&I policies. The **Structural Reform Support Service** (SRSS) also helps EU countries to design and carry out structural reforms as part of their efforts to support job creation and sustainable growth.

Given the size of the challenges ahead, having an ambitious target for investing in R&I will be crucial. Although the EU has yet to fulfil its R&D investment ambition in 2020, the **3 % target** has proven to have clear mobilising effects. National R&I investments that are aligned with a common direction can significantly accelerate the transition towards an environmentally, socially and economically sustainable Europe. The **European Research Area** (see Box 0-3) can drive such an ambition and make a significant contribution to addressing our challenges by building critical mass across countries, leveraging the renewed European Semester along the SDGs.

BOX 0-3 The European Research Area

The European Research Area (ERA) provides a framework to join up our national and European R&I agendas, strengthen national, regional and local capabilities, bridge gaps in R&I performance, and achieve the critical mass needed to maintain our international competitiveness and tackle the major challenges we face together.

The ERA is key for all dimensions that relate to **researchers** in Europe, including their working conditions and mobility (see message #7). It has the potential to mainstream core value and principles and boost ownership of R&I in all Member States and Associated Countries.

Similar to the overarching nature of the challenges that we face, the need for an innovation policy to enable the transformations required can be seen as an **overarching policy message that can be reinforced when considered together with the following 10 policy messages**.

READ MORE IN:

Chapter 1	Megatrends and sustainability
Chapter 4	Equality and cohesion
Chapter 9	Transformative innovation and socio-technical transitions to address grand challenges

#2 Making sure that growth does not leave anyone behind … people, regions, countries and firms

- 72 %, the share of total R&D expenditure by the top world 250 R&D investors
- 27 of 266 regions account for half of EU R&D spending
- 19 of the 29 EU unicorns are currently located in capital regions

There are laggards in EU R&I. There is a concentration of R&I activities in a few regions, countries and companies in Europe, and different EU R&I divides can be observed according to several indicators.

- At the level of ***people***, digitalisation, automation, and robotisation risk creating job displacement and further shrinking the labour share of income, which could have consequences for inequality, particularly income inequality and inequality of opportunity.
- At the level of ***regions***, Europe shows high concentration and agglomeration effects, with no upward convergence of regions and, for some regions, a strong need to shift to an innovation-driven growth model.
- At the ***country*** level, the EU R&I landscape presents very strong disparities. North-western Member States continue to show stronger R&I performance than other Member States. The EU has shown convergence in economic output with many countries catching up since 2000, but the economic growth in many central, eastern and southern European countries slowed down in the post-crisis decade.
- At the ***company*** level, the widening gap in terms of productivity between frontier firms and the rest points to a lack of technology diffusion. At the bottom of the distribution, the misallocation of resources, including credit, barriers to entry and inefficient product and labour markets eases the survival of less-productive firms which would otherwise have exited the market (zombie firms). However, among laggard firms, some are entering the economy, operating below their productivity potential during the first stage of their development. For these firms, R&I can play a key role by improving their absorptive capacity and allowing them to catch up with firms with higher productivity.

To tackle these different R&I divides, the EU needs to support the cohesive and inclusive growth of companies, regions and countries. R&I should be promoted through place-based policies to boost underutilised regional potential and strengthen regional innovation systems, especially in less-developed regions, to increase EU competitiveness as a whole and close the R&I divide. Cities are also key actors which need to be acknowledged and can play a significant role. There is a need to encourage public support to R&I for the catching-up laggard firms, increasing their capacity to absorb and adopt technology. It is also essential to ensure that Europeans have the skills to accompany the new technological revolutions (see also policy message #3).

This implies greater coordination at all levels of R&I policies and Cohesion Policy[3],

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[3] The implementation of smart specialisation strategies since the reform of the European cohesion policies in 2014 represents an important step in the right direction.

together with education and training. R&I policy plays an important role for laggard companies and regions to catch up by improving the conditions to speed up knowledge creation and diffusion, through investment, regulation, science-business links, framework conditions, and the capacity and quality of R&I systems. In this context, the **ERA** is key.

READ MORE IN:

Chapter 3	Productivity, structural change and business dynamism
Chapter 4	Equality and cohesion
Chapter 5	Investment in intangible assets
Chapter 10	The bottom also matters: policies for productivity catch-up in the digital economy
Chapter 12	The research and innovation divide in the EU and its economic consequences

#3 Equipping Europeans with the skills to navigate the changing world

- 8.2 % decline of middle-skills employment within the workforce over 1995-2018
- 133 million new work roles may emerge worldwide until 2022
- 8 out of 10 firms consider lack of staff with the right skills a barrier to their investment activities

With technological change, new jobs will require new knowledge and skills for workers to adapt and progress in the fast-moving labour market. The rise of digital technologies and their convergence with the physical world is already affecting millions of workers and companies around the world, changing the nature of many jobs. Today, and even more so in the future, more and more jobs will require specific skills that combine technological knowledge and problem solving together with soft skills such as collaboration or empathy. Europe's population is slowly making progress in mastering the increasingly important digital skills, but more is needed to broaden and upgrade the skills set demanded in the digital age.

In this context, there is a need to step up efforts and look for new orientations regarding skills. The **Skills Agenda**[4] is going in this direction, and also supports the green and digital transition. As the pace of innovation continues to accelerate, governments need to act and reinforce the competitiveness of their economies for the future. They will have to find

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[4] For example, by modernising vocational education and training policies, developing skills intelligence, engaging with industrial sectors/value chains, incentivising learners to take their upskilling in their own hands, helping people to have their skills validated and recognised, and developing an EU framework for micro-credentials to facilitate the recognition of shorter training.

an investment framework and strategies that enable people to harness the benefits of the technological revolution and avoid negative scenarios. Europe's prosperity and social model depends on its ability to ride the new wave of innovation ahead of us, whilst ensuring broad participation in the benefits accruing from these innovations.

Overall, EU policies need to tackle the mismatches of available skills on the labour market and improve skills intelligence and recognition. With very limited growth in the share of adults participating in education and training, it is important to increase adult participation in learning, in particular for those most in need of access to learning. This means incentivising investments in training, mentoring, coaching and other activities that promote lifelong learning and soft skills, such as the capacity to adapt and adopt new technologies in a fast-changing world. The EU must also attract talents to research in order to sustain its scientific excellence as a time when international competitors (in particular China) are expanding their talent pools. Against this backdrop, education and training will be key to refining and amplifying research skills in Europe. As skills are essential to most of the Commission priorities, including the Green Deal, social Europe, the gender strategy, and the industry strategy, there is a need for increased **synergies among programmes such as Horizon Europe, the ESF and Erasmus+**. Further strengthening links between the **ERA and the European Education Area** will be required to ensure skills and education are key drivers of Europe’s competitiveness and innovation.

READ MORE IN:

- **Chapter 4** Equality and cohesion
- **Chapter 5** Investment in intangible assets
- **Chapter 11** The consequences of AI-based technologies for jobs

#4 Fast-forwarding to gender equality in and through R&I

- Women represent about a third of all EU researchers and one fifth of researchers in the business sector
- 73 % of platform workers are men
- 16 % of start-up founders worldwide are women
- Only 6 % of unicorn founders worldwide are women; in the EU it is 2 %
- Women represent just over a quarter (27 %) of board members in the largest publicly listed companies

Despite progress, gender inequalities are persistent in Europe, as well as in R&I activities. Everyone benefits from greater female participation in the knowledge economy but we are not there yet: despite some progress, women are still under-represented in R&I and the digital economy. In education, gender imbalances among graduates are larger compared to enrolled students. Although women represent roughly half of EU graduates at doctoral level, they represent only about a third of all EU researchers and only one fifth of researchers in the business sector.

There is also a pronounced gender gap in the creation of innovative startups. The emergence of digital technologies does not help to close the gap, as observed by the lower participation of women in ICT-related fields and platform work. A gender diversity gap in AI research also persists, although it is less pronounced in Europe than in other regions worldwide.

This calls for efforts to be pursued at all levels to promote gender equality. Gender equality and gender 'mainstreaming' (the integration of a gender perspective in the preparation and evaluation of policies) in research, the promotion of these policies in R&I, and support for women's participation in the labour market should be maintained, getting them in the right position or type of job and, where possible, reinforced in order to make further progress. The EU must also tackle the start-up gender gap, beyond the classical market failures.

READ MORE IN:

Chapter 3	Productivity, structural change and business dynamism
Chapter 4	Equality and cohesion
Chapter 5	Investment in intangible assets
Chapter 7	R&I enabling artificial intelligence

R&I for global leadership

#5 Shaping Europe's competitive edge in the global race for technology

- The EU accounts for about one fifth of the world's R&D, publications and patents
- China's share in R&D worldwide has increased almost fivefold from 5% in 2000 to 24% in 2017; this rapid increase can be observed for most R&I indicators
- Productivity growth in the EU over 2008-2018 has been reduced by half compared to 1995-2007

The rapid pace of technological development among global competitors is creating concerns over technological sovereignty. While the EU is a global R&I powerhouse, accounting for almost 20% of R&D worldwide but with less than 7% of the world's population, it lags behind global competitors for various indicators, including in terms of investment in R&I and other intangibles, especially from the private sector. Furthermore, these competitors are evolving rapidly. The rise of China in particular is quite impressive and can be illustrated in technologies such as AI, where the Chinese evolution over time is significant, even though Europe shows a strong performance. EU's scaling-up performance also lags behind the United States and China: for each EU private unicorn there are eight in the United States and four in China.

Against this backdrop, R&I can reinforce companies' ability to be competitive at the global level through improved productivity, resulting in jobs and creation of value, in a sustainable way. Competitiveness, productivity and innovation are separate although very closely interrelated concepts. In the global context, it would be a mistake to ignore the fact that innovation can drive EU competitiveness through productivity growth: spurring innovation acts directly on what is produced, making goods better and cheaper, as well as ensuring that what is used to produce is done efficiently. Productivity can also help overcome the trade-off between environmental policy and long-term growth. Increasing efficiency in the production process can be compatible with producing in a sustainable way and supporting the sustainable transition. However, despite the rise in digital technologies in the past decade promising large productivity gains, productivity growth has been sluggish, holding back more robust economic growth in Europe and other advanced economies.

EU technological sovereignty at risk has several implications which link R&I policy to industrial policy. An **EU industrial strategy**, supported by a vibrant ecosystem that allows for the scaling up of its innovators and SMEs (see policy message #7), is key to countering the deindustrialisation trends in the EU and increasing long-term EU competitiveness while meeting the needs of a transition towards a climate-neutral and sustainable economy. It is crucial that the industry plays its part in achieving EU technological sovereignty by safeguarding essential elements of strategic value chains, including raw materials, assembly lines, machine tools and services. The EU's strategy for cooperation in R&I with third countries should take into full consideration the need to protect EU strategic interests. R&I cooperation also provides a common basis for engagement, developing trust and common agendas that can be blueprints for common governance of broader issues. In this context, science diplomacy can be an effective instrument of soft power in support of EU external action. Furthermore, these international considerations should be made in the light of European values and the European identity, including the choice of a different social protection system compared, for example, to the USA.

At the same time, the EU approach to R&I has long been one of openness to the world to facilitate brain and knowledge circulation, combined with strategically targeted actions with key partner countries. This multilateral approach is at the heart of EU efforts for international coordination towards achieving the SDGs, and has served EU interests by establishing mutually beneficial cooperation with international partner countries. This approach is becoming increasingly necessary as more and more new centres of excellence and markets develop outside Europe. Attracting talents to EU R&I is key to sustaining EU excellence in R&I as other countries, in particular China, are expanding their talent pools while the EU is facing negative demographic developments. Moreover, in the current R&D and geopolitical landscape, setting up a level playing field for fair competition and cooperation with third countries is lagging behind in some cases, calling for the EU to redouble negotiating efforts while anticipating any risks to its interests. Against this backdrop, **ensuring multilateralism and purposeful openness, while assertively negotiating a global level playing field, should be at the heart of the EU's approach to international cooperation**.

READ MORE IN:

- **Chapter 3** Productivity, structural change and business dynamism
- **Chapter 5** Investment in intangible assets
- **Chapter 6** Scientific performance, knowledge flows and innovation output
- **Chapter 7** R&I enabling artificial intelligence

#6 Modernising R&I policy to make it fit for purpose in the digital age

- 7/10 of the top companies by market capitalisation are US and Chinese tech giants
- 72% share of total R&D expenditure of the top world 250 R&D investors (out of the top 2000 R&D investors)
- EU28 accounts for 8% of global AI private investments
- 60% of all AI science is in fields other than computer science

Digitalisation is transforming R&I. All areas of research are becoming data-intensive, increasingly relying upon and generating big data. Technology, notably in the business-to-consumer (B2C) segment, is spreading faster than ever due to the transition from physical to digital goods combined with network effects in the age of digital transition. The convergence of the digital and physical worlds is increasing innovation complexity and leading to deep-tech science-driven innovations. There are increasing industry concentration and mark-ups over time (both in Europe and to a greater extent in North America), not confined to digital-intensive sectors. The market dominance of ‘tech giants’ is not only visible in terms of R&D concentration and market capitalisation, but also when it comes to some of the key technologies underpinning digitalisation, such as search engines, operating systems and cloud infrastructure. While the R&I investments needed to produce deep-tech innovations can prove costly, companies that sell digital products can manage to operate almost under ‘zero marginal costs’.

R&I in AI has experienced significant development over the recent years. Data explosion, stronger computational power, more sophisticated algorithms and open source software have enabled breakthroughs in AI R&I. AI is increasingly blending with digital technologies such as blockchain and with the physical world in fields such as advanced manufacturing and materials science. In terms of performance, the EU ranks among global leaders in AI science but trails in AI innovation, although it is in line with its share in global R&D. Private investments are on the rise, notably in the United States and China, but EU investments remain insufficient.

Digital transition means policy-making needs to evolve. With innovation moving at an unprecedented speed, policy should react faster to the changing contexts. Fostering deep-tech, science-driven innovations requires the right policy mix, such as supporting frontier research, R&D labs, innovation and digital hubs, appropriate research and digital infrastructures, and access to capital for digital R&I. To exploit the full potential of science digitalisation, policies must be adapted to reinforce digital skills of researchers and across society, promote open science as well as ensuring the necessary investments in high-quality data infrastructures. There is also a need to improve digital competences (see message #3) and foster the adoption of digital technologies.

The EU should capitalise on its scientific and industrial strengths to lead in AI development, and foster technologies that both benefit and augment its potential. The EU and Member States should join forces to raise the level of public and private investments in AI, deepen the **Digital Single Market**, achieve AI technology sovereignty and diffuse AI practices across the Union. AI also requires enhancing talent production and retention in the EU, investments and capacity-building in related digital technologies, such as high-performance computing, European cloud and micro-electronics, and digital infrastructure, notably 5G.

Europe should improve the 'trust in tech'. The promotion of guiding principles of trustworthy, human-centric, and ethical AI is a strength and not an obstacle to the EU AI innovation ecosystem. This also calls for improving access to data for innovation in Europe while providing clarity about principles and regulations regarding privacy and the ethical use of data.

The rise in concentration has implications for business dynamism, competition policy, and wealth distribution. There is a need to support European digital companies to compete globally in providing cloud infrastructure, operating systems and other digital technologies that are underpinning digitalisation.

READ MORE IN:

Chapter 2	Changing innovation dynamics in the age of digital transformation
Chapter 5	Investment in intangible assets
Chapter 7	R&I enabling artificial intelligence
Chapter 11	The consequences of AI-based technologies for jobs
Chapter 14	Digital adoption in Europe and the United States

#7 Ensuring scientific leadership and stimulating knowledge flows within the EU

- The EU accounts for one fifth of publications and highly cited publications in the world. The EU's share of highly cited scientific publications in food and bioeconomy is 27 %
- 13 % of EU researchers are currently employed in another country with large differences between Member States

The EU is a powerhouse in science. It is a champion in scientific production and ranks among the top players in excellence, although not at the top, with the USA maintaining its global leadership in terms of scientific quality. New global developments, such as the UK's exit from the EU, the sharp rise of China, digitalisation, and a new focus on sustainability are impacting the EU's scientific performance.

EU science is and should remain open. Europe's diversity, freedom of movement of people and cooperation between R&I actors is potentially an unrivalled source of R&I performance. The EU leads in terms of **open science policy**, with a significant impact and structuring effects on research performance. However, it can do more and foster further knowledge flows between disciplines and actors. Yet stark disparities remain between countries in international and inter-sectoral mobility patterns in the EU. In general, countries with higher R&I performance tend to have a higher inflow and outflow of researchers. Furthermore, the gap in productivity performance between highly productive economies and firms at the frontier and the rest points to a clear lack of technology diffusion in Europe.

In this context, it is essential to support the dissemination of research results, researchers' mobility, public-private cooperation and (open) international cooperation, as they are key ingredients for knowledge diffusion, creating solutions to grand challenges and boosting competitiveness in Europe. While the EU's open access policy is well advanced, with a strong open access and open data mandate in the EU Framework Programme, there is a need to step up efforts in implementing its ambitious European open and FAIR data policy.

To remain a leading global scientific player and ensure that knowledge flows between EU actors, Europe needs a strong ERA. The EU and its Member States must strengthen efforts to increase the effectiveness and performance of the public research systems through stronger R&I investments and policy reforms. This means improving further national R&I systems, continuing to facilitate and strengthen the interaction between industry and academia, stepping up efforts to implement an ambitious European open data policy, and strengthening the capacity of small firms to engage in R&I collaborations. Completing the **Single Market** is also key to fostering knowledge diffusion across the continent.

READ MORE IN:

- **Chapter 6** Scientific performance, knowledge flows and innovation output

#8 Building a vibrant and resilient R&I ecosystem in the post-Siemens-Alstom era

- 7 out of 30 top global start-up ecosystems are in the EU
- 7 % of 'today's unicorns' are based in the EU
- 8 times more venture capital funds are raised in the USA than in the EU
- In 2018, the share of public sources in total venture capital funds was 22 %

Although Europe is rich in ideas and talent, it can improve the framework conditions and ecosystem in which business takes place. While top-performing EU Member States have very efficient products and labour markets, on average, the EU lags behind the United States and Japan in these aspects. Institutional quality is high in the core of the EU and in capitals, with a high degree of regional variation and heterogeneity within and across countries. Lower access to risk capital remains a constraint to scaling up: in the United States, eight times more venture capital funds are raised for innovation than in the EU. Slightly more than 1 in 10 enterprises in the EU are high-growth, but only a relatively small share are in high-tech, medium-high-tech manufacturing and high-tech knowledge-intensive services. Overall, the EU presents 7 ecosystems in the world 'top 30' start-up ecosystems, compared to 12 in the United States and only 3 in China. It also presents a decline in business dynamism over time, which is observed in other regions in the world and may hamper productivity growth.

Europe needs to better support the scaling up of its innovators and SMEs. When it comes to tech scaleups and unicorn companies, a pronounced scaling-up gap remains in relation to the United States and (sometimes to) China. Europe should capitalise on its strong science and richness of ideas for innovation to have key players in the global scene that reflect EU's values and ambitions. This is compatible with a 'tech-with-a-purpose' approach which integrates social and environmental concerns in business missions to ensure that new products and services bring not only economic but also societal value. Overall, there is a strong need for policy initiatives that aim to tackle the scaling-up needs in terms of capital in EU startups, such as the **European Innovation Council**, the **VentureEU** programme, and the different financial instruments available via the **European Investment Bank**.

These results also call for policies that tackle the heterogeneity among Member States by ensuring efficient framework conditions and institutional quality across regions and countries, in particular in the peripheral economies in the south and east. There is a need to improve overall framework conditions for innovation, including access to finance – risk capital and other alternative sources of financing – and the deepening of the **Single Market** to ensure the scaling-up of 'made in EU' disruptive ideas, and their permanence in the EU, while maintaining a global outreach. It also means building more resilient start-up ecosystems underpinned by a strategic vision that builds upon the EU's industrial strengths and tackles societal challenges by providing solutions addressing, for example, climate change (interlinked with the European Green Deal).

READ MORE IN:

- **Chapter 3** Productivity, structural change and business dynamism
- **Chapter 8** Framework conditions
- **Chapter 13** Regulations and technology diffusion in Europe: the role of industry dynamics

R&I for economic and societal impact

#9 Maximising the value of R&I results for society, the economy and policy

- The EU accounts for 1 in 5 PCT patent applications worldwide
- The EU is third after the USA and South Korea in terms of public-private co-publications

Producing excellent solutions is not enough. It is necessary to go beyond the approach of innovation output only and have a more holistic approach to ensure robust exploitation of R&I results and, overall, knowledge valorisation. This refers to the process of creating value from knowledge and turning the results into sustainable solutions with economic value and societal benefits. R&I can only play a decisive role in shaping social, environmental and economic transitions if excellent results are quickly made available and put to practical use on a large scale.

Europe needs to make more of its R&I. Even though the EU outperforms the United States in terms of scientific output and number of researchers, it is surpassed in scientific quality, technological progress, share of high-tech sectors in the economy, and business-academia linkages. Hence, Europe needs to address its deficiencies by promoting a culture of knowledge valorisation in European R&I policy, ensuring that knowledge-based institutions know how to manage their intellectual capital and improving the links between academia, industry, citizens and policymakers.

This calls for a reinforced knowledge-valorisation policy in Europe that relies on a set of instruments acknowledging different knowledge-valorisation channels. This means supporting European intellectual property policy and culture as well as fostering science-industry interaction and engaging citizens and local communities in knowledge uptake by the markets and by society.

READ MORE IN:

- **Chapter 6** Scientific performance, knowledge flows and innovation output

#10 Making the EU's regulation innovation-friendly and forward-looking

Europe needs a fit-for-purpose, forward-looking and overall innovation-friendly regulatory framework to ensure well-functioning markets that incentivise competition and innovation, maximising the impact of EU R&I investments. Regulation, when featuring adequate levels of stringency and appropriate timing, can steer innovation towards addressing societal needs. At the same time, regulation needs the flexibility to adapt to an industry and society that are evolving rapidly. It should strike a balance between predictability and flexibility, and should also guarantee fair competition without sanctioning failure or risk-taking.

There is room to make regulation smarter in Europe, in particular for R&I. There are strong differences between the EU Member States in terms of perceived regulatory quality. However, compared to China, Europe appears to enjoy substantially more trust and confidence regarding its regulations and standards. This means that Europe should capitalise on its acquis while facing potentially unfair practices; this calls for proper agility and flexibility in its regulatory framework.

A fast-moving and increasingly complex environment poses new challenges for regulation design. The growing role of digitalisation in various sectors of the economy may not always be properly reflected in regulation, and the same applies to the increasingly data-driven nature of innovation. In this context, experimental approaches to regulation, including the so-called **'regulatory sandboxes' and policy experimentation** can also be relevant.

Regulation design can be a crucial lever for stimulating R&I to deliver on policy objectives. It goes beyond improving the environment for doing business and can contribute to achieving sustainable growth and desirable social and environmental benefits. Using horizon scanning and innovative regulatory approaches to harness future technological advances and steer them towards delivering on European Commission priorities, the innovation principle can provide valuable insights into other policies in the areas of climate, environment, health, food, competitiveness and industry. It can help harness future techno-logical advances and steer them in the direction of delivering on European Commission priorities.

READ MORE IN:

- **Chapter 8** Framework conditions
- **Chapter 13** Regulations and technology diffusion in Europe: the role of industry dynamics

#11 Anticipating the future world through better evidence for policy

R&I policy has to deal with a lot of uncertainties, and related risks, maybe even more so than in other policy fields because of the intrinsic forward-looking nature of R&I. Priorities and choices must be informed, and evidence from various sources, such as indicators, analyses, and policy evaluations, are essential to guide policymaking. However, when it comes to predicting or forecasting future developments, the task is not a trivial one. Although the notion that the future is uncertain is hardly novel, it poses challenges for policies that take a long time to set up and execute as they must rely on longer-term forecasts that can have a poor track record. Debates on the future of work illustrate the need for solid evidence in order to better anticipate upcoming developments in the labour market. While technological transformation is not expected to be friction free, there is still little evidence, beyond the perception of stakeholders, on the extent of massive disruption across sectors. In this context, faster and more accurate forecasts that provide better quality can be more desirable, for example, to identify the required future skills, but they imply policy design that allows for a faster response.

Horizon scanning is key for a strategic R&I policy that anticipates the future world. A good understanding of capacities and aspirations for future innovation is an invaluable basis for reflection and debate on the potential impacts of different investment decisions and on the normative and strategic considerations that should guide such investment decisions. A scan of the horizon at a specific point in time raises our awareness of potentially important areas of R&I and enables a better-informed R&I strategy. It allows us to ask ourselves whether or not we need to invest in all these areas and why, and by so doing, to better understand the opportunity cost of our choices. Foresight analyses and horizon scans should be systematic, continuous and comprehensive, feeding into decision-making processes that are engaging and participative, involving broad sets of stakeholders and the concerned publics, in a new EU R&I policy that will successfully pave the way to a fair, green and digital Europe.

READ MORE IN:

- **Chapter 11** The consequences of AI-based technologies for jobs
- **Chapter 15** Scanning the innovation horizon and throughout the whole report

PART

I

CHAPTER

1

MEGATRENDS AND SUSTAINABILITY

KEY FIGURES

100 %
increase in greenhouse gas emissions since 1980

2x
more Europeans aged 80+ by 2100

45 %
of global wealth owned by the richest 1 %

0
countries in the world meet basic needs for its citizens at a globally sustainable level of resource use

84 %
of Horizon 2020 investments relate to at least one SDG

What can we learn?

- **R&I activities, and R&I policy, take place in a context where global and long-term forces are influencing our needs**, including climate change, an ageing population, and growing inequalities.
- **Climate change** is the most serious among these trends.
- **R&I is key for addressing SDGs, going beyond GDP**.
- **More than 80% of investments under Horizon 2020** can be directly related to **addressing specific SDGs**.

What does it mean for policy?

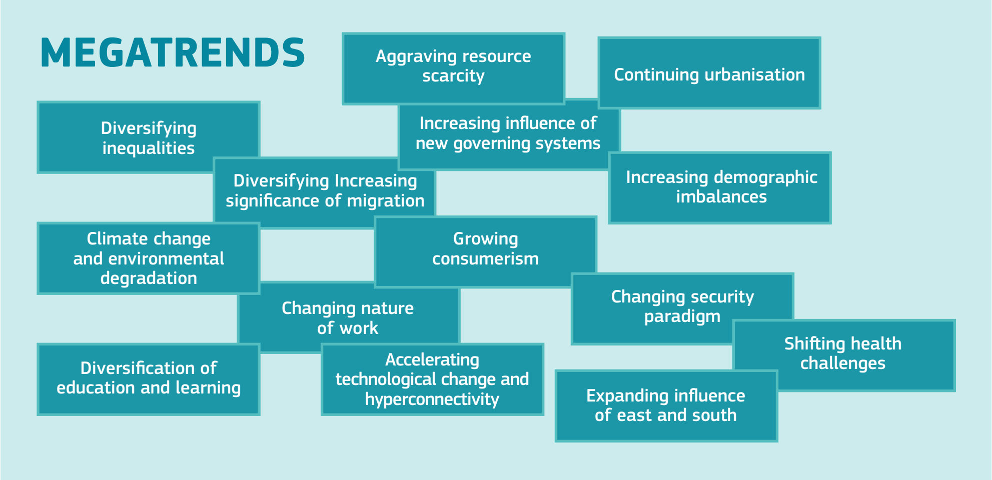
- **SDGs require transformative change**. EU R&I policy can set a direction to generate knowledge and solutions for this transformation.
- **Transformative R&I policy** can also be a key enabler of the European process for SDG policy coordination.
- **Transformative innovation and systemic transitions** involve several new policy challenges, such as horizontal policy coordination, the diffusion of radical innovations and providing directionality.

1. Megatrends, the long-term driving forces shaping our future

R&I activities, and R&I policy, take place in a context whereby global and long-term forces are influencing our needs. These forces, or *megatrends*[1], are shaping our world and will drastically influence our future (Figure 1-1). While the COVID-19 pandemic has been disrupting our society in recent months, the EU has been facing global forces in the longer term that are influencing our needs, including climate change, loss of biodiversity, an ageing population, and growing inequalities. It is crucial that we understand what these forces mean for R&I: how they affect R&I, but also how R&I can contribute to addressing the challenges they entail, by providing solutions for them, by enabling a better understanding of them, and by making our society more resilient in the long term (Ricci et al., 2017).

The COVID-19 crisis is unprecedented and the world is struggling to contain the pandemic. It has disrupted our lives, economy and society and stopped almost all economies worldwide from fully functioning. **While R&I is at the core of the response to the pandemic itself** in the areas of virology, vaccine development, treatments and diagnostics, **it will be also crucial in the economic recovery from the crisis**, not only to spur economic activity, but also to accelerate the transitions that our planet and society need - a new economy for health and well-being in a broad sense (physical, mental, skills, social, environmental and economic aspects).

Figure 1-1 Megatrends in the EC Megatrends Hub



Source: European Commission

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter1/figure-1-1.xlsx

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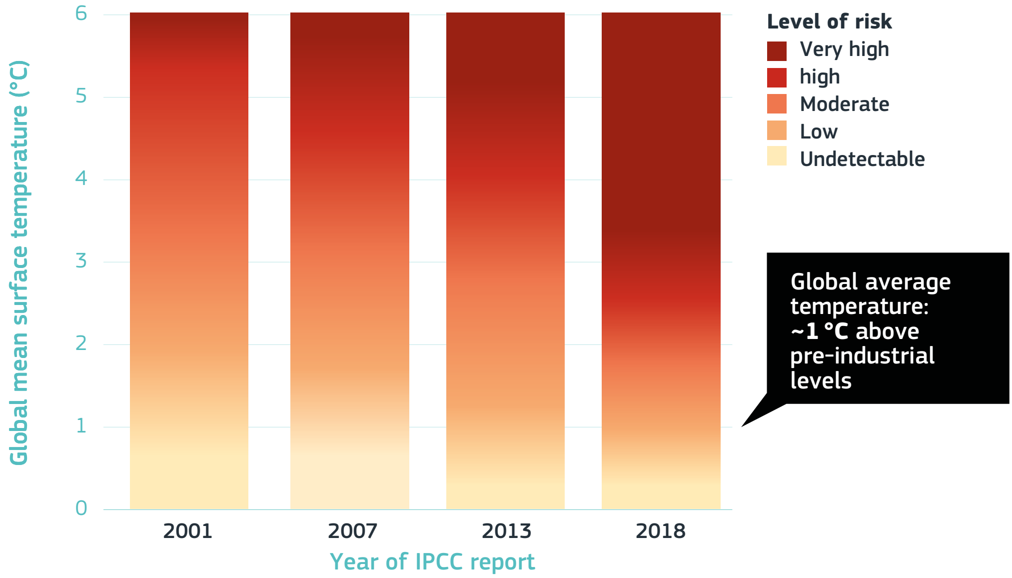
[1] See the EC Megatrends Hub or OECD (2016).

Climate change poses an existential threat

Among these megatrends, climate change poses an existential threat and requires enhanced ambition and greater climate action by the EU and at the global level[2]. The scientific case for climate action has become increasingly overwhelming and shows that a business-as-usual scenario, with continued pollution and greenhouse gas emissions[3], largely driven by economic and population growth, will lead to a further increase in global warming, ocean acidification, desertification and changing climate patterns (Figure 1-2). This has immediate implications for food security, rising sea levels and stronger storms affecting coastal areas, health issues, migration, and growing economic damage. At the same time, the Earth's biodiversity and resilience show persistent declining trends. These trends are significantly driven by resource extraction and processing which account globally for half of total greenhouse gas and 90% of biodiversity loss due to land use (United Nations, 2019a). Hence, collective action is required to steer the Earth system, i.e. biosphere, climate, and societies, to stabilise it in a habitable state. This can include **'decarbonisation of the global economy, enhancement of biosphere carbon sinks, behavioural changes, technological innovations, new governance arrangements, and transformed social values'** (Steffen et al., 2018).

Figure 1-2 Too close for comfort

Abrupt and irreversible changes in the climate system have become a higher risk at lower global average temperatures.



Global average temperature: ~**1 °C** above pre-industrial levels

Science, research and innovation performance of the EU 2020

Source: Lenton et al. (2019)

Note: IPCC refers to Intergovernmental Panel on Climate Change

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter1/figure-1-2.xlsx

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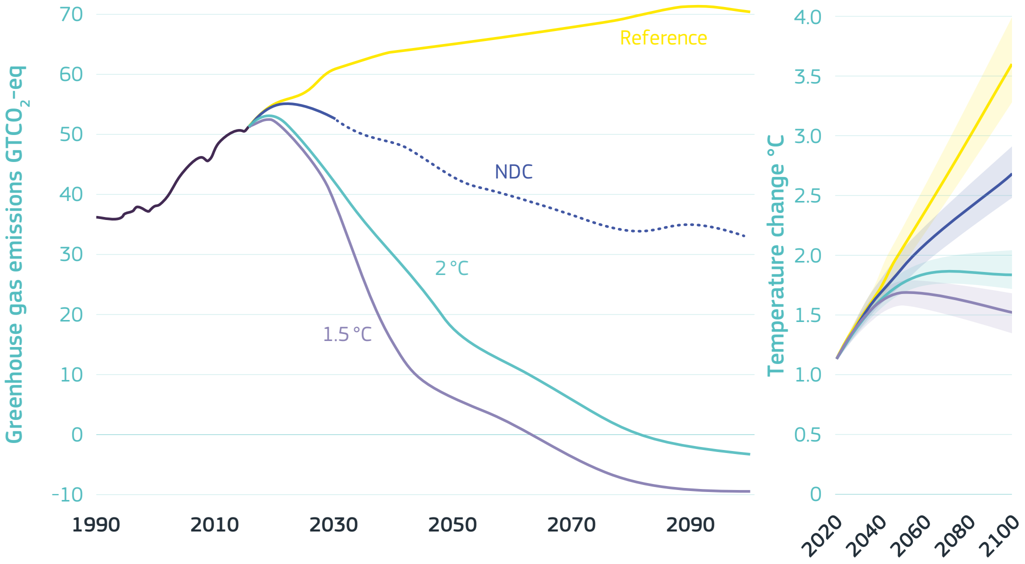
[2] https://www.consilium.europa.eu/media/41123/17-18-euco-final-conclusions-en.pdf

[3] Greenhouse gas emissions have increased by 100% since 1980, raising the average global temperature by at least 0.7 degrees Celsius (IPBES, 2019).

In this context, the 2015 UNFCCC[4] Paris Agreement set the goal of keeping a global temperature rise in this century well below 2 degrees Celsius above pre-industrial levels and pursuing efforts to limit the temperature increase even further to 1.5 degrees Celsius. The IPCC special report Global Warming of 1.5 °C (IPCC, 2018) states that 'climate-related risks to health, livelihoods, food security, water supply, human security, and economic growth are projected to increase with global warming of 1.5 °C and increase further with 2 °C. [...] Pathways limiting global warming to 1.5 °C with no or limited overshoot would require rapid and far-reaching transitions in energy, land, urban and infrastructure (including transport and buildings), and industrial systems (high confidence)' (Figure 1-3).

Figure 1-3 Global GHG emissions and global average temperature change (with median probability)



Source: GECO 2018 (POLES-JRC 2018; MAGICC online)

Note: The NDC[5] scenario assumes that the global average rate of decarbonisation implied by the NDCs in 2020-2030 is maintained over 2030-2050.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter1/figure-1-3.xlsx

Current trends for emissions and energy consumption are not on track to meet either the 2 °C or the 1.5 °C targets. Reaching these targets implies that the global energy system and energy consumption patterns would have to undergo a profound and immediate transformation to sustain unprecedented levels of global annual decarbonisation rates. Global greenhouse gas emissions would need to be cut by half by 2050 compared to 1990 and drop to zero around 2080 in order to keep temperature change under 2 °C. The 1.5 °C

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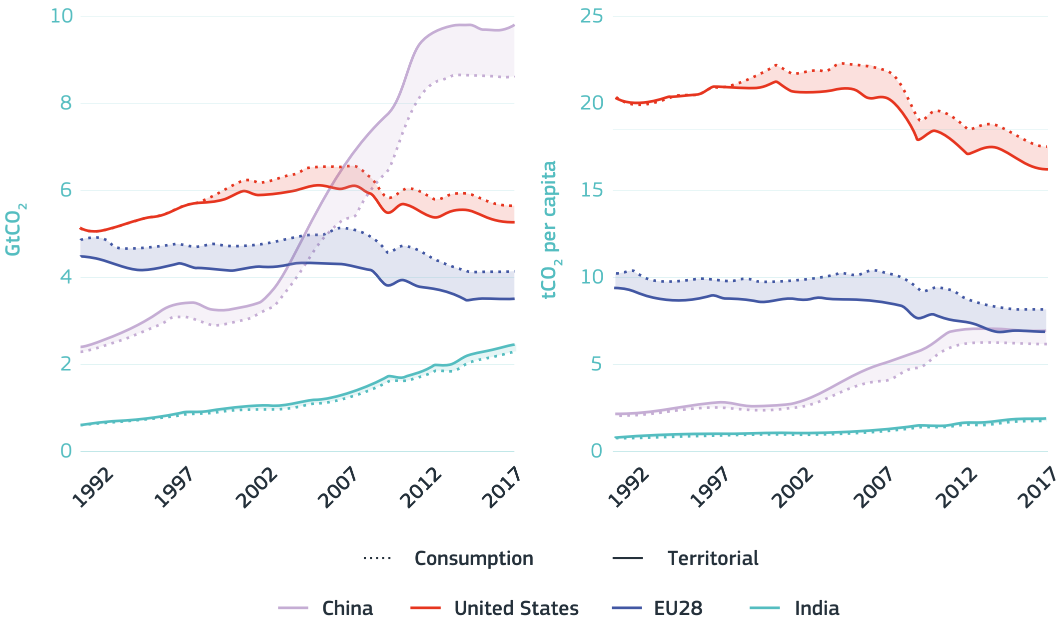
[4] United Nations Framework Convention on Climate Change.

[5] Nationally Determined Contributions.

target means an even faster reduction of emissions (European Commission, 2018). In the global context, carbon is embodied in trade flows, such that the carbon footprint from territorial emissions can differ significantly. Current net flows of embodied carbon are from developing countries to developed countries, such as the EU or the United States. These flows can offset the efforts made in terms of reducing emissions. As a result, while territorial EU emissions per capita are on a par with China (Figure 1-4), consumption-based emissions per capita are significantly higher in the EU (United Nations, 2019b).

Figure 1-4 CO_2 allocated to the point of emissions and consumption



Source: United Nations (2019b). Emissions Gas Report

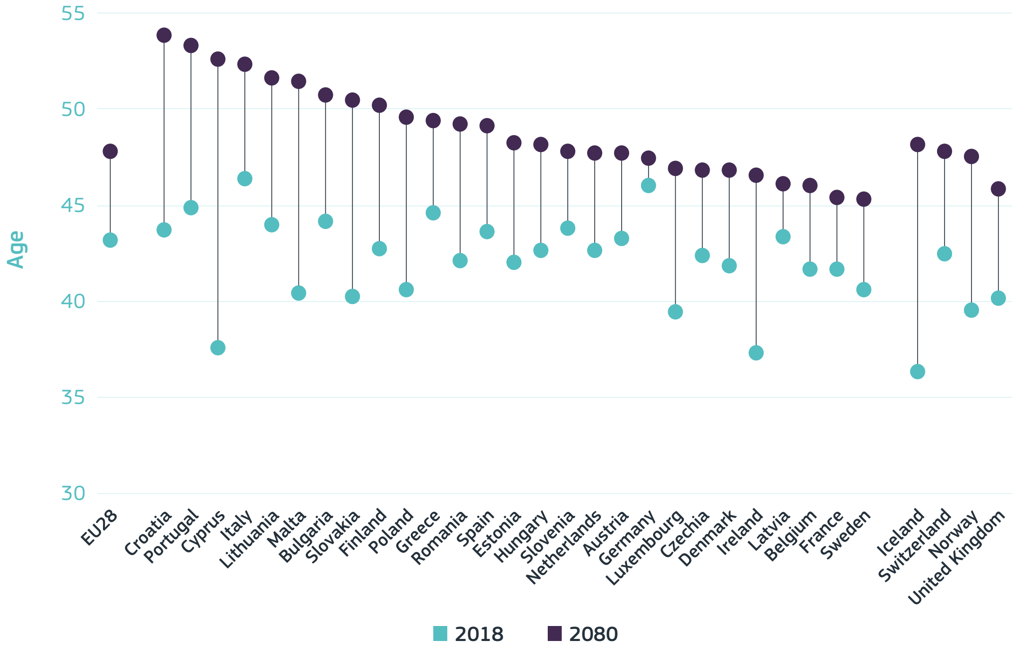
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter1/figure-1-4.xlsx

R&I will be key to achieving the climate goals. It can enable non-polluting and affordable sources of energy. Developing low-carbon technologies and solutions for decarbonisation are needed to achieve a 2 °C scenario and mitigate the consequences of climate change. According to the GECO 2018 report, 'in particular, technologies like biomass combustion with carbon capture and sequestration (BECCS) would allow CO_2 removals through using biomass energy (BE) – assumed to be carbon neutral – combined with CCS. The availability of this technology at affordable costs could be key in limiting temperature change to below 2 °C or even further.' R&I can provide solutions for and a better understanding of the challenges related to climate change and the ongoing degradation of the natural environment, including loss of biodiversity.

EU population is ageing

Another trend that directly relates to R&I is the EU's ageing population. In 2018, 20% of the EU population was aged 65 years or over. By 2100, the share of people aged 80 years or more is expected to more than double, reaching 14.9% of the entire population[6]. The median age of the EU28 population is projected to increase by 4.7 years, from 43.1 years in 2018 to 47.8 years in 2080[7] (Figure 1-5). The EU's old-age-dependency ratio[8] is projected to nearly double – from 30.8% in 2018 to 58% by 2100. The total age-dependency ratio is projected to increase from 54.2% in 2018 to 83.5% by 2100[9]. This is the result of consistently low birth rates and high life expectancy that are reshaping the EU age pyramid (Figure 1-6). One consequence of increased longevity is that people will have to work more years before they retire (Eurostat, 2019). Despite that, the number of people of working age is projected to shrink in the EU, while the share of retired people is expected to increase. An ageing population is not a phenomenon specific to the EU as the entire planet is ageing. However, one continent stands apart: Africa, in particular sub-Saharan Africa, presents very young demographics and will be the demographic engine of the world in the 21st century (EPRS, 2020).

Figure 1-5 Median age, 2018 and 2080(1)



Source: Eurostat (online data code: demo_pjanind and proj_18ndbi)
Note: (1)Values for 2018 are a baseline projection.
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter1/figure-1-5.xlsx

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[6] Based on Eurostat: Population projections at national level (EUROPOP2018).

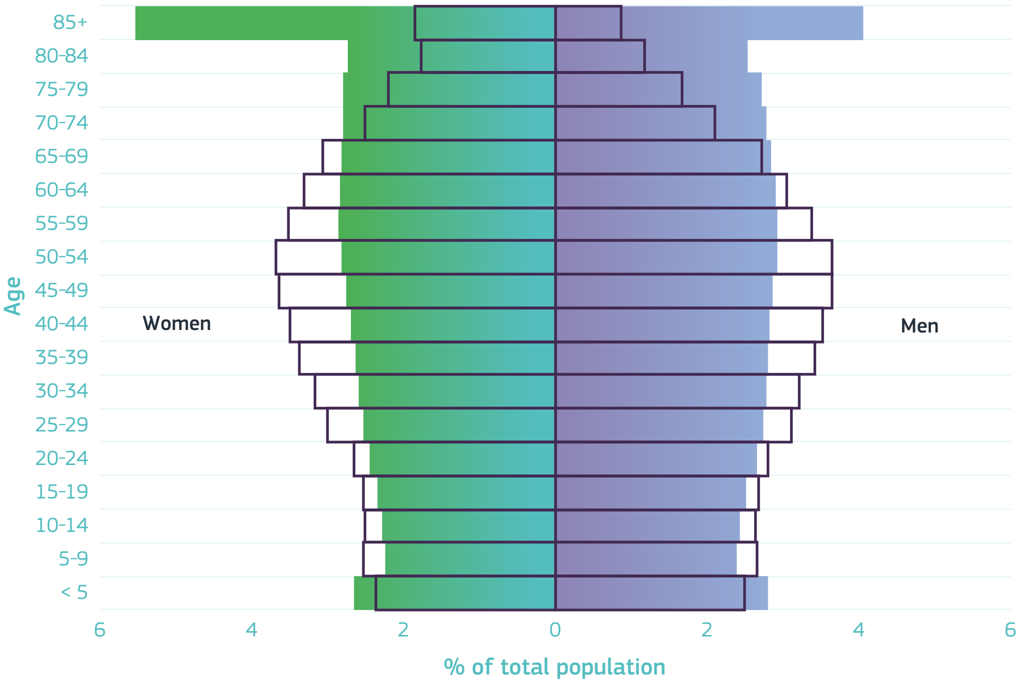
[7] Based on Eurostat: Population projections at national level (EUROPOP2018).

[8] Ratio between the population aged 65+ and those aged 15-64.

[9] Based on Eurostat: Population projections at national level (EUROPOP2018). See also European Commission's Competence Centre on Foresight – Megatrends Hub.

This trend has several consequences for R&I. First, it means that R&I will be increasingly expected to address the need for ageing-related innovations, as ageing will involve changes in lifestyle and a growing demand for specific products and services. There will be a greater need for R&I to address ageing-related illnesses, support active ageing and foster technologies such as robotics and neurosciences which can provide support to the elderly[10]. Second, productivity will need to increase to compensate for the declining share of the population in working age, together with inflows of high-skilled migrants, especially in the case of an ageing R&I workforce.

Figure 1-6 EU age pyramid, 2018(1) and 2100(2) (as % of total population)



Solid colour: 2100 **Bordered: 2018**

Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on Eurostat (online data code: demo_pjangroup and proj_18np)

Notes: (1)Provisional. (2)Projections (EUROPOP2018).

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter1/figure-1-6.xlsx

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[10] See OECD (2016).

Inequalities[10] are growing, in particular in the context of digitalisation and technological acceleration

There are concerns that new technologies may exacerbate social and geographical inequalities through job and wage polarisation, income disparities, regional disparities, and 'winner takes most' markets and industries. Intense discussion on the growing divergences and inequalities between groups of people are also increasingly focused on geographical imbalances, as described by the 'geography of discontent' or economic imbalances with emerging analyses on the lack of productivity diffusion between leading and laggard firms.

BOX 1-1 Geography of discontent

The term geography of discontent refers to a set of local economic conditions that characterise declining and lagging-behind areas (Rodríguez-Pose, 2018; McCann, 2019). It has been shown that unfavourable local conditions such as, for example, regional unemployment (linked to industrial decline) and their perception have repercussions regarding trust towards the political institutions or can drive anti-system and populist voting in Europe (Dijkstra et al., 2018).

Increased inequality as well as underperforming productivity and growth dynamics are becoming the main challenges for Europe's social political agenda. Overall, compared to other countries, Europe is a more equal place to live. This situation is largely driven by Europe's distribution of incomes and resources. Nevertheless, the commonly used Gini coefficient as a measure of inequality of income shows that EU income inequality has increased during the last two decades (Figure 1-7)[12]. Greater inequalities challenge the balance between distributional tensions and preferences for equity, in particular within countries and for population groups of a certain age or place of residence (OECD, 2019a; World Bank, 2019). Gender inequalities also remain in Europe, with an average EU gender pay gap of 16 % and extremely slow progress over time (European Commission, 2019a and 2019b).

These evolutions challenge the view that high competitiveness and strong investments in R&I automatically lead to more equality, driven by higher growth and more jobs. There is growing awareness that competitiveness and inclusiveness must go hand in hand. Recent evidence suggests that overly high levels of inequality are not economically, socially or politically sustainable (Iammarino et al., 2018; IMF, 2019; OECD, 2019b). If there is no diffusion of innovation, there is a risk that the benefits of innovation will be limited to skilled individuals, areas or companies with strong R&I assets. Evidence focusing on top income inequality and its interplay with innovation shows that technological change is associated with a higher share of income for the entrepreneur, at the expense of workers' compesation hence increasing the top inequalities (Aghion et al., 2016).

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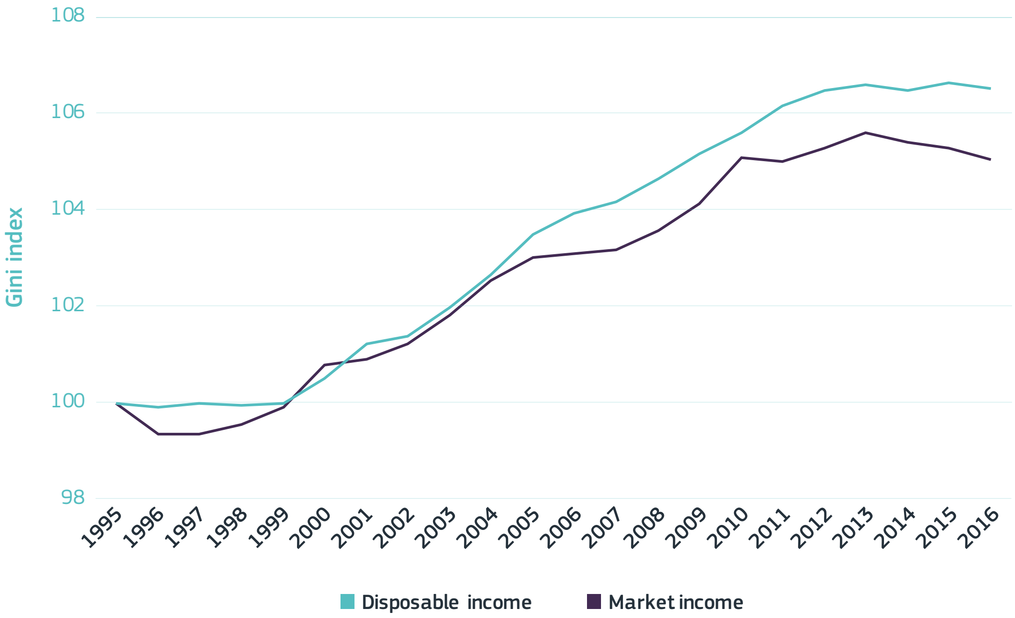
[11] Recent figures suggest that the 45 % of global wealth is owned by the richest 1 % (Credit Suisse Research Institute, 2019).

[12] The Gini Index for market income (before taxes and social transfers) in the EU rose from 46 in 1995 to 48.4 in 2016, being larger than Japan (42 in 2015) and Korea (34 in 2016) but lower than the United States (50.8 in 2016).

Figure 1-7 EU[1] - Gini index of inequality – market income and disposable income (1995 = 100), 1995-2016



Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on Eurostat

Note: (1)EU is the weighted average of the values for the 27 EU Member States.

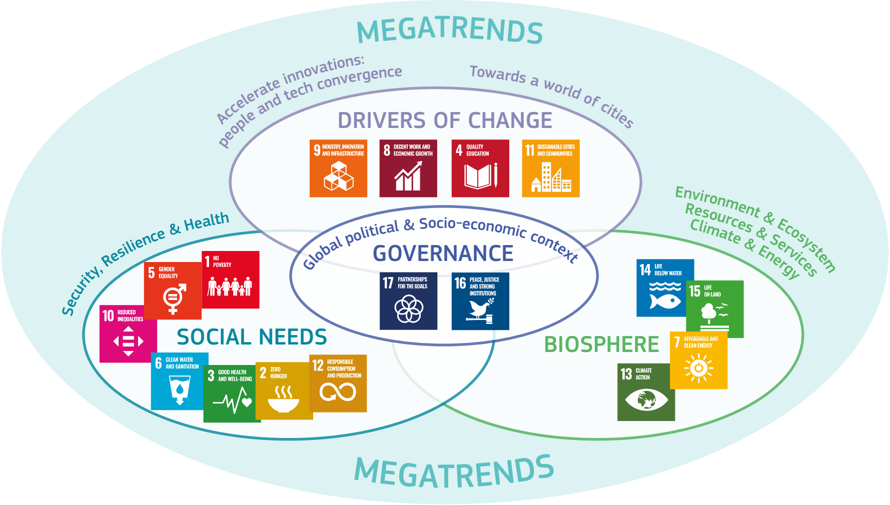
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter1/figure-1-7.xlsx

The rapid changes in global value chain configurations enabled by the application of new technologies have important implications for the new models of work organisation and workplace management. So far, most of the debate has focused on the phenomena of **skill-biased technological change**, whereby greater automation and digitalisation could enable the displacement of low-skilled jobs while increasing the demand for high-skilled jobs (software and data experts, engineering, etc.). These shifts in production technology that favour skilled labour over unskilled labour have provoked discussions on the effects of technological change on labour market and wage inequalities (Acemoglu and Autor, 2011; Okazawa 2013). **Routine-biased technological change** represents a more recent approach predicting that automation and digitalisation will lead to a decline in jobs that are rich in the routine component while increasing jobs that entail fewer routine tasks. This adjusted approach captures well the latest changes in the employment distribution with a declining share of middle-skilled occupations relative to high- and low-wage occupations, defined as ‘job polarisation’ (Sebastian and Biagi, 2018). In this context, skills will largely determine Europe's competitiveness and capacity to drive innovation. Chapter 5.2 ‘Investment in education, human capital and skills’ elaborates on the skills required in future labour markets, while Chapter 4.1 ‘Innovation, the future of work and inequality’ explains in more detail the impacts on labour markets.

2. An aspiration towards sustainability

These trends mean that our climate and environment, economy and society are experiencing profound changes that will fundamentally alter our current way of life. This is happening against a backdrop of rapid technological change that is redefining our economies and societies. Taken together, these challenges imply the need for three deep transitions along the axes of ecology, economy and society, going beyond the traditional focus on GDP growth. In this context, the EU and its Member States have signed up to the **UN 2030 Agenda for Sustainable Development[13] that specifies 17 Sustainable Development Goals** with 169 targets to guide the transition towards sustainable development (Figure 1-8). The SDGs represent an integrated concept that reconciles economic with social and environmental challenges.

Figure 1-8 Megatrends and Sustainable Development Goals



Source: BOHEMIA project (European Commission, 2018)
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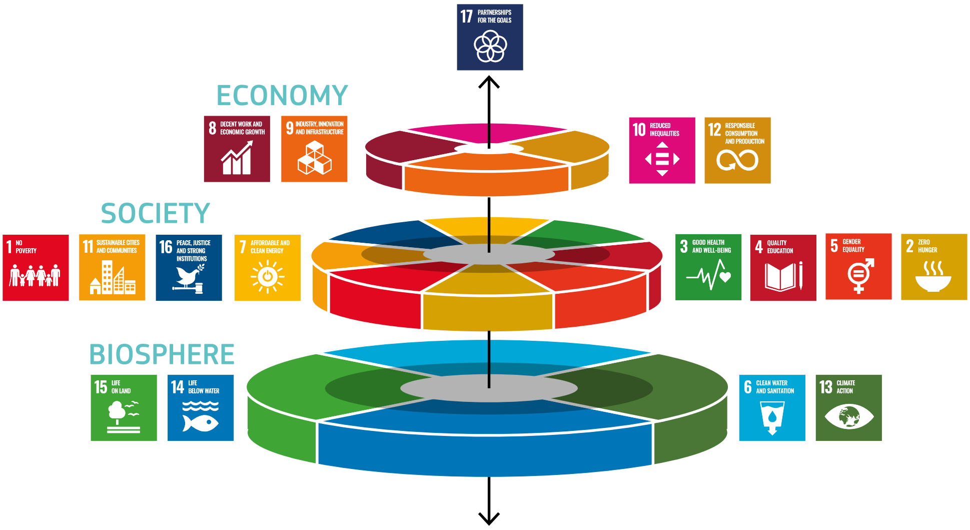
[13] https://sustainabledevelopment.un.org/post2015/transformingourworld

Economic, social, and environmental sustainability are not separate. They are interdependent and build upon one another. A prosperous and efficient economy thrives within a healthy, inclusive and resilient society, and both depend on a healthy biosphere. Thus, restoring and growing the stock of life and prosperity supporting ecosystems is a key dimension of economic sustainability. The shift from a sectoral to a holistic perspective is visualised in the 'wedding cake' model of sustainability (Figure 1-9), developed by the Stockholm Resilience Centre. This vision implies that the economy serves society so that it evolves within the safe operating space of the planet. These interconnections also imply that there are trade-offs and synergies between the SDGs. While the SDG framework shows many synergies, those related to higher incomes, better access to energy, more economic growth, and industrial and infrastructure investments tend to increase the overall extraction and consumption of natural resource, making it harder to achieve targets on their efficient use, the better management of chemicals and waste, climate mitigation and the protection of terrestrial ecosystems and biodiversity (EEA, 2020). The key challenge lies in making the right policy choices to leverage the synergies and minimise the potential trade-offs among the SDGs.

Figure 1-9 **Sustainable Development Goals**



Source: Stockholm Resilience Centre

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Sustainability implies that we should thrive in a safe and just space between planetary boundaries and social boundaries[14] (Raworth, 2017). On the one hand, an environmental ceiling of planetary boundaries should not be crossed as this would mean unacceptable environmental degradation and potential tipping points in Earth systems. On the other hand, many dimensions of human deprivation lie below social foundations. Moving into the space between these two boundaries is an aspiration that requires 'far greater equity in the use of natural resources, and far greater efficiency in transforming those resources to meet human needs' (Raworth, 2012).

Currently, no country in the world seems to meet basic needs for its citizens at a globally sustainable level of resource use. O'Neil et al. (2018) aim to quantify the transgression of biophysical boundaries and achievement of social thresholds for over 150 countries (Figure 1-10). They show that 'physical needs such as nutrition, sanitation, access to electricity and the elimination of extreme poverty could likely be met for all people without transgressing planetary boundaries. However, the universal achievement of more qualitative goals (for example, high life satisfaction) would require a level of resource use that is 2-6 times the sustainable level, based on current relationships.' Europe achieves the social thresholds for almost every indicator, but it does so by transgressing the safe levels for almost all biophysical boundaries. The only one that Europe does not exceed is water use. At the other extreme, countries like Sri Lanka stand within the safe boundary for every single environmental indicator but only achieve an acceptable level for three of the social indicators. The situation in the United States is similar to the EU, with most social thresholds achieved and biophysical boundaries transgressed. In comparison, China presents more shortfalls regarding the social dimensions but less overshoot on the biophysical aspects.

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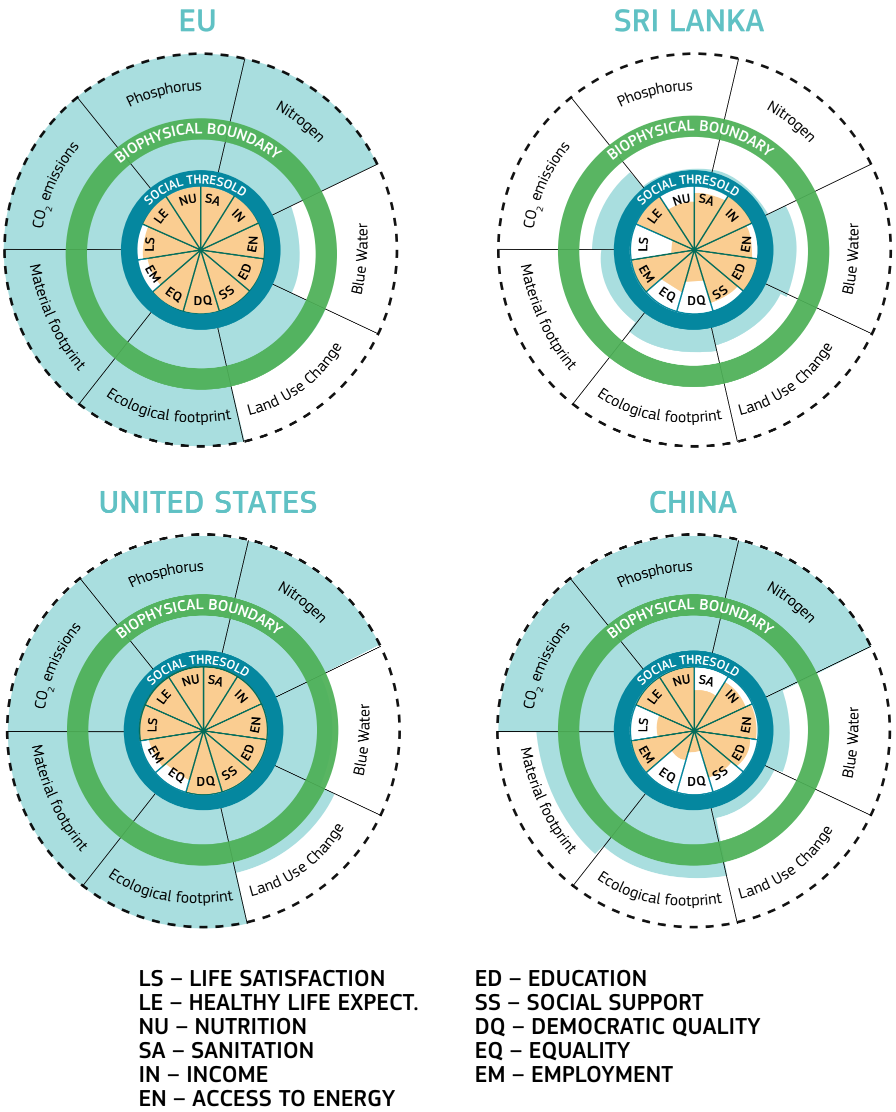
[14] Planetary boundaries' is a concept which refers to a series of sustainability limits beyond which lie tipping points for many earth systems that could result in the planet becoming inhospitable for humanity. In her book 'Doughnut Economics', Kate Raworth joined the idea of planetary boundaries with that of a social foundation to provide the 'safe operating space' for humanity.

Figure 1-10 Doughnut representation of biophysical boundaries and social thresholds



Source: https://goodlife.leeds.ac.uk/

Note: Orange wedges show social performance relative to a threshold associated with meeting basic needs (blue circle); light blue wedges show resource use relative to a biophysical boundary associated with sustainability (green circle). Wedges with a dashed edge extend beyond the chart area. Ideally, a country would have orange wedges that reach the social threshold and light blue wedges within the biophysical boundary. This graphic is based on Kate Raworth's work on Doughnut Economics. Here, EU refers to EU+UK.

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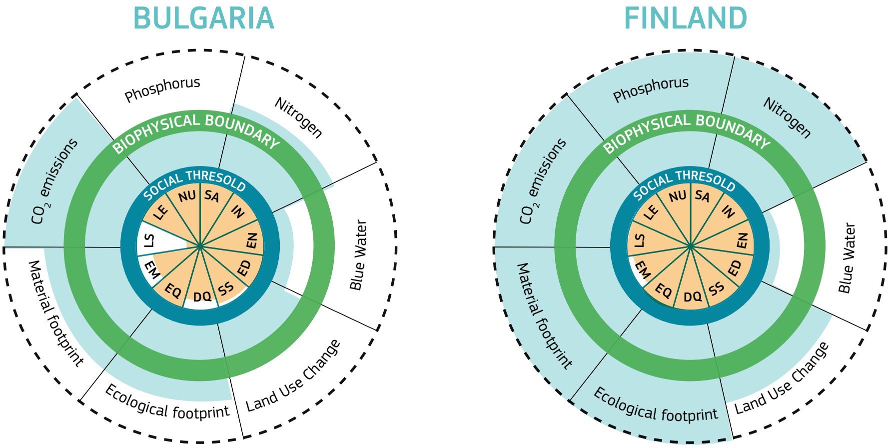
There are also disparities between Member States in terms of social and biophysical achievements. Bulgaria presents the lowest average level of transgression of biophysical boundaries[15] and Finland the highest (Figure 1-11). All EU countries transgress at least five out of the seven biophysical boundaries, with Spain, Portugal and Greece transgressing all of them. There is more dispersion in terms of social achievements, with the lowest thresholds achieved in Latvia (4 out of 11), Lithuania and Portugal (5), while the Netherlands and Austria achieve all social thresholds.

Figure 1-11 **Extreme biophysical scores in the EU**



LS – LIFE SATISFACTION
LE – HEALTHY LIFE EXPECT.
NU – NUTRITION
SA – SANITATION
IN – INCOME
EN – ACCESS TO ENERGY
ED – EDUCATION
SS – SOCIAL SUPPORT
DQ – DEMOCRATIC QUALITY
EQ – EQUALITY
EM – EMPLOYMENT

Source: https://goodlife.leeds.ac.uk/
Note: Orange wedges show social performance relative to a threshold associated with meeting basic needs (blue circle); light blue wedges show resource use relative to a biophysical boundary associated with sustainability (green circle). Wedges with a dashed edge extend beyond the chart area. Ideally, a country would have orange wedges that reach the social threshold and light blue wedges within the biophysical boundary. This graphic is based on Kate Raworth's work on Doughnut Economics.
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter1/figure-1-11.xlsx

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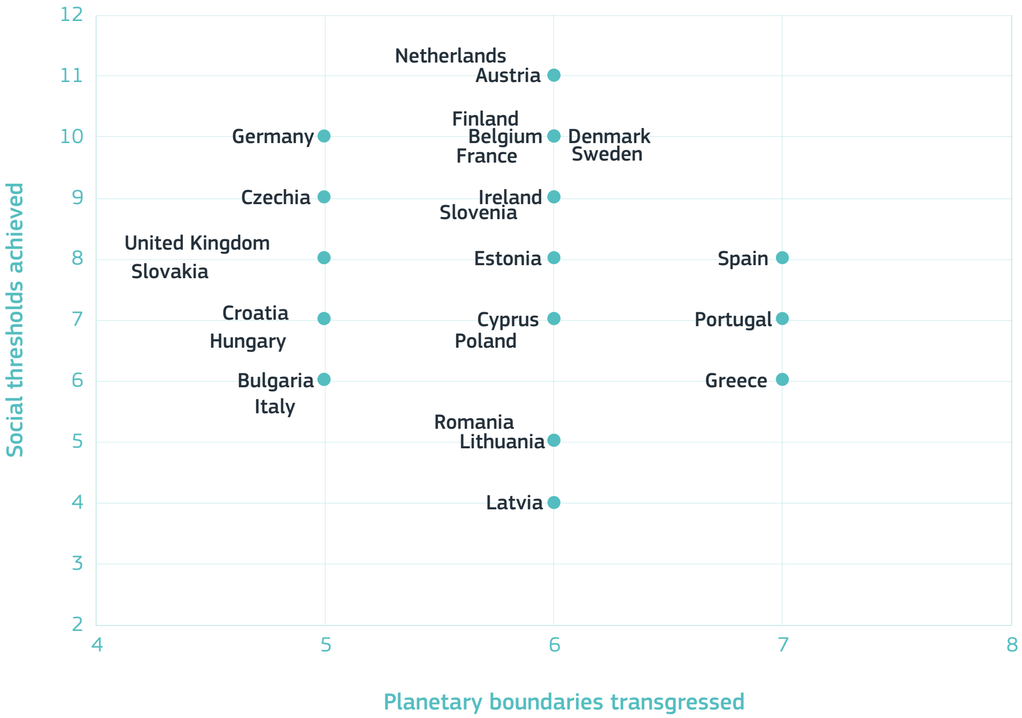
[15] Based on the average score of the dimensions.

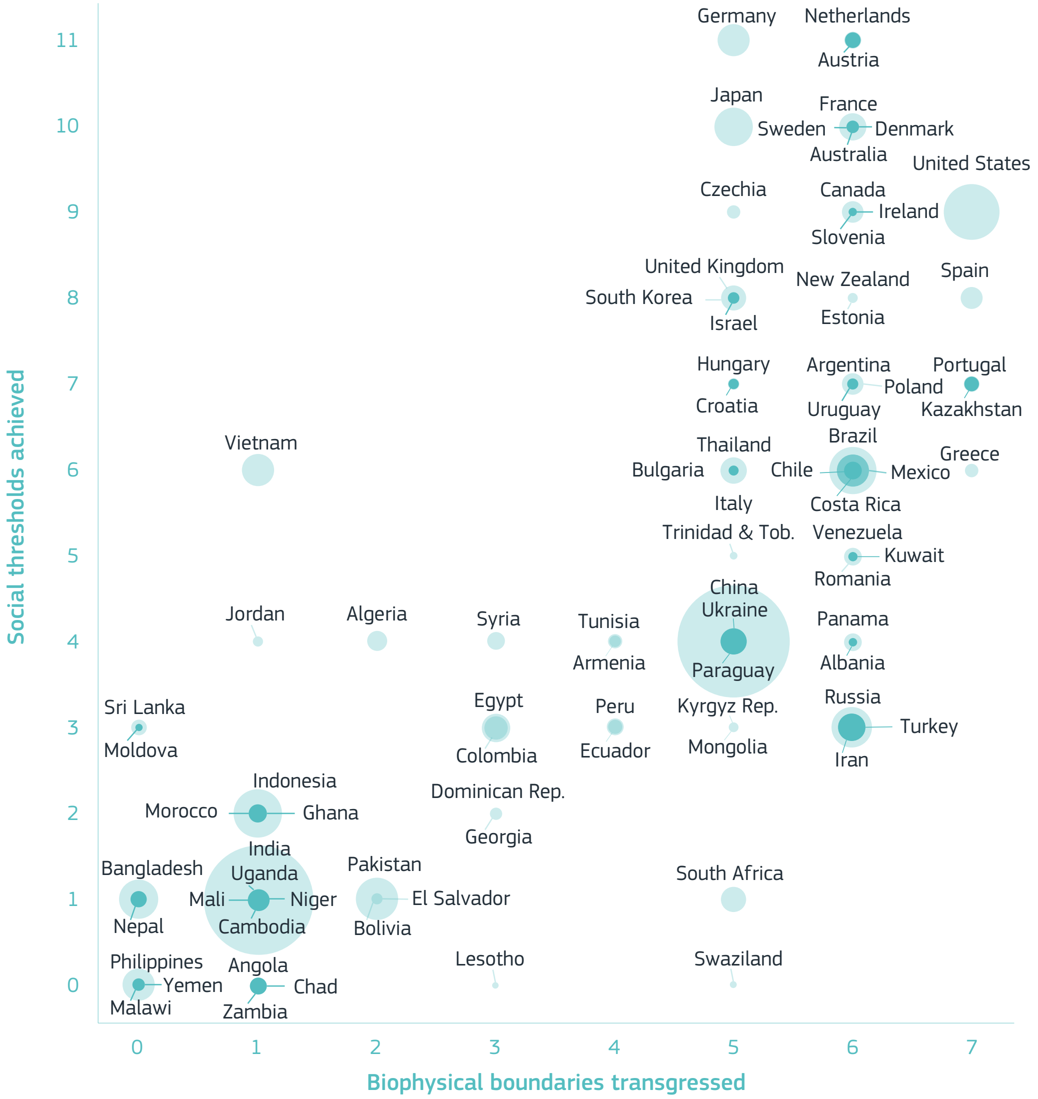
These results suggest that countries that do well on the social indicators are using resources at an unsustainable level. This shows the challenge of achieving social thresholds while not exceeding the biophysical boundaries (Figure 1-12), using resources at a level that is high enough to meet people's basic needs (the social foundation) but not higher than the ecological ceiling (as determined by the planetary boundaries), as conceptualised by Raworth (2017). O'Neil et al. (2018) present an overview of countries at the global level that illustrates the relationship between these two dimensions (Figure 1-13).

Figure 1-12 Biophysical boundaries and social thresholds in the EU28



Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit, based on https://goodlife.leeds.ac.uk/
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter1/figure-1-12.xlsx

Figure 1-13 Biophysical boundaries and social thresholds – global perspective



Source: O'Neil et al. (2018)

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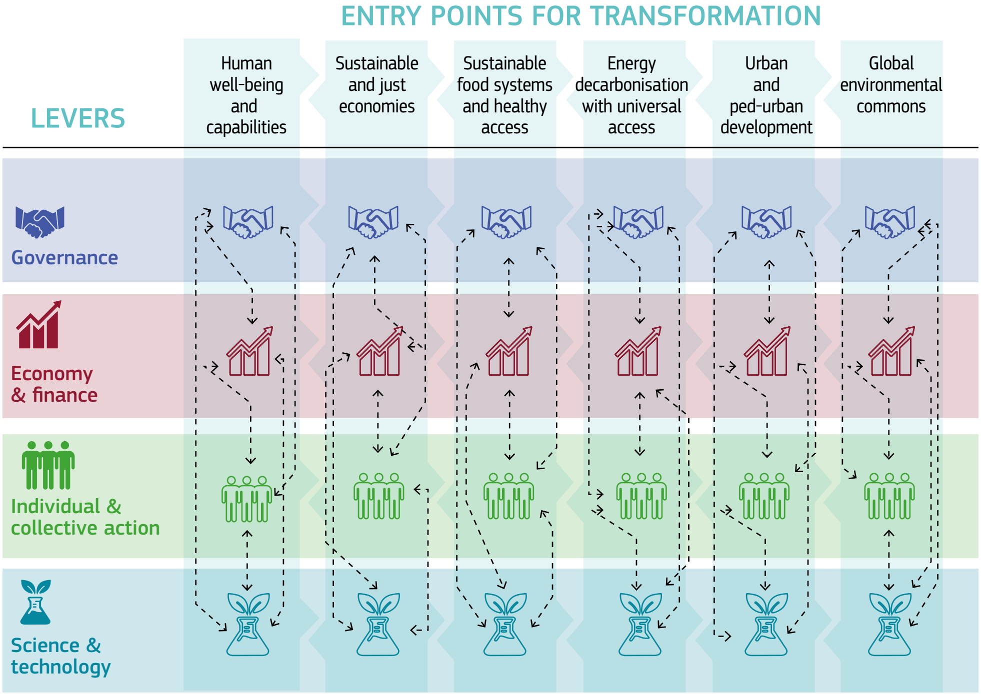
3. R&I can accelerate the transition to a sustainable Europe

The interconnection between social, economic and environmental issues call for systemic change in which R&I plays a key role. EPSC (2019) highlights the need for policy action directed at 'capturing the multiple dimensions of sustainability [...] to overcome the often siloed approach pursued by most actors at all levels of government', referring to the inextricable links of the safe and just space for humanity between social shortfall and ecological overshoot. In this context, cross-cutting policies such as R&I will play a key role in achieving sustainable development. They have the unique capacity to set directionality without being prescriptive, and to create synergies across policies to increase overall impact. Science and technology are key levers for the transformation required to address SDGs (United Nations, 2019b). However, R&I will need to interact with other levers, such as governance, economy and finance, and individual and collective action, in order to bring about the transformations required to address the SDGs (United Nations, 2019b) (Figure 1-14).

Figure 1-14 **Entry points for transformation**



Source: United Nations (2019c), Global Sustainable Development Report

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R&I is a cornerstone for a robust European project in a global context that can accelerate the transition to sustainability, while improving our well-being and ensuring longer-term prosperity. First, R&I is needed to produce novel solutions in areas like health, digital technologies, industrial transformation, resilient societies, natural resources, energy, mobility, environment, food, low-carbon economy and security. R&I solutions also enable both economic and environmental efficiency to be improved while developing new sustainable ways to satisfy human needs. Second, R&I helps to build the necessary knowledge and understanding of the phenomena to be addressed. Third, R&I, in particular frontier research, can strengthen society's resilience by building a reservoir of knowledge over the long term (Ricci, 2017). Hence, R&I can become a compass helping the EU to navigate the complexities of the 'Anthropocene' and to co-create a common route. R&I can also be the engine room for answers and solutions in the transformation towards sustainability, contributing to solving challenges at the global level. Figure 1-15 presents some of our main findings on how R&I contributes to sustainability.

Figure 1-15 Sustainability across the report

▸ **Consumers are increasingly putting pressure on companies to become more environmentally friendly**, with millennials leading this push for change in organisations. ▸ **Indicator**: › Percentage of respondents who said that it is 'extremely' or 'very' important that companies implement programmes to improve the environment, with each generation.	Continue reading in Chapter 2 - Changing innovation dynamics in the age of digital transformation
▸ **Productivity growth and sustainability can reinforce each other**. Productivity can help overcome the trade-off between environmental policy and long-term growth. ▸ **Indicators**: › Sectors most affected by the transition to sustainability in the energy sector (million jobs) › Growth of the environmental sector in the EU.	Continue reading in Chapter 3.1 - Productivity puzzle and innovation diffusion
▸ Despite some progress, a pronounced **gender gap remains in the creation of innovative startups**. ▸ **Indicators**: › Evolution of the share of innovative startups with at least one female founder, 2000-2016 › Share of innovative startups founded between 2000 and 2017 with at least one female founder by country › Number of unicorns with at least one female founder, by year of first venture capital round raised, 2013 - May 2019 ▸ A **'tech with a purpose' approach** would leverage R&I to create the solutions that match the urgency of the environmental and social challenges of our time.	Continue reading in Chapter 3.3 - Business dynamics and its contribution to structural change and productivity growth

▶ It is important for **adult learning systems to be inclusive and aligned with skill needs in order to reach out to workers at most risk of job loss or displacement**. ▶ **Indicators**: › Participation rate in adult training › Highest and lowest shares of job-related adult learners ▶ The emergence of digital technologies does not help to close **the gender gap** as observed by lower participation of women in ICT-related fields and platform work. ▶ **Indicators**: › Share ICT specialists by sex › Share of platform learners by age and sex › Female-founded startups across different sectors – share of companies with at least one female founder (%)	Continue reading in Chapter 4.1 - Innovation, the future of work and inequality
▶ **The increasing level of knowledge complexity[16] suggests that even the metropolitan areas and well-connected regions concentrate top scientific publications in the fields of societal challenges**. ▶ **Indicator**: › Relative specialisation of top regions by societal challenges	Continue reading in Chapter 4.2 - Regional R&I in Europe
▶ **The United States leads in climate-related R&D spending, China has recently quadrupled its spending, slightly overtaking the EU**. ▶ **Indicator**: › Investment in climate R&I ▶ **Member States are slowly steering their national budgets towards societal and environmental challenges**. ▶ **Indicator**: › Evolution of government budget allocations to R&D in the EU	Continue reading in Chapter 5.1 - Investment in R&D
▶ **Gender imbalances among graduates are larger compared to the number of enrolled students where women represent 54%**. ▶ **Indicator**: › Share of tertiary graduates by sex ▶ **Women are a minority in the top academic grade and their position in recent years has improved only slightly**. ▶ **Indicator**: › Share of females as head of institutions in the higher education sector ▶ Although females represent roughly half of EU graduates at doctoral level, **women represent only about a third of all EU researchers and only one fifth of researchers in the business sector**. ▶ **Indicator**: › Total researchers	Continue reading in Chapter 5.2 – Investment in education, human capital and skills

▶ **Science is key in addressing societal challenges**. The EU leads high-quality scientific publications in the **food/bioeconomy and climate/environment** sectors. ▶ **Indicators**: › Regional collaboration matrix for SDG core and citing papers › Share of scientific publications by societal challenge › Shares (%) of top 10 % scientific publications by societal challenges, 2006 and 2016 › EU specialisation by societal challenge compared to its major competitors, 2005-2009 and 2014-2018 › EU specialisation compared to the US › Global performance of EU universities against UN SDGs in the Times Higher Education University Impact Rankings 2019	Continue reading in Chapter 6.1 - Scientific performance
▶ The EU is **leading technological progress in the fields of energy, climate and environment and food and bioeconomy**. ▶ **The total number of patent applications related to the societal challenges increased over time in all fields**. ▶ **Indicators**: › Total number of PCT patent applications by societal challenge, 2000-2016 › Share of PCT patent applications by societal challenges, 2016 vs. 2006 › EU27 Specialisation Index by societal grand challenge (vs. rest of the world) › EU27 Specialisation Index(1) by societal grand challenge (vs. United States and China), three-year average period	Continue reading in Chapter 6.3 - Innovation output and knowledge valorisation
▶ **AI is a potential game changer for productivity and sustainability**, provided the right complementary skills, infrastructure and management culture are in place. **R&I solutions are needed to mitigate the environmental footprint of AI**. ▶ **Indicators**: › How AI and digital technologies can contribute to cutting global emissions across sectors (estimates) ▶ **The lack of gender diversity in AI research persists although over time progress is being made, notably in European countries**. ▶ **Indicators**: › Percentage of AI and non-AI papers with at least one female author by country, 2018	Continue reading in Chapter 7 - R&I enabling artificial intelligence

Science, research and innovation performance of the EU 2020

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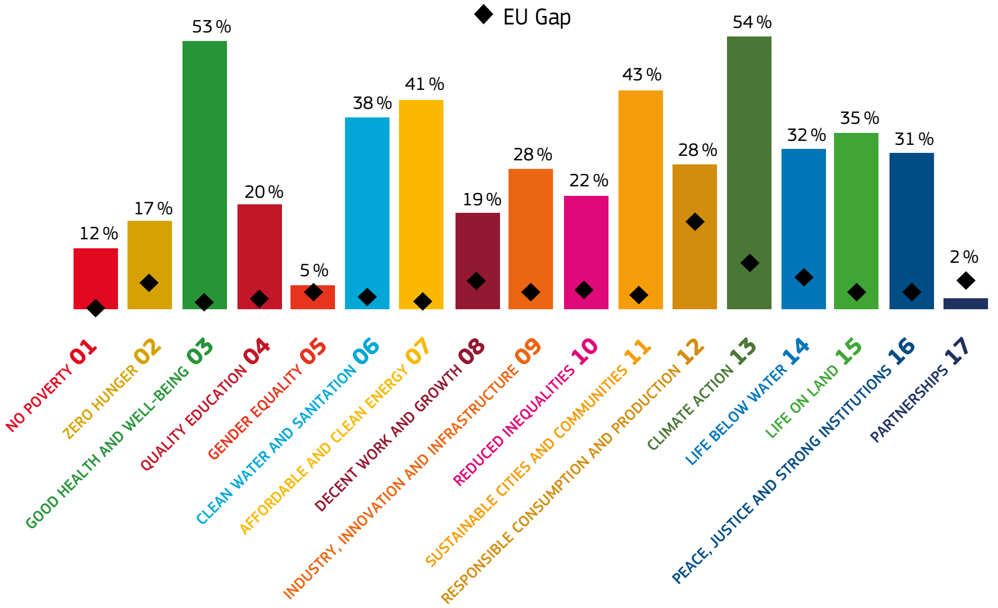
16 Refers to assets for innovation activities of the knowledge economy. See Chapter 2 Changing innovation dynamics in the age of digital transformation or earlier publications, such as Westlund, 2006.

R&I projects under Horizon 2020 illustrate how R&I can foster the Sustainable Development Agenda (see Box 1-2). Potentially, 84% of current Horizon 2020 investments relate to at least one of the SDGs. All three pillars of the programme appear to contribute to the SDGs to a similar degree ('top-down' and 'bottom-up' investment) which could indicate an underlying systemic move towards an 'SDG-inspired' R&I. The largest share of investment relates to climate action and good health and well-being (54% and 53% of the current Horizon 2020 investment, respectively) (Figure 1-16). Conversely, the focus of EU R&I investment on responsible production and consumption is low compared to the current EU performance gap in this area (28% of current Horizon 2020 investment). The EU performance gap is based on the latest EU distance to target reported by the UN Sustainable Development Report 2019 (Sachs et al. (2019)).

Figure 1-16 Share of Horizon 2020 investment and the EU distance to target, by SDG[1]



Source: European Commission (2020). Monitoring Flash: Sustainable Development Goals

Note: [1]The report uses a methodology based on the keyword search to relate projects funded with SDGs. For each of the SDGs, a list of keywords was assembled based on the compilation and cross-checking of keywords used for similar endeavours (i.e. Mapping Austrian Research Contributions to the Sustainable Development Goals, Aurora Universities Network SDG analysis and Australian Guide for Getting Started with the SDGs in Universities).

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BOX 1-2 Examples of R&I projects providing solutions that contribute to SDGs (funded by the EU R&I Framework Programme)

Never-ending battery

EU funding helped an Estonian company produce an energy-storage device called an ultracapacitor which is 100 times more powerful than an ordinary battery and can withstand 1 million recharge cycles. Skeleton's ultracapacitors are based on graphene, a two-dimensional form of carbon with remarkable properties. The company raised EUR 13 million to build a manufacturing facility in Germany capable of producing millions of new ultracapacitors a year.

More about the SKLCarbonP2 project.

Making old buildings energy efficient

Old buildings consume a lot of energy. Finding a solution to decarbonise Europe's building stock is a vital part of the fight against climate change. The EU-funded BERTIM project has developed a new industrial solution that cuts the energy consumption of renovated buildings by half, and the time spent on the building site by 30%.

More about the BERTIM project.

On the way to zero-emission flights

Commercial aircraft are a major source of emissions. The EU-funded MAHEPA project is developing and testing hybrid electric propulsion using light aircraft and is studying whether or not the system can be scaled up to power commercial aircraft. The project is developing modular components for hybrid airplanes scheduled to fly in 2020.

More about the MAHEPA project.

Greener water transport with an electric ferry

Europe has around 900 ferries for cargo, cars and passengers, which account for 35% of the world fleet. For more energy-efficient vessels that emit less carbon dioxide in the future, an EU-funded project will demonstrate a fully electric ferry. It will have a 40-km range, a speed of 25 km/h, and capacity for some 30 cars and 200 people. The prototype ferry will connect the island of Aeroe (DK) to the mainland.

More about the E-ferry project.

Using CO_2 as a raw material to make plastics

The technology allows for the conversion of steel-sector emissions into carbon to produce polyols, a widely used plastics component. Global demand for polyols is around 4 million tonnes per annum. Producing even 10 % from exhaust emissions and waste gas would save up to 150 000 tonnes of fossil raw materials annually and, at the same time, an equivalent amount of CO_2 emissions. The technology has numerous applications which can lead the way to a more sustainable chemical sector.

More about the Carbon4PUR project.

Reactor optimisation by membrane-enhanced operation

The technology enables the same chemical (aldehydes) to be produced from the same feedstock but in a much more efficient process: the reduction of side-product formation (and as a consequence cutting CO_2 emissions by 90 %), omitting distillation leading to energy savings of up to 5.3 GWh (78 % less than compared to the state of the art), and an 8 % reduction in feed products to produce aldehydes, plus a substantial cost reduction (OPEX).

More about the ROMEO project.

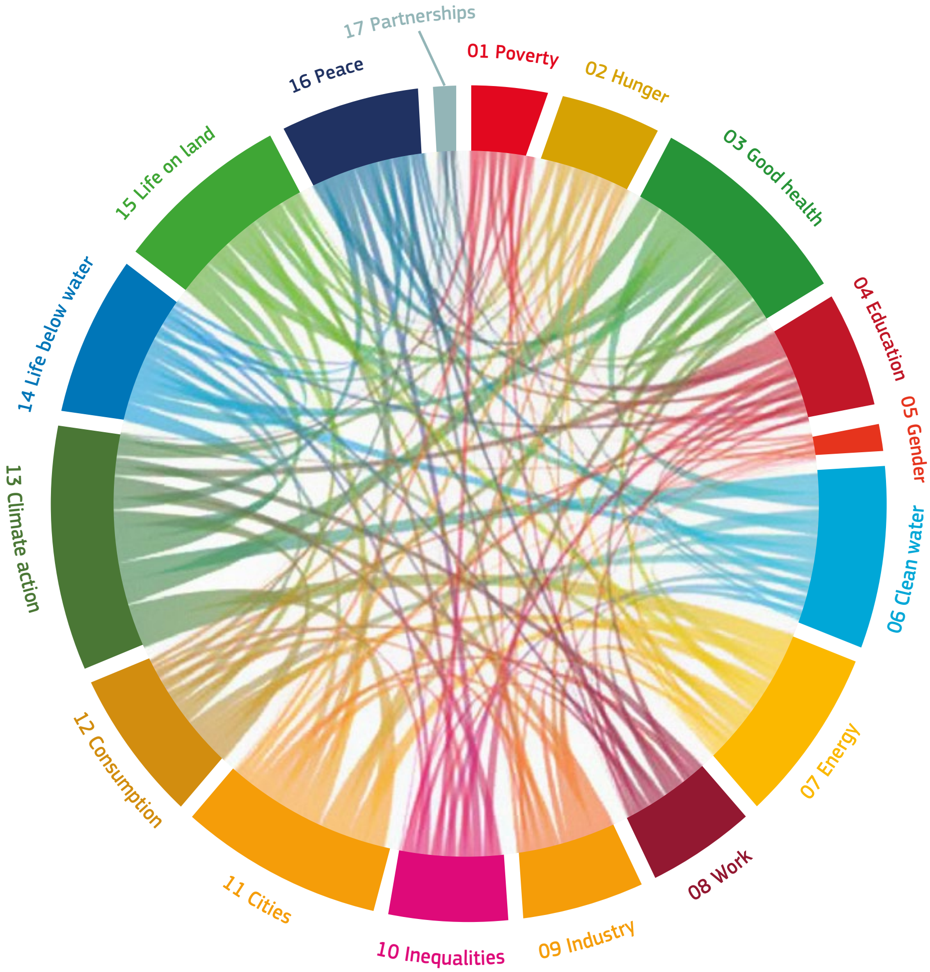
A secure platform for the flexible management of shared process resources

Resource efficiency offers major economic opportunities for the European process industry, both in terms of cost savings as well as opportunities to offer greener products and services. Industrial symbiosis is the use by one company or sector of by-products, including energy, water, logistics and materials, from another. The development of a secure platform allows for the flexible management of shared process resources with intelligent decision-support tools. It provides plant operations and production managers with the robust and reliable information that they need in real time to effectively and confidently share resources (plant, energy, water, residues and recycled materials) with other companies in an optimum symbiotic ecosystem. There is the potential for a 10 % reduction in industry's GHG emissions, while industry has less needs for fresh water across Europe: up to 40 %. In future, there will be a need to move from industrial symbiosis towards industrial urban symbiosis (with a much higher potential for reducing energy, water or material needs).

More about the SHAREBOX project.

R&I projects also illustrate significant interconnections between SDGs. Given the systemic nature of sustainable development, the current investment is highly interconnected – on average Horizon 2020 project potentially relates to three different SDGs (Figure 1-17). Some observed interlinkages, such as climate, energy and water, are expected, while others, such as climate action and good health, are more surprising. This also shows the high levels of trade-offs and synergies between SDGs and their targets. R&I can help to overcome these trade-offs, although there is also a risk of their exacerbation[17].

Figure 1-17 Overview of the interlinks between SDGs based on Horizon 2020 projects



Source: European Commission (2020), Monitoring Flash: Sustainable Development Goals

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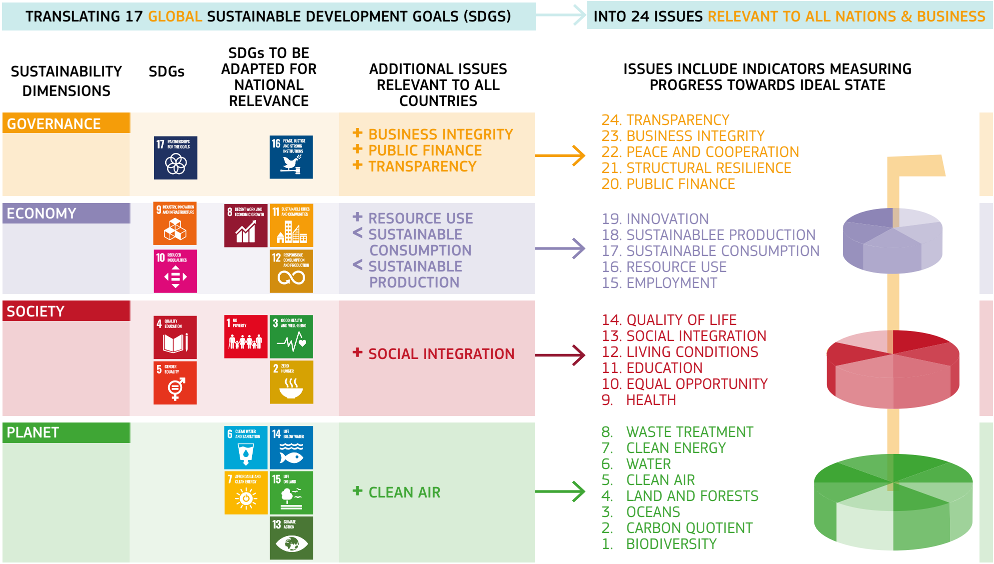
[17] For example, as shown by Vinuesa et al. (2020) AI can act as an enabler for 79 % of all targets, although the progress of 35 % of them may be inhibited by AI, at least to some extent. This requires policies that help direct the vast potential of I towards the greatest benefit for individuals and the environment, as well as towards achieving the SDGs.

4. Conclusion: a transformative innovation policy

The EU is fully committed to sustainable development and endorses its holistic and integrated approach, mainstreaming the SDGs into EU policies and initiatives, with sustainable development as an essential guiding principle for all of its policies. This calls for policy coherence for sustainable development across different dimensions: social, environmental and economic, in relation to our people, planet and prosperity. Hence, it requires an integrated multidimensional policymaking approach, which is directional and evidence-based (Figure 1-18). The sustainability transformation is also an unprecedented governance challenge at all levels from local to global. This results from the combined effect of the urgency, the scale of the necessary transformations, and the complexity and interdependence of issues in a context of fragility and unpredictability. Well-conceived and coherent policies should stimulate the three sustainability dimensions – environmental, social and economic – to reinforce each other. In order to achieve this, **EU R&I policy should be guided by principles such as co-creation, diffusion, uptake, transformation and the directionality of research and innovation** (Box 1-3).

Figure 1-18 Example of translation of 17 SDGs into four dimensions



Source: Muff et al. (2018)

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter1/figure-1-18.xlsx

BOX 1-3 The theoretical background behind principles for transformative R&I policy

Co-creation: European strengths lie in the robust culture of using the community approach for collective action. The founding principle of European cooperation through the EU was to facilitate and cultivate the building of trust, understanding and sharing as a method of achieving common goals (Monnet, 1996) in a community open to ideas, innovation and peace. The efforts of the last 60 years have cultivated a robust culture of doing things together resulting in stronger pan-European collaborations necessary to address the most pressing continental issues at hand. These efforts have also recognised the fact that no EU Member State is big enough to tackle issues such as energy transitions and the fight against climate change alone. These issues profoundly challenge almost all aspects of our society. So right effort should be met with the right action. A co-creation approach that is horizontal, inclusive, with a sense of a common European purpose, would respond directly to the challenges and crises of our time.

Diffusion: a functioning European innovation system requires the right links among actors and the knowledge flows between them to be nurtured and progressively created. Chaminade and Edquist (2010) describe how the innovation systems theory was a reaction to the inadequacies of the neoclassical 'market failure' approach to justify public intervention to support innovation processes. They postulate that interventions by the public sector should be done in those cases in which the system does not function well, i.e. where system actors are not communicating well. If we observe the whole of the EU as a big potential innovation system, comprising universities, entrepreneurs, citizens, governments and the environment, there is a case to ensure that knowledge flows freely and that at a systemic level there is no unfair concentration to hamper economic and social progress.

Uptake: a modern European R&I innovation strategy should create system conditions that are favourable for market uptake and societal benefit of research and innovation. The challenges of designing effective innovation policies, including their industrial dimensions, imply understanding the dynamics and roles of technological development. Tassey (2007, 2014) introduces new elements relevant to the transition from basic science to commercial products - generic technology platforms, infratechnologies (e.g. measuring methods and standards) and proprietary technologies. His model opens up the space for exploring interdependencies in both markets and innovation systems over time, and at the level of a critical commercialisation path for the industrialisation of emerging innovations. Hence, it is not enough to promote research results and individual pieces of innovation – there is also a need to ensure a systemic approach that extends to all the technology elements needed for successful uptake to happen.

Transformation: R&I will have a major role in supporting a profound transformation of our value chains, which is needed to achieve the SDGs. The incentives for systemic changes in industries, especially legacy industries (e.g. agro-food, energy, legacy IT, transport, construction), and in customer behaviour are often too low in the short term. These changes can also involve high risks in the medium term so long-term benefits for sustainability are difficult to capture. However, innovation, especially digital innovation, is causing wide-ranging industrial transformations (McFee and Brynjolfsson, 2017). One of the roles of public policy interventions through R&I will be to facilitate these reconfigurations of value chains. Even if innovations often come from small and medium-sized enterprises (SMEs), most of such organisations may not have the required resources and organisational skills to compete in globally disrupted and changing value chains. In the past, this was addressed in certain sectors by ensuring rich access to venture and other capital (Janeway, 2018), but legacy sectors, which are also being disrupted and transformed, call for the deployment of a full range of innovation policy interventions (Bonvillian and Singer, 2017).

Directionality: an SDGs framework for the implementation of EU R&I policy calls for direction and an effective framework for coordination, alignment and synchronisation. This framework calls for steering of R&I to address specific issues but it does not prescribe the way how they should be addressed. Research into policy design for investment in R&I indicates that there can be different methods for priority setting in the research agenda, involving the science push or demand pull for innovation (Nemet, 2009; Stewart, 1995; Mazzucato, 2017). Different approaches have been explored to explain and systemise how R&I contributes to technological change. Because technological transitions in societies take distinct (Geels and Schot, 2007; Svensson and Nikoleris, 2018) and converging (Bainbridge and Roco, 2016; Roco and Bainbridge, 2013) integral pathways it is necessary to be able to direct the evolution of the R&I portfolios. Such directionality should be based on sound evidence gathered for example from foresight analysis (Schaper-Rinkel, 2013). In this context, an agile, responsive and socially accountable R&I policy that provides directionality must integrate a **horizontal approach that encompasses the coordination of policy instruments, an alignment of policy objectives and the synchronisation of investments**.

EU R&I policy can set the direction (see Box 1-4) to generate knowledge and solutions for the transformation towards sustainability, while improving our well-being and ensuring long-term prosperity and enhancing Europe's competitiveness as a global sustainability leader. It should promote systemic approaches beyond disciplines, sectors and policy areas. When challenges cross several policies, such as the food system, the strength of R&I is evidence-based orchestration. Transformative R&I policy can be a key enabler of the European process for SDG policy coordination. This is only possible with synergies between the environmental, social, and economic dimension of sustainable development by following a comprehensive, systemic, and ambitious approach at the EU level. A new transformative R&I policy will also need to engage with other actors in society to deploy new solutions on a massive scale, in particular the radical innovations required for such a transformation[18].

BOX 1-4 Transformative innovation and socio-technical transitions to address grand challenges

Frank Geels, University of Manchester

Transformative innovation and systemic transitions are gaining increasing attention in the context of three policy problems. First, addressing the climate change problem will require radical innovation and low-carbon transitions in many systems. Second, addressing other grand societal challenges (like ageing, obesity, energy security, urban quality of life, inequality) and the SDGs will require transformative innovations in healthcare, agro-food, and urban systems. Third, low-carbon and sustainability transitions offer attractive growth prospects.

Transformative innovation and systemic transitions involve several new policy challenges:

1. Horizontal policy coordination
2. Transform social, business model and infrastructural innovation, not just technologies
3. Wider set of actors and coalitions (startups, cities, communities, citizens, NGOs)
4. Visions and missions (drive and directionality)
5. Diffusion of radical innovations into markets and society

Continue reading in Chapter 9 - Transformative innovation and socio-technical transitions to address grand challenges

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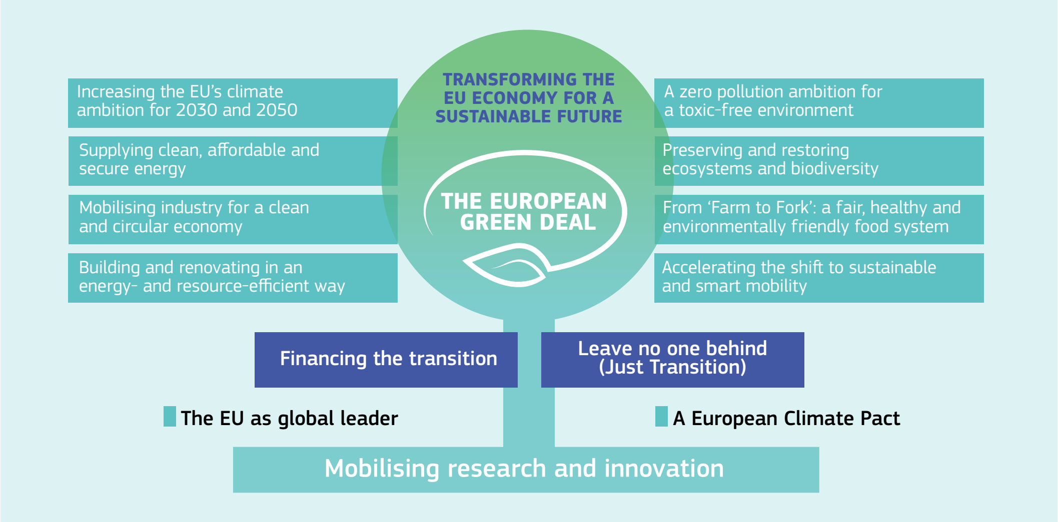
[18] The Joint Research Centre is making an important contribution to the operationalisation of transformative innovation with the recently launched Territorial Reviews of Industrial Transition (https://s3platform.jrc.ec.europa.eu/industrial-transition).

R&I will play a crucial role in driving the transition to a climate-neutral Europe and green economy. The European Green Deal Communication confirms that: 'New technologies, sustainable solutions and disruptive innovation are critical to achieve the objectives of the European Green Deal' (Figure 1-19). To deliver on the Green Deal, Horizon Europe will continue to create new knowledge and solutions to attain the SDGs and will provide even more directionality through its mission-oriented approach (e.g. on climate change, healthy oceans, climate-neutral and smart cities, and soil health and food) and European partnerships. In addition, it has set a 35% spending target for climate. It is also important to acknowledge that the vast majority of current Horizon 2020 programme investment is expected to foster the Sustainable Development Agenda.

Figure 1-19 European Green Deal



Source: DG Research and Innovation, adapted from the Communication on The European Green Deal[19]
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter1/figure-1-19.xlsx

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[19] COM(2019) 640 final.

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CHAPTER
2

CHANGING INNOVATION DYNAMICS IN THE AGE OF DIGITAL TRANSFORMATION

KEY FIGURES

2 years, 8 months
time it took Skype to reach 100 million users worldwide

5 percentage points
decline in entry rates in digital-intensive sectors compared to 2001

72 %
share of R&D expenditure of the top 250 R&D investors in the world's top 2000

7/10
top companies by market capitalisation are US and Chinese tech giants

What can we learn?

- **Consumer-driven innovations are spreading faster than ever** due to the transition from physical to digital goods combined with strong network effects in the digital age. This is in contrast to the apparent insufficient diffusion of productivity-enhancing technologies across firms.

- **Convergence of the digital and physical worlds is increasing the complexity of innovation** and leading to deep-tech science-driven innovations.

- There is **increasing industry concentration (also for R&I indicators)** and mark-ups over time (in Europe but to a greater extent in North America), not confined to digital-intensive sectors.

- **The dominance of 'tech giants' is not only visible in terms of R&D concentration** and market capitalisation **but also when it comes to some of the key services and infrastructure underpinning digitalisation**, such as search engines, operating systems or cloud infrastructure.

- While R&I investments needed to produce deep-tech innovations can prove costly, **companies that sell digital products can operate under almost 'zero marginal costs'** which can contribute to a greater ability to dominate markets.

What does it mean for policy?

- Promote the **access to data** for innovation in Europe while providing clarity about **principles and regulations** governing privacy and the ethical use of data.

- The increase in concentration has implications for business dynamism, **competition policy, and wealth distribution. Promote competition policies 'fit for the digital age' and measure and assess the impact of the 'digital economy'**.

- With innovation moving at unprecedented speeds, **policymaking also needs to react faster** to the changing contexts. Also, new rules are needed to ensure digital business activities are taxed in a fair and growth-friendly way.

- **Fostering deep-tech, science-based innovations requires a policy mix** that supports frontier research, multidisciplinary teams, R&D labs, innovation and digital hubs, and the availability of capital, notably patient capital.

- Create the right framework conditions for **digital firms in the EU to be able to succeed and compete globally** in the markets providing digital technologies that are underpinning digitalisation.

1. The 5 Cs of the changing dynamics of innovation: celerity, complexity, concentration, costs and consumers

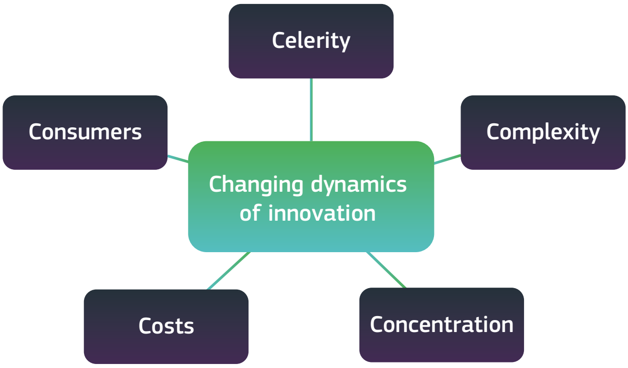
Digitalisation is transforming every aspect of our world. The rise of new technologies, in particular digital technologies and their convergence with the physical world, is affecting millions of workers and companies. New technologies have triggered a global race for investment, talent, knowledge and research. This has several consequences, in particular in terms of industrial policy. Moreover, these new digital technologies have redefined the way in which markets operate and have attracted more attention to high-growth innovative platform-based companies, e.g. the so-called 'tech giants' (Google, Apple, Facebook, Amazon, Microsoft, Baidu, Tencent, Alibaba), a set of global companies which are reaping large economic benefits. The traditional 'innovation pipeline' – research leading to discovery leading to innovation and growth – no longer describes the reality, or not necessarily in those terms.

Furthermore, many innovations in the digital age have enabled companies to operate under a paradigm of close to 'zero marginal cost'. For instance, more and more individuals playing music and using software does not generate additional costs for the company. Innovation has also become more 'consumer-centric' as consumers increasingly look for customised 'solutions' rather than 'products' or 'services'.

At the same time, new technologies are promising large productivity gains although these have yet to materialise. In particular, productivity growth, which largely depends on R&I, is sluggish and continues to hold back more robust growth (see Chapter 3.1 - Productivity puzzle and innovation diffusion).

Hence, in this chapter, we describe in more detail the five main characteristics of the changing dynamics of innovation in the age of digital transformation – celerity, complexity, concentration, costs and consumers - as represented in Figure 2-1.

Figure 2-1 Main characteristics of the 'changing dynamics of innovation'

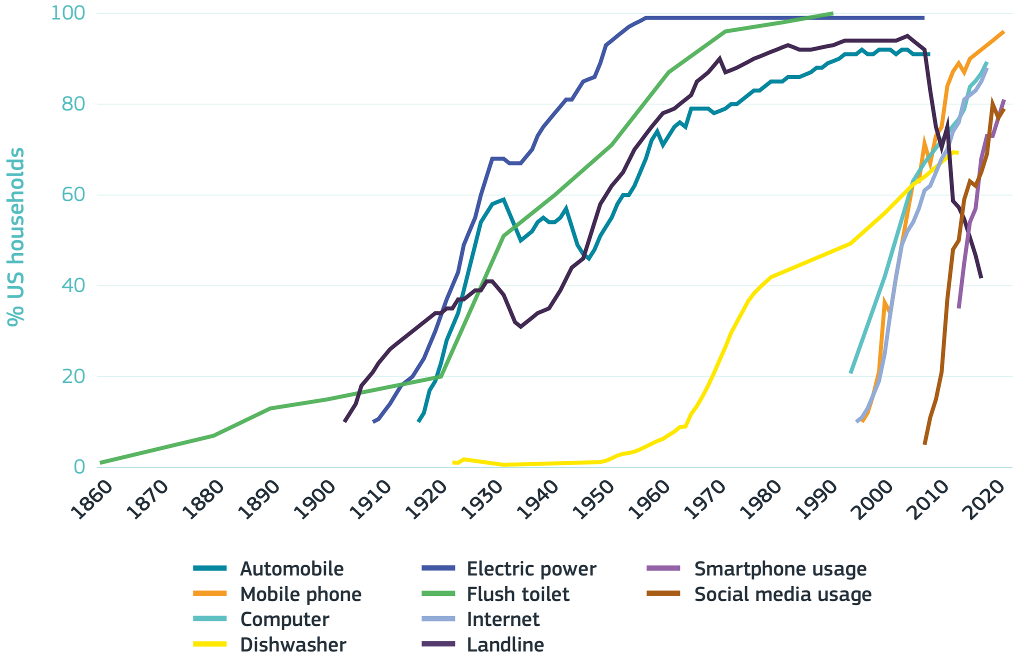


Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter2/figure-2-1.xlsx

2. Celerity

Technology, and notably consumer-driven innovation, is spreading faster than ever due to the transition from physical to digital goods combined with strong network effects in the age of digital transformation. The pace of change in consumer-driven innovation has accelerated tremendously over time in the era of digitalisation and increasing connectivity. Indeed, innovations are being adopted at a higher rate than in previous decades and centuries. Figure 2-2 shows that it took much longer for potentially all US households to have a flush toilet in their homes, own a car and a dishwasher, or have electricity than to use the internet and even less to use a smartphone or engage in social media channels. The steeper the lines in the graph, the faster the adoption rates for those technologies. However, as noted in Chapter 3.1 - Productivity puzzle and innovation diffusion, a slowdown in innovation diffusion continues to hold back a stronger uptake of innovations across companies and industries, even if business-to-consumer (B2C) innovations have been adopted at faster rates than before, fostered by digitalisation.

Figure 2-2 Technology adoption rates of selected innovations[(1)] over time, US households, 1860-2019



Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit, adapted from Hannah Ritchie and Max Roser (2019). Data retrieved from: 'https://ourworldindata.org/technology-adoption', based on multiple sources

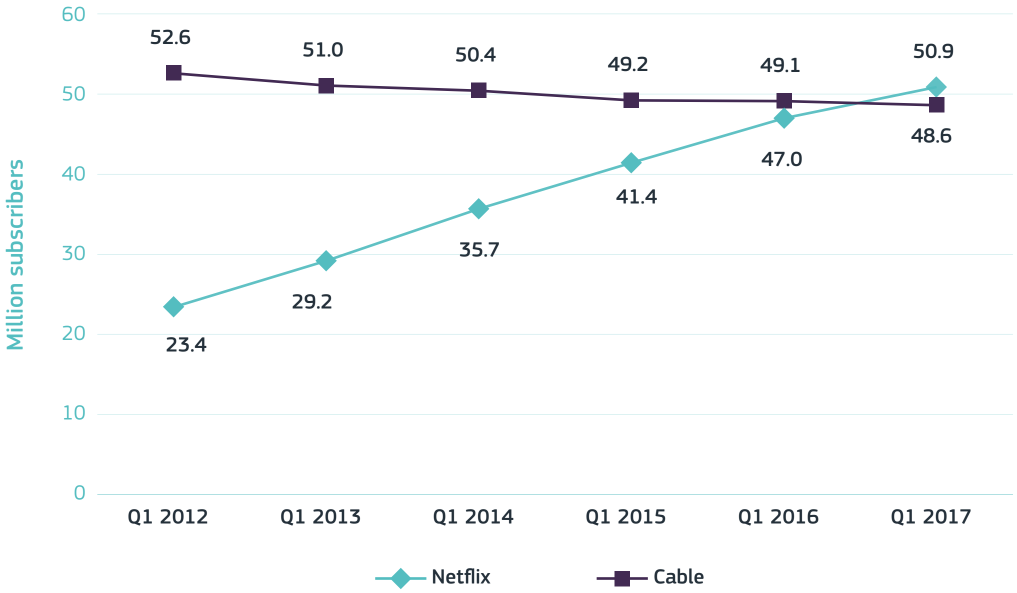
Note: (1)Technology adoption rates measured as the percentage of households in the United States using a particular technology. The dataset is a compilation of multiple sources to construct a broad overview of the adoption of technology in the United States. The multiple sources of the dataset as well as the definition of the variables are described in Hannah Ritchie and Max Roser (2019).

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter2/figure-2-2.xlsx

As mentioned by the European Commission (2018a), with innovation changing at an unprecedented speed, what was innovative before becomes non-innovative extremely quickly. For example, mobile phones failed to make the transition to 'smartphones' on time and rapidly lost their market share and relevance. Another example is 'Pay television': it appears that cable TV's subscription base has been in decline, in favour of the almost linear growth of Netflix subscribers (Figure 2-3). Netflix is a subscription-based online streaming platform for movies and TV shows which also produces in-house content. This streaming platform makes use of sophisticated algorithms to generate new content and recommendations according to user preference. It would appear that, since 2017, the number of Netflix subscriptions in the United States has surpassed the number of subscribers to Pay TV. Another example is the decline in the photographic industry from 121 million of shipments worldwide in 2010 to only 19 million in 2018, partly due to the global expansion of smartphones with embedded cameras (Statista, 2019).

Another way to look into the speed of technology adoption is to consider the time it took for new products and services to reach 100 million users since they were launched to the public (Figure 2-4). The telephone was launched in 1878 and it took 75 years for 100 million people to use it since it also relied on the parallel development and expansion of physical infrastructure. This compares to 16 years for the mobile phone, launched in 1979, and 7 years for the internet. In the 2000s, digitalisation spread to the economy quicker than ever, which means that less and less time was needed for new digital products to reach a customer base of 100 million users. For instance, it took just 2 years and 8 months for

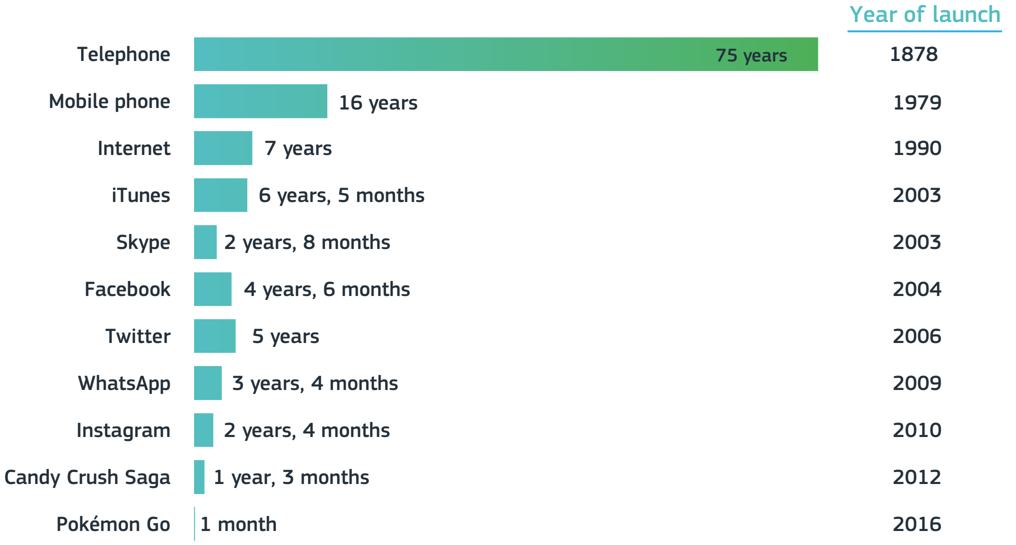
Figure 2-3 Number of Netflix subscribers vs. pay-tv subscribers in the United States, in millions, 2012-2017



Source: Statista based on Netflix, Leichtman Research Group
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter2/figure-2-3.xlsx

Skype to get 100 million registered users, 2 years and 4 months for Instagram to register 100 million monthly users, and only 1 month for 100 million downloads of Pokémon GO. These examples illustrate how digitalisation has profoundly changed areas such as communication (from the telephone, to the mobile phone, Smartphone, to Skype and WhatsApp) or the entertainment industry (from vinyl, CD-ROMs, iTunes to YouTube and Spotify in the music business, for example).

Figure 2-4 Time for new products and services to reach 100 million users(1), by year of launch



Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit, adapted from BCG (2015) and based on ITU (Telephone and Mobile phone), Scientific American (World Wide Web), Internet Live Stats, Fortune (iTunes), Facebook, Wired (WhatsApp), Techcrunch (Instagram), AppMtr.com (Candy Crush Saga), arinsider.co (Pokemon Go), Searchengineisland (Twitter)

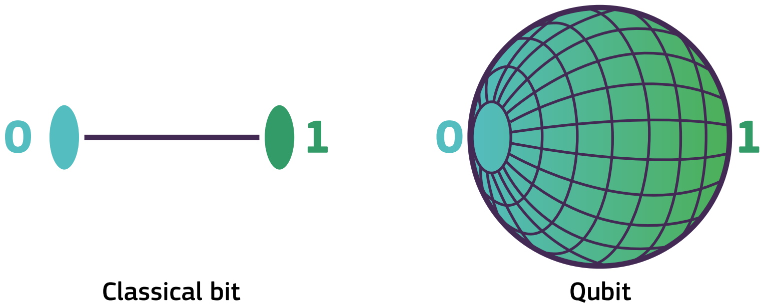
Note: (1)iTunes: number of accounts; Facebook: monthly active users; WhatsApp: active users; Instagram: monthly users; Candy Crush Saga: Facebook users only; Pokemon Go: number of downloads; Twitter: active users; Skype: registered users.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter2/figure-2-4.xlsx

Network effects are also underpinning the speed of these developments, particularly in the digital age. According to Metcalfe's law, 'the effect of a network is proportional to the square of the number of connected users of the system'. Essentially, each new user brings more and more value to the network, which is behind the spectacular growth of social media networks and certain apps.

Quantum computing has the potential to solve highly complex problems in less time than classical computers, which could speed up scientific discoveries and predictions in the future. Unlike classical computers which use 'bits' (i.e. 0 or 1), quantum computers use 'quantum bits' or 'qubits' which allow for the so-called superposition phenomenon, as qubits can take the two values of 0 and 1 simultaneously (Figure 2-5). As a result, qubits enable greater computing power, which could lead to new applications in fields such as big data, cryptography, medicine, weather prediction, and machine learning.

Figure 2-5 Visual representation of the difference between a bit (for classical computers) and a qubit (for quantum computers)



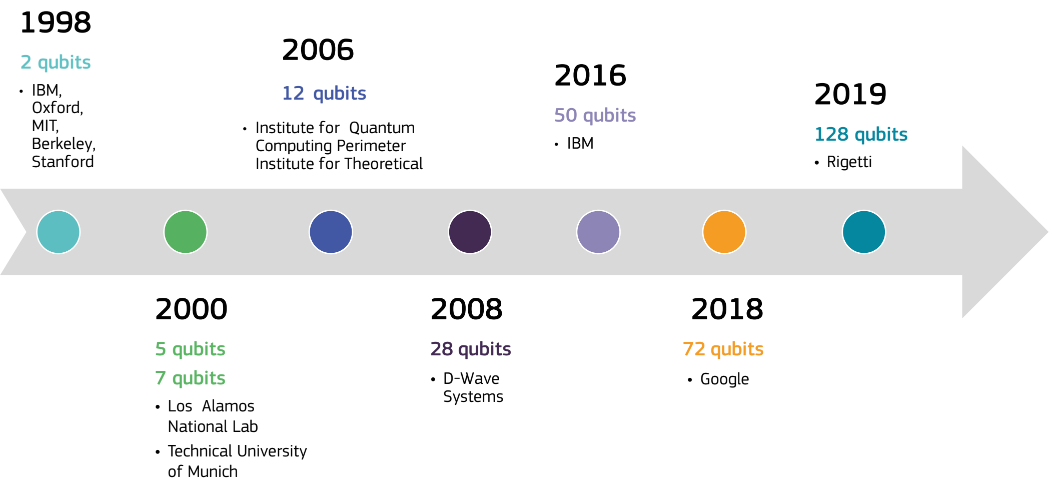
Science, research and innovation performance of the EU 2020

Source: https://www.austinchronicle.com/screens/2019-04-19/quantum-computing-101-a-beginners-guide-to-the-mind-bending-new-technology/

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter2/figure-2-5.xlsx

As argued in the MIT Technology Review (2019), the 'immense processing power of quantum computers could ultimately help researchers and companies discover new drugs and materials, create more efficient supply chains, and turbocharge AI'. Some tech giants, such as IBM and Google but also startups like Rigetti, are pushing the frontier forward, resulting in a substantial increase in the number of qubits (and hence computing power) from only 2 in 1998 to 128 in 2019 (Figure 2-6). Thus, advances in quantum computing could further increase the speed of R&I across different scientific fields in the future.

Figure 2-6 Number of qubits achieved by year and organisation, 1998-2019



Science, research and innovation performance of the EU 2020

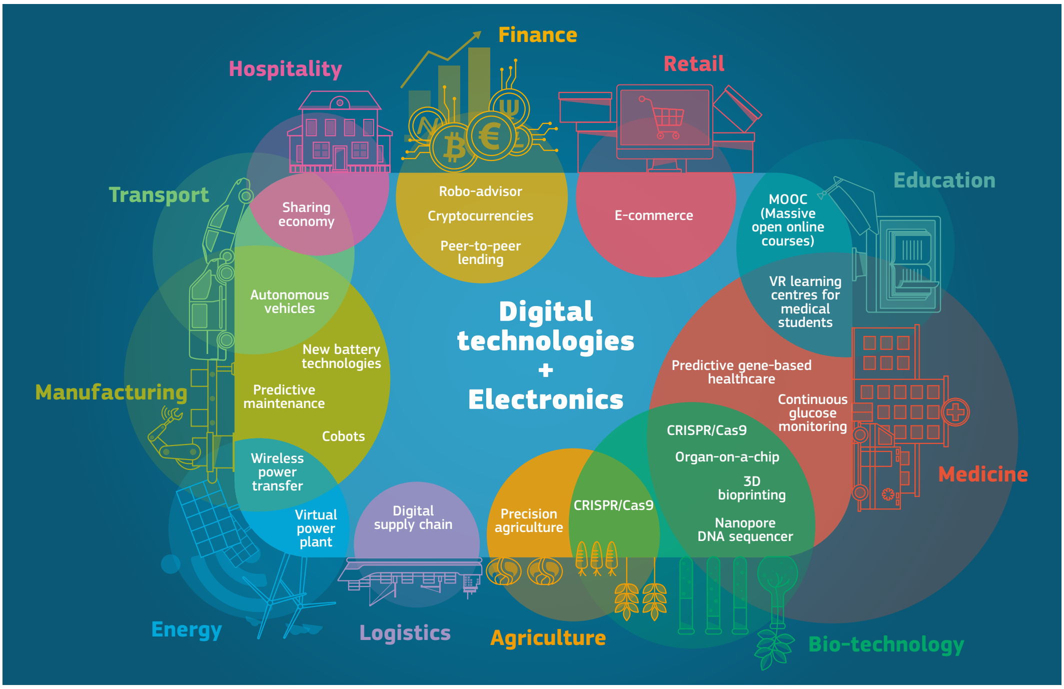
Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit, adapted from CBInsights and based on http://www.qubitcounter.com/

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter2/figure-2-6.xlsx

3. Complexity

Convergence of the digital and physical worlds is increasing the complexity of innovation. Innovations are increasingly the result of the convergence between digital technologies and scientific fields leading to ‘deep-tech innovations’ (Figure 2-7). In other words, this means deeply transformative and increasingly science-based and complex innovations. This includes digital supply chains, precision agriculture, 3D bioprinting, autonomous vehicles, among many others. In order to reap the full benefits of these deep-tech innovations, companies must have in place the right economic competencies, which include an organisational structure that enables the agility and flexibility among teams to master different technologies and new business models, management quality with a strategic vision, staff training, and branding (see Chapter 5.3 - Investment in economic competencies). Moreover, despite having the potential to be deeply transformational, these innovations may take years and sometimes decades to be market ready. As a result, deep-tech, science-driven innovations require ‘patient capital’ funds that account for the higher uncertainty involved as well as the longer time span to enable them to be tested, improved and hopefully made commercially viable (see Chapter 8 - Framework conditions).

Figure 2-7 Deep-tech innovation: science-based digitally-enabled innovations

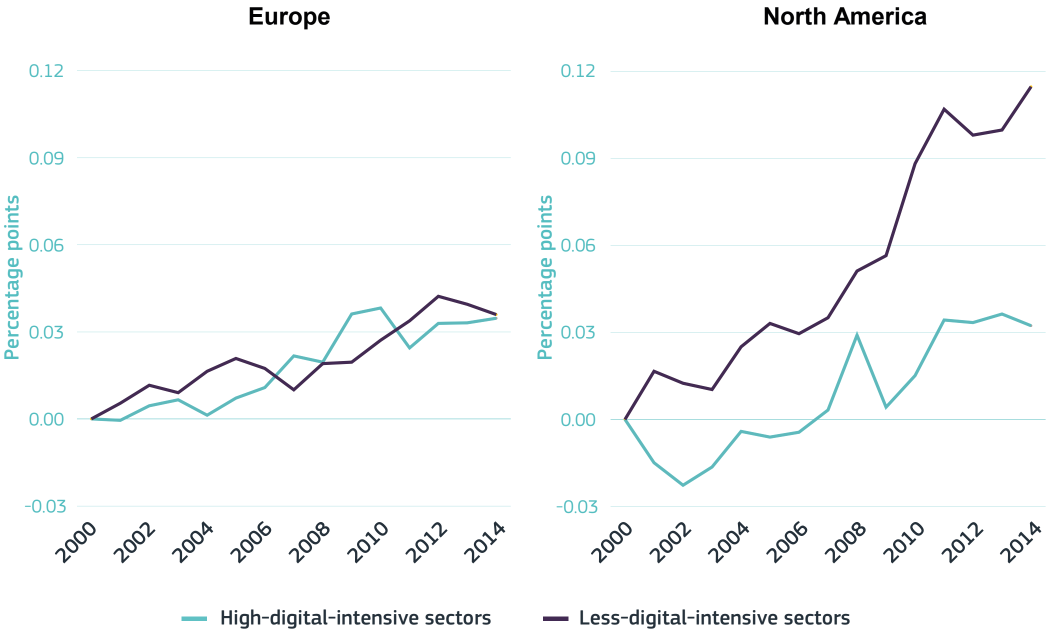


Source: European Commission, DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter2/figure-2-7.xlsx

4. Concentration

Industry concentration is a rising phenomenon in North America, and to a less extent in Europe[1]. Bajgar et al. (2019) show that overall sales concentration has been increasing since 2000 in both North America and Europe (Figure 2-8). It is interesting to note that the rising trend in industry concentration in terms of sales is observable in both digital-intensive and other sectors of the economy. In fact, concentration in North America appears more pronounced in sectors other than those with higher digital intensity, even though concentration in the latter appears to have be on the rise since 2007. This could relate to the significant growth in the US in high-tech business dynamism in the early late 1990s and early 2000s (Decker et al., 2016), which was then interrupted. In Europe, differences in concentration in both sectors are not as evident as they are in the United States and Canada.

Figure 2-8 Concentration in digital-intensive vs. less-digital industries in Europe and North America(1), 2000-2014



Source: Bajgar et al. (2019)

Note: (1)The countries for Europe include BE, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IT, LV, NL, NO, PL, PT, SE, SI, and for North America include CA and US. Included industries cover 2-digit manufacturing and non-financial market services. Concentration metrics reflect the share of the top 8 firms in each industry (CR8). The graphs can be interpreted as the cumulated absolute changes in levels of sales concentration for the mean 2-digit sector within each region. For instance, in 2014, the mean European services industry had 4 percentage point higher sales concentration than in 2000.

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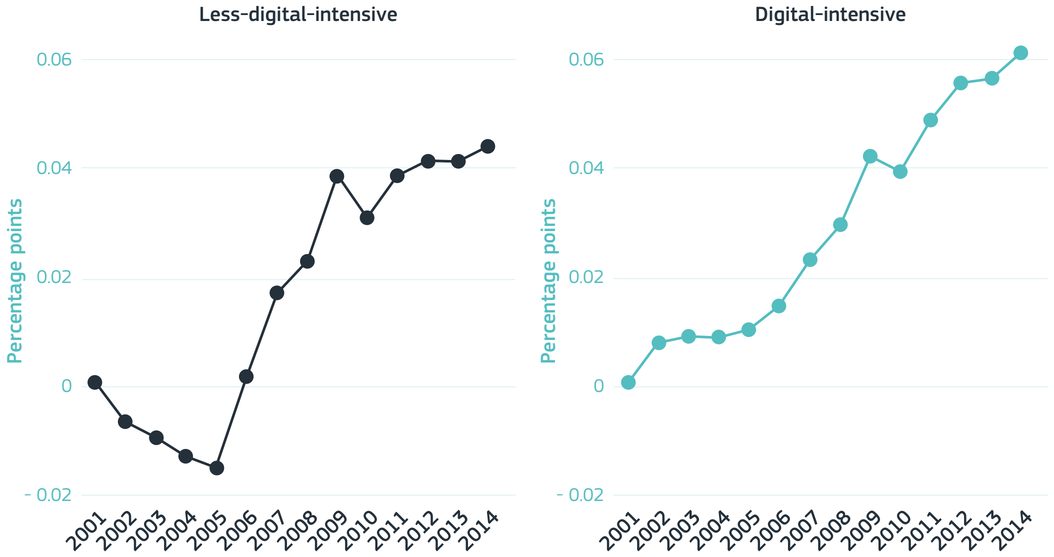
[1] In fact, industry concentration in Europe seems more stable (average over the period will be close to zero).

Increasing concentration can also be observed by the rise in average mark-ups over time. Mark-ups in the top digital-intensive sectors are higher and growing faster than in the rest of the economy. As mentioned in De Loecker and Eeckhout (2017), mark-ups are a market power measure for how much higher prices are relative to marginal costs. Calligaris et al. (2018) studied the evolution of mark-ups over time to investigate whether they are on the rise in the age of digital transformation, and whether there are differences between the top 25 % most digital-intensive and the less digital-intensive sectors of the economy. Indeed, Figure 2-9 shows that mark-ups have risen over time in both top-intensive and less-intensive digital sectors, although this increase has been more pronounced in the top digital-intensive sectors (see Chapter 10 - The bottom also matters: policies for productivity catch-up in the digital economy).

Figure 2-9 Mark-up growth over time in digital-intensive vs. less-digital-intensive sectors, 2001-2014



Source: OECD based on Calligaris, S., C. Criscuolo and L. Marcolin (2018)

Note: This graph fixes the ranking of sectors to the initial period (2001-03), and shows only mark-ups estimated assuming a Cobb-Douglas production function.

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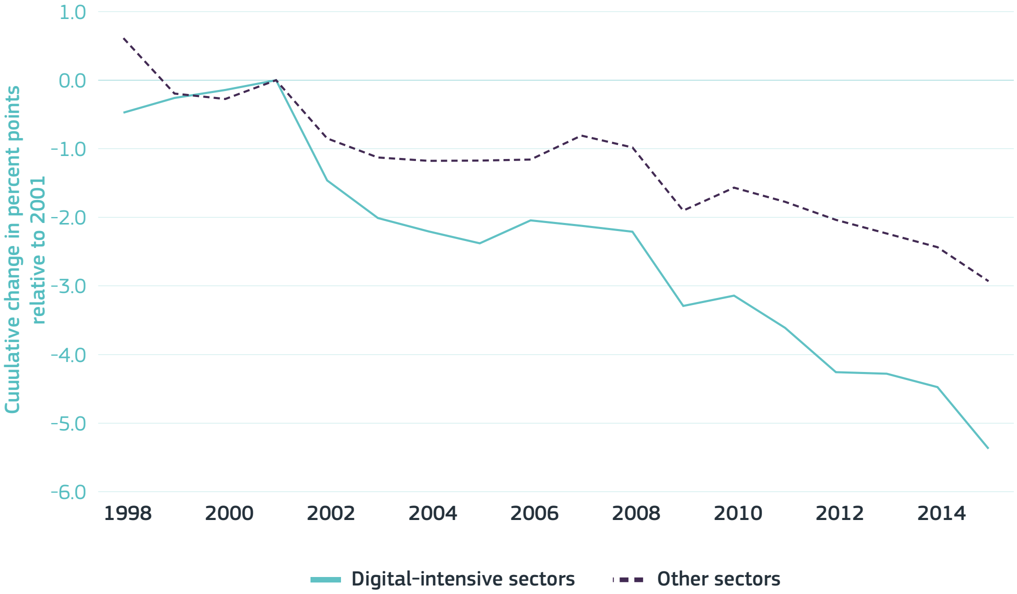
Increasing mark-ups in the top digital-intensive sectors may partly explain the faster decline in entry rates in those sectors. As mentioned in Chapter 3.3 - Business dynamics and its contribution to structural change and productivity growth, business dynamism appears to be on decline, including in Europe. Calligaris et al. (2018) focus on entry rates as a proxy to measure business dynamism in digital-intensive sectors relative to other sectors of the economy. Their analysis shows that the decline in entry rates since 2001 has been more visible in top digital-intensive sectors (Figure 2-10). This suggests that the rise in mark-ups and the concentration of benefits of innovations in a handful of global digital giants may be deterring new firms from entering the most digital-intensive sectors. As a result, the productivity gap between frontier and laggard firms may continue to widen as productivity gains may become concentrated in a small number of firms (see Chapter 3.1 - Productivity puzzle and innovation diffusion).

Figure 2-10 Change in entry rates by sector digital intensity, within-sector trends relative to 2001, 1998-2015



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Source: Calvino and Criscuolo (2019)

Note: The figure reports average within-country-industry trends, based on the year coefficients of regressions within country-sector, with and without interaction with the digital intensity dummy. Digital-intensive sectors are reported with a solid line and other sectors with a dashed line. The dependent variable is entry rates. The baseline year is set to 2001. Each point represents average cumulative changes in percentage points since 2001.

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Over the past decade, technology-related companies companies have climbed up in market capitalisation to dominate the top 10 global companies. Digitalisation has enabled new innovations and business models, and technology and ICT-related companies have mastered the potential of digital transformation to generate new products and services as well as, for example, new sales and marketing strategies. In particular, in 2009, only Microsoft was within the top 10 global companies by market capitalisation, while in 2019, there were seven ICT-related companies – Microsoft, Apple, Amazon, Alphabet, Facebook, Alibaba and Tencent (Figure 2-11). For example, Apple and Alphabet climbed 31 and 18 positions, respectively, compared to the 2009 ranking.

Most of the so-called 'digital' or 'tech' giants benefit from the increasing connectivity of their users which also gives them access to enormous volumes of data in their customer base. For example, Facebook´s revenue model is almost entirely based on Facebook Ads[2] which target users according to certain criteria (e.g. age, gender, nationality). This gives these global companies a competitive advantage. At the same time, data privacy issues should be duly taken into account and regulations should ensure their full compliance. Importantly, in the digital era, there is a **'mismatch' between where value is created and where taxes are paid**. The European Commission (2018c) has proposed new rules to ensure that digital business activities are taxed in a fair and growth-friendly way.

Figure 2-11 Top 10 global companies (1-10) by market capitalisation(1), 2019 and 2009

Company	Industry	Country	31 March 2019		31 March 2009		Change in rank between 31 March 2009 and 31 March 2019
			Rank	Market capital-isation (USD bn)	Rank	Market capital-isation (USD bn)	
Microsoft	**Technology**	United States	**1**	905	6	163	+5
Apple	**Technology**	United States	**2**	896	33	94	+31
Amazon.com	**Consumer services**	United States	**3**	875	:	31	-
Alphabet	**Technology**	United States	**4**	817	22	110	+18
Berkshire Hathaway	**Financial**	United States	**5**	494	12	134	+7
Facebook	**Technology**	United States	**6**	476	-	81(1)	-
Alibaba	**Consumer services**	China	**7**	472	-	168(1)	-
Tencent	**Technology**	China	**8**	438	-	13	-
Johnson & Johnson	**Healthcare**	United States	**9**	372	8	145	+1
Exxon Mobil	**Oil & Gas**	United States	**10**	342	1	337	-9

Source: Bloomberg and PwC analysis, 2019

Note: (1)Market capitalisation at IPO date.

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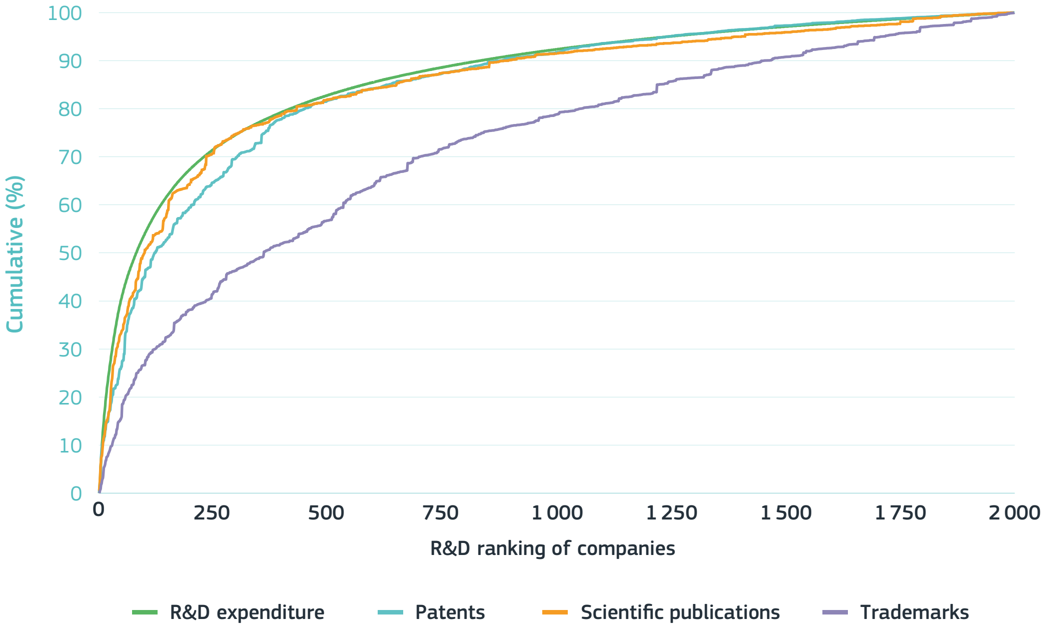
[2] https://www.visualcapitalist.com/how-tech-giants-make-billions/

Concentration can also be observed when it comes to scientific publications and innovation outputs by the top R&D investors. Dernist et al. (2019) looked into the top 2 000 R&D investors worldwide. Having linked this information to data on publications, patents and trademarks, the authors found that the top 250 R&D investors alone actually account for around 72 % of total R&D expenditure, 71 % of publications, 65 % of patents and 42 % of registered trademarks among the top corporate R&D sample (Figure 2-12). When extending the analysis to the top 2 000 corporate R&D investors, the authors concluded that this group of companies was responsible for almost two thirds of patents filed at the largest intellectual property (IP) offices worldwide, for example.

Figure 2-12 R&D investment, publications and IP bundle of the world's top 2 000 R&D investors, 2014-2016(1)



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Source: Dernist et al. (2019) based on Joint Research Center-OECD, COR&DIP© database v.2., 2019

Note: (1)Data relate to companies in the top 2 000 corporate R&D sample, ranked by R&D investment in 2016. The IP bundle refers to the number of patents and trademarks filed in 2014-16, and owned by the top R&D companies, and the number of scientific articles are those published by authors affiliated in the top R&D companies during the same time-period, using fractional counts. See Box 2-1 for further details on the coverage.

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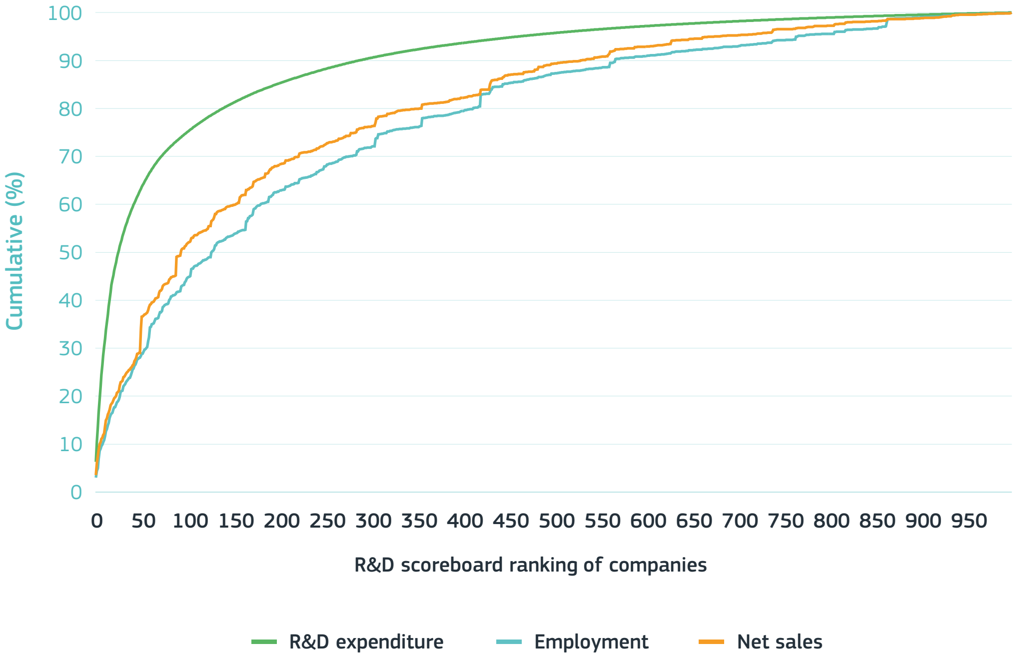
The concentration of R&D activities as well as sales and employment is a phenomenon that is also evident in Europe. When looking to the top 1 000 R&D investors in the EU, an unequal distribution of R&D expenditure among companies (Figure 2-13) can be observed. The same uneven picture applies to sales and employment, albeit less pronounced than R&D investments. For example, the top 25 R&D investors in the EU account for half of the group's R&D expenditure.

Figure 2-13 R&D investments, employment and net sales of the top EU28 1 000 R&D investors, 2019



Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit, based on EU Industrial R&D Investment Scoreboard 2019

Note: Data refers to the top 1 000 R&D investors in the EU. There are a few missing values for companies regarding employment and net sales.

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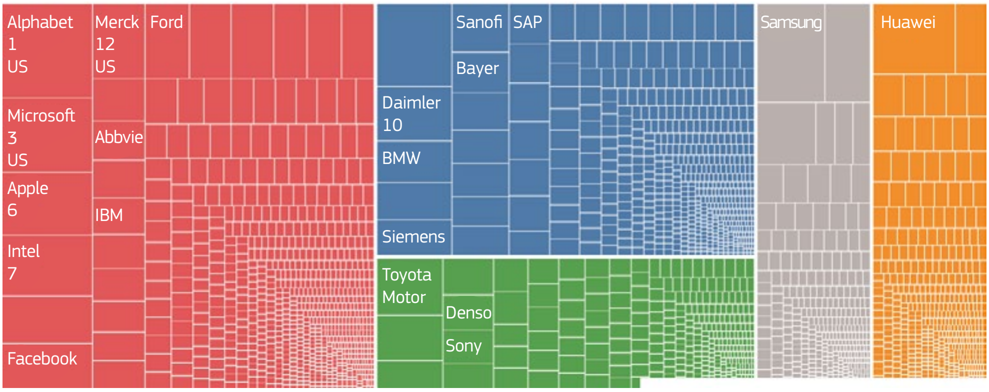
The rising concentration of R&D investments among a relatively small number of players is also visible at the global level. According to European Commission (2018), the top 2 500 R&D investors account for 90 % of the world's business-funded R&D. Moreover, just a few companies account for a significant share of all R&D expenditure (Figure 2-14) in each region.

When it comes to AI science and innovation, the weight of the world´s top corporate R&D investors also appears to be higher than in other companies, as measured by publications, patents and trademarks. As mentioned in Chapter 7 - R&I enabling artificial intelligence, in recent years there has been a boom both in AI publications and patenting activity. In this context, the global 2 000 corporate R&D investors seem more active than other players in producing AI scientific publications and patenting and generating trademarks for their innovations (Figure 2-15). This indicates that the development of AI R&I may also become increasingly concentrated.

Figure 2-14 World top 2 500 R&D investors by region, 2018/2019



Science, research and innovation performance of the EU 2020

Source: European Commission, 2019 EU Industrial R&D Investment Scoreboard

Note: US companies are represented in red, EU28 companies in blue, Japanese companies in green, Chinese companies in orange, and the Rest of the world in grey.

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Figure 2-15 AI-related patents, trademarks and publications of top R&D investors relative to other actors[(1)], 2014-2016

Science, research and innovation performance of the EU 2020

Source: Dernist et al. (2019) based on Joint Research Center-OECD, COR&DIP© database v.2., 2019

Note: (1)Share in total patents, trademarks and publications, top R&D investors and other actors.

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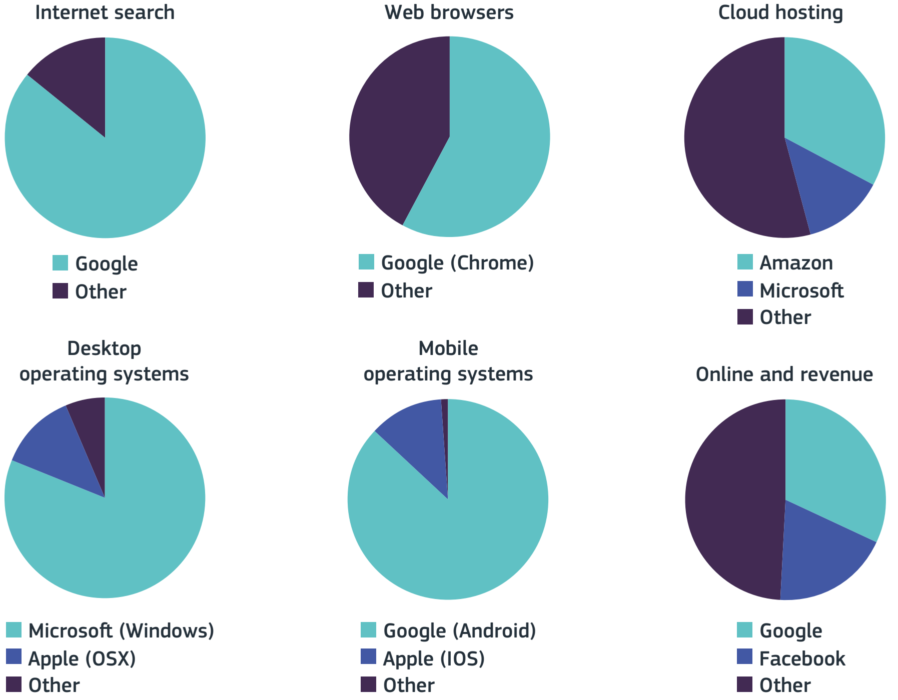
The dominance of US tech giants is not only visible in terms of R&D investments but also when it comes to some of the pillars underpinning digitalisation, such as search engines, operating systems and cloud infrastructure. Figure 2-16 shows that just a few companies – Google, Amazon, Microsoft, Apple and Facebook – account for very large shares in different digital markets, notably internet search, web browsers, cloud hosting, desktop and mobile operating systems, and online advertising revenues. For example, Google is the clear leading search engine with a market share close to 90%[3]. Amazon alone is the top cloud infrastructure provider with 33% market share worldwide. Van Reenen (2018) argues that the 'growth of platform competition in digital markets has led to the dominance by a small number of firms such as internet search (Google), operating systems for cell phones (Apple, Android), ride-sharing (Uber), home sharing (Airbnb)'. Moreover, the author[4] highlights that the mechanism of competing on platforms means that, for example, in the case of Google, online searches will give the company increasingly larger amounts of data which will optimise their algorithms. As a result, this will attract more users to the platform and hence generate further advertising revenues. Moreover, the ownership and control of users´ data for advertising or improving the quality of products has led to considerable concerns over data privacy as well as market power.

Figure 2-16 Global market shares by company - internet search, web browsers, cloud hosting, desktop operating systems, mobile operating systems and online advertising revenue, 2017



Source: https://mitsloan.mit.edu/ideas-made-to-matter/will-regulating-big-tech-stifle-innovation (September 2018), based on Synergy Research, CNBC, Statista

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter2/figure-2-16.xlsx

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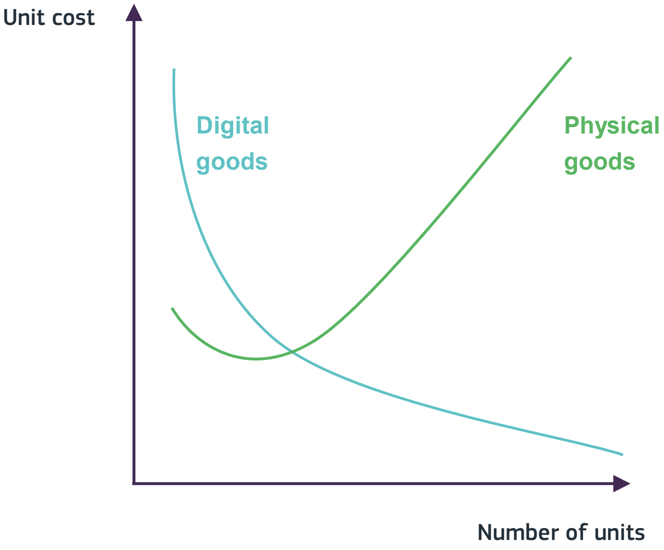
[3] https://www.statista.com/statistics/216573/worldwide-market-share-of-search-engines/

[4] https://mitsloan.mit.edu/ideas-made-to-matter/will-regulating-big-tech-stifle-innovation

5. Costs

While the R&D investments required to produce deep-tech innovations can prove costly, companies that sell digital products can manage to operate under close to 'zero marginal costs', as a result of the diminishing importance of tangible capital in the era of digital transformation. Digital products and services (e.g. smartphone apps) have the inherent economic properties of non-rivalry – i.e. many users can use them simultaneously without restricting the access of others to the same digital good – and of being infinitely expandable (Eurofound, 2018) which means they can be used an infinite number of times and at no cost. In other words, the marginal cost for digital goods declines indefinitely[5] (Figure 2-17). Indeed, the biggest transformation created by digitalisation concerns the 'move from atoms to bytes'[6]. While 'physical innovations' such as the landline telephone rely on inputs for their production based on atoms (e.g. physical infrastructure, raw materials, human capital) which follow the laws of physics, in the digital age, bytes allow a digital good to be produced at close-to-zero marginal cost since there is almost zero cost for reproduction and communication (Guellec and Paunov, 2018). Therefore, digital companies do not have the same needs for physical infrastructure and tangible capital as other industries. In fact, they often benefit from IT platforms, software systems and tools, cloud storage capacity, etc. which tend to be more inexpensive than other types of tangible assets.

Figure 2-17 The evolution towards 'zero marginal costs' for digital goods



Science, research and innovation performance of the EU 2020
Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit, based on Essays, UK. (2018) and Rifkin (2014)
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[5] See, for example: https://praxtime.com/2013/01/06/digital-economics-the-zero-marginal-cost-economy/ and https://www.goodreads.com/book/show/18594514-the-zero-marginal-cost-society

[6] https://www.weforum.org/agenda/2018/06/how-long-does-it-take-to-hit-50-million-users

6. Consumers

Network effects can also play an important role in fostering the use and uptake of digital technologies, even though there is the risk of 'consumer lock-in'. In the case of social networks (but also other digital products such as online platforms or certain software tools), the higher the scale of users in the networks the greater the consumer value from that interconnectedness. However, consumers may be 'locked in' to such products or services as the cost associated with changing provider is too high since their network is established through a different provider. For instance, Microsoft's strong position in terms of office operating systems means that a network of people are using the same systems to work and collaborate in a compatible way. For this reason, the incentives to change to a different operating system provider are low considering the cost of learning and setting new harmonised standards for sharing information and communicating.

Business model innovation contributes to capturing greater value from new goods and services. In particular, various digital business models have emerged to benefit from the new opportunities brought by the digital age. As mentioned in Baden-Fuller and Haefliger (2013), 'business models mediate the link between technology and firm performance'. Box 2-1 summarises the different approaches to business model innovation, especially in the digital age.

BOX 2-1 Business model innovation: capturing value

Companies increasingly compete not only on the products and services they sell but also in terms of the underlying business model. In fact, business model innovation can be a true disruptor in many markets and an important differentiator when there is a high degree of competition.

For example, in clothing retail there are many established brands, including strong European multinationals such as the United Colors of Benetton (Italy) or H&M (Sweden), with successful business models. In this context, the business model of ZARA (Spain) enabled the company to differentiate itself from its competitors. For example, instead of outsourcing most of its production to Asia, it also has production units in Spain and Portugal. Moreover, the company has collections which change on a weekly basis rather than the longer design cycles of its competitors[7].

Another example is that of Skype in the telecommunications sector. Skype was created by Niklas Zennström (Sweden) and Janus Friis (Danish), in cooperation with Ahti Heinla, Priit Kasesalu, and Jaan Tallinn (Estonia). While calls and, in particular, international calls can be expensive, Skype used the VoIP – Voice over Internet Protocol – technology to allow users to communicate over the internet by voice, for free if you subscribe to the free version. Moreover, it relies mainly on software development, thereby reducing the need for physical infrastructure.

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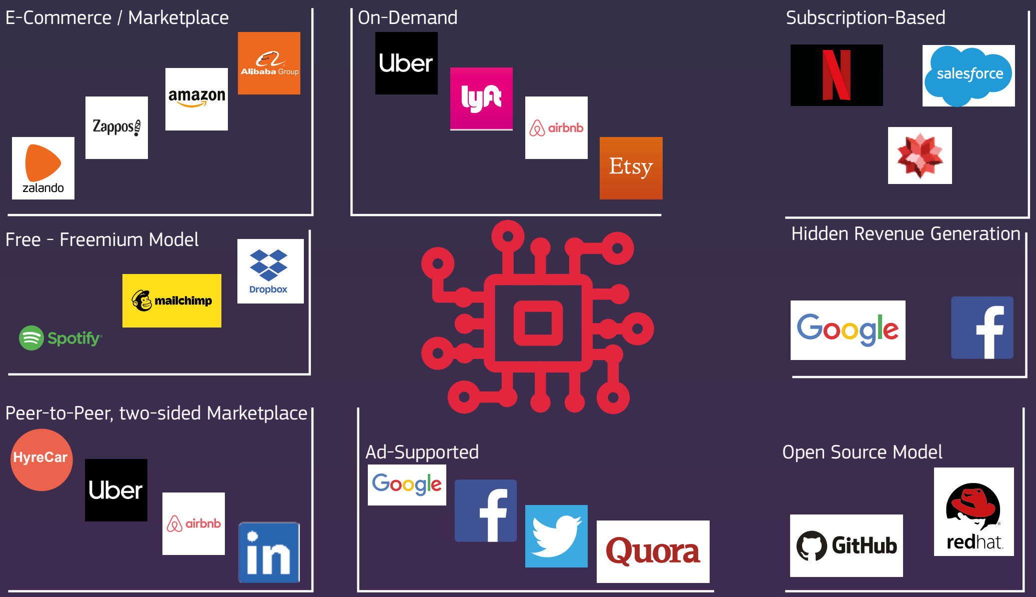
[7] https://www.slideshare.net/jindrichweiss/55-business-models-to-revolutionize-your-business-by-michaela-csik

In the era of digitalisation, companies operating in the digital space are adopting different business model strategies. Figure 2-18 simplifies the different approaches being used.

These include, in a nutshell:

- **E-commerce/marketplace**: an online platform connecting buyers and sellers.
- **On-demand**: aggregate niche-service providers on a platform providing a user-friendly experience, running mainly on mobile apps.
- **Subscription-based**: the access implies the payment of a fee with a certain regularity, typically every month or every year.
- **Freemium**: a basic version of the service is offered alongside a premium (paid) version.
- **Peer-to-peer**: individuals directly transact with each other with little or even no intermediation from others.
- **Ad-supported**: mainly based on advertising as the source of revenue.
- **Open source**: involves not only the owners of the project but also the community.

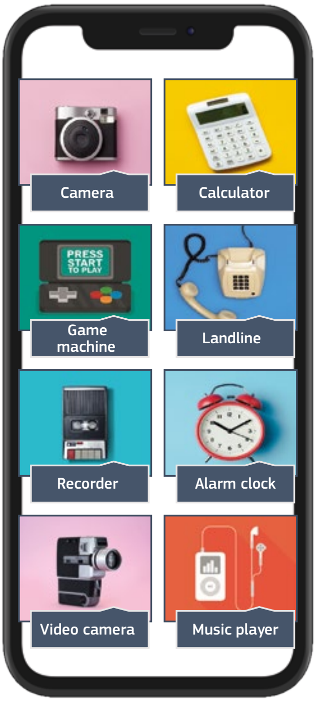
Figure 2-18 Mapping of digital business models and examples of companies



Source: https://fourweekmba.com/digital-business-models/
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter2/figure-2-18.xlsx

The widespread use of smartphones and other tech gadgets has underpinned the creation of the 'digital consumer', enabling free digital goods in a single device and making many physical (and paid) goods obsolete. Since the creation of the smartphone in 2007, apps and other digital tools and services have boomed. Moreover, as noted by Brynjolfsson and Collis (2019), today, smartphones provide for free many of the functions of physical paid goods, such as the alarm clock, calculator, game machine, landline, recorder, video camera, or a music player, as represented in Figure 2-19.

Figure 2-19 How the smartphone enabled free digital goods in a single device, and substituted paid goods



Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit, adapted from Brynjolfsson and Collis (2019)

Note: Images extracted under the licence with stock.adobe.com: © samrit, #201880065; © Dariia Chernenko, #282607942; © chinnarach, #275830884; © patrick, #141611205; © Matt, #308036749; © moreiraalison, #288587446; © dark322, #311919896; © khagani_m, #229130888; © mix3r, #162491327.

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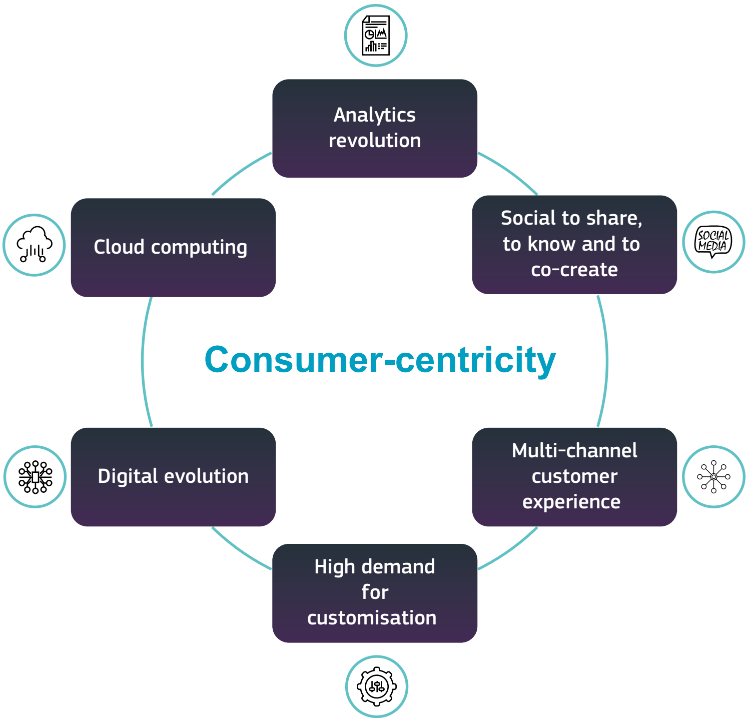
Moreover, e-commerce is on the rise (OECD, 2019) since the cost of digital payments has also declined. As a result, the physical and digital worlds are becoming more and more interconnected, leading to faster and first-hand innovations consumers can choose from. In addition, tech gadgets such as the smartphone and tablet, allied to widespread internet use also mean that consumers are able to access to a lot of information, including in real-time.

Thus, innovation is becoming increasingly customer-centric. In other words, consumers are no longer mere users of new technologies but are actually driving innovations. As they are more informed than ever, companies face even greater pressure, including trying to anticipate future needs. Another growing practice is to have customers' involvement and feedback early in the process of creating a new product or service so that companies can customise the new solutions to the exact needs of the consumer and hence differentiate from their main competitors to secure a higher market share. Figure 2-20 presents an overview of the main trends driving consumer-centric behaviour. These include the big data analytics revolution, extensive social networks and interconnectedness, multi-channel customer experience, a strong demand for almost tailored-made and personalised products and services, and the rise of cloud computing, although there are certainly other factors behind this trend.

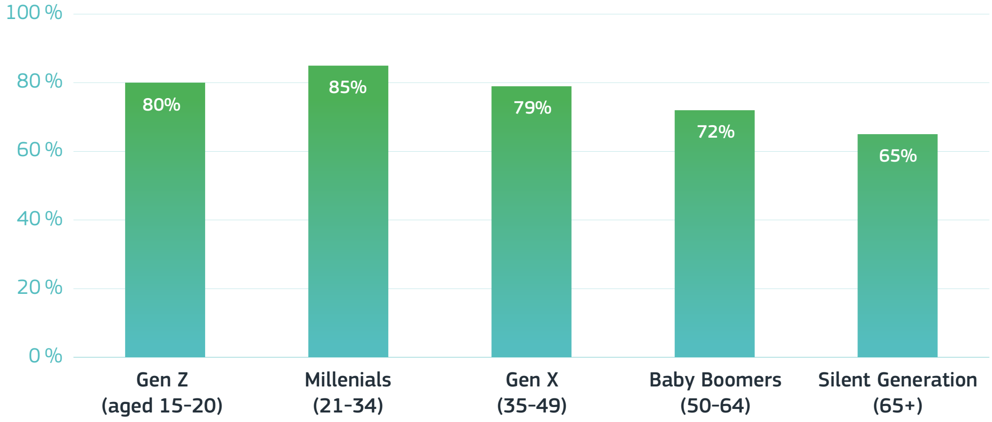
Figure 2-20 **Visual representation of the trends shaping consumer-centric behaviour**



Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit, adapted from Accenture
https://insuranceblog.accenture.com/the-customer-centric-insurer-how-digital-is-creating-a-more-uncertain-competitive-landscape
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter2/figure-2-20.xlsx

Consumers are also increasingly putting pressure on companies to become more environmentally friendly, with millennials leading this push for change in organisations. Overall, it seems that all generations are demanding companies take tougher action to become more environmentally sustainable. In particular, it is the younger generations (Gen Z and Millenials) who seem to be the most concerned about making this change (Figure 2-21). As noted in Wade et al. (2019), 'sustainability and digitization have developed more or less independently of each other, but it's time for these two worlds to merge'. The authors call for the **rise of "corporate digital responsibility" that encompasses social, economic, technological, and environmental aspects**.[8]

Figure 2-21 Percentage of respondents who said that it is 'extremely' or 'very' important that companies implement programmes to improve the environment, by generation



Source: The Conference Board® Global Consumer Confidence Survey, conducted in collaboration with Nielsen Q2 2017

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter2/figure-2-21.xlsx

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[8] https://sloanreview.mit.edu/article/corporate-responsibility-in-the-digital-era/?utm_source=twitter&utm_medium=social&utm_campaign=sm-direct

7. Conclusions

Digitalisation has deeply transformed our economies and societies. In the digital age, the adoption of technologies is happening at an unprecedented speed due to the rise of digital innovations combined with strong network effects. In this context, **fostering the uptake and diffusion of digital skills, competences and practices** across individuals, companies, regions and countries is paramount. At the EU level, the expected Updated Skills Agenda for Europe, and the Digital Skills and Jobs Coalition, aim to tackle the digital skills gap. Furthermore, policies must be faster to react to the changing contexts.

Moreover, digital technologies such as artificial intelligence are increasingly merging with the physical world across a wide range of sectors, leading to a new wave of 'deep-tech innovation' that has intrinsically different 'needs' to other types of innovation. In particular, **deep-tech innovation is very science-based, multidisciplinary and capital-intensive**. The risk associated with these innovations is also very high as they may take some time to be market-ready (if ever), although the private and social returns from a commercially viable and disruptive product may also be extremely high. As a result, these innovations require 'patient capital', multidisciplinary teams, R&D labs, and well-connected innovation hubs, among other factors. Within Horizon Europe, the European Council will support breakthrough, deep-tech innovators.

Industry concentration is also on the rise, although the phenomenon is more prevalent in North America than in Europe. Similarly, **increasing concentration is also visible in terms of R&D investments and outputs such as sales**, whereby most of the benefits are concentrated in a small group of 'superstar' firms. Furthermore, some of the technologies underpinning digitalisation, such as cloud infrastructure, appear to be concentrated in a few US tech giants. This calls, for instance, for competition policies that are 'fit for the digital age'.

Access to data is also increasingly seen as a competitive advantage to thrive in the digital era and gain market shares, especially at a time when innovation is more and more 'customer-centric' and enabling product differentiation. However, access to data should be in line with principles and regulations regarding privacy and the ethical use of data. In the EU, the General Data Protection Regulation (GDPR) provides guidance on the fair use of data. Moreover, the European Data Strategy will make more data available for use in the economy and society, while keeping those who generate the data in control. It will ensure that European rules, in particular privacy and data protection, as well as competition law, are fully respected. The EU will create a single market for data where €4-6 billion will be invested in total in common European data spaces and a European federation of cloud infrastructure and services[9].

Measuring the digital economy to understand its impacts is key. For instance, new studies argue that the digital economy has been underestimated in traditional measures such as gross domestic product, or that consumers' welfare linked to digital innovations is also not being duly accounted for[10]. **In a global and digital economy, international tax rules need to be rethought** as they 'do not capture business models that can make profit from digital services in a country without being physically present', nor do they account for the new ways in which profits are created including 'the role that users play in generating value for digital companies'.[11]

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[9] For more information please visit https://ec.europa.eu/digital-single-market/en/content/european-digital-strategy

[10] See for instance Brynjolfsson and Collis (2019), 'How Should We Measure the Digital Economy?'.

[11] https://ec.europa.eu/taxation_customs/business/company-tax/fair-taxation-digital-economy_en

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CHAPTER
3.1

PRODUCTIVITY PUZZLE AND INNOVATION DIFFUSION

KEY FIGURES

1.0 %
the rate of productivity growth in Europe between 2010 and 2018

65.7 %
the contribution of R&I to total productivity growth in a sample of EU countries

12 %
the gap in real labour productivity between the EU and the United States in 2018

0.5 %
the annual growth rate of Total Factor Productivity in the EU after the crisis

What can we learn?

- **R&I are at the core of the productivity and competitiveness** of our economy.
- **Productivity growth and sustainability can reinforce each other**. Productivity can help overcome the trade-off between environmental policy and long-term growth.
- Despite the rise in digital technologies in the past decade promising large productivity gains, **productivity growth has been sluggish**, holding back more robust economic growth in Europe and other advanced economies.
- **The gap in productivity performance** between highly productive economies and firms at the frontier and the rest points, among other factors, to a **lack of innovation diffusion** in Europe.

What does it mean for policy?

- **R&I policy that aims to enhance productivity** will reinforce companies' ability to be competitive at the global level, benefitting jobs and creating value.
- **R&I policy plays an important role for catching-up** of laggard companies and regions by improving the conditions to speed up knowledge creation and diffusion (investment, regulation, science-business links, framework conditions, and capacity and quality of national R&I systems).

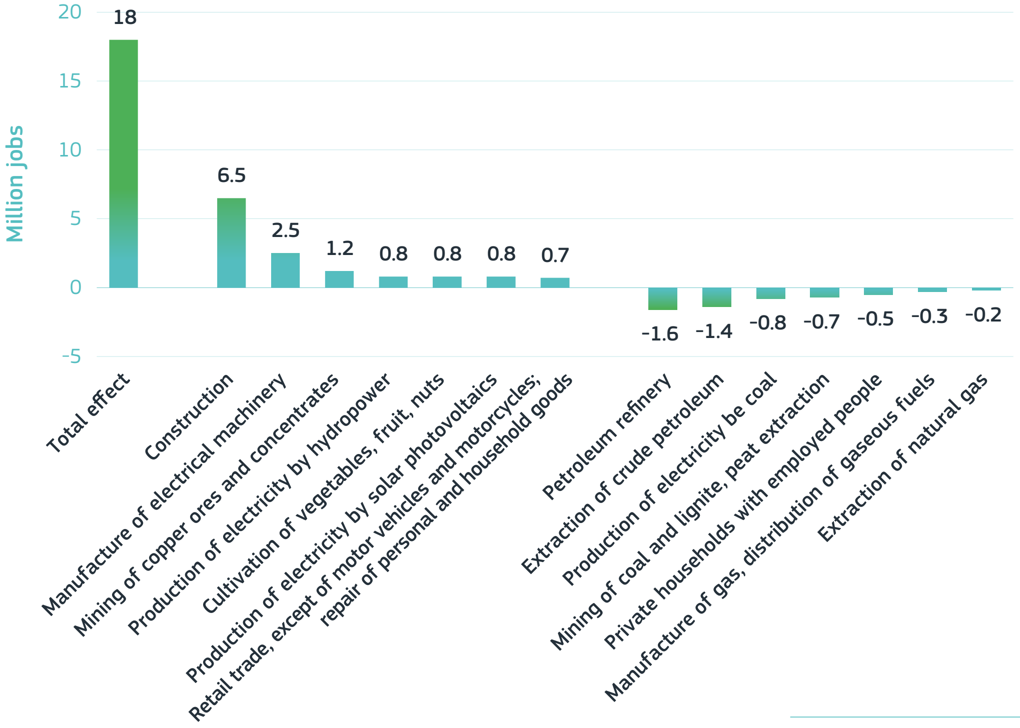
1. Productivity, competitiveness and innovation are closely related

Higher productivity means stronger competitiveness, which is crucial for EU companies in a globalised economy. This is even more true as the EU risks gradually losing its competitiveness, with slow innovation, adoption of technologies and productivity growth in a context where technology is changing fast and new global players are emerging rapidly (European Investment Bank, 2019). Higher productivity will also be essential in the future in the light of ageing societies to compensate for a declining share of the workforce in the population. In this context, productivity will be a key determinant of Europe's future prosperity.

Competitiveness, productivity and innovation are separate concepts but are very closely interrelated. In the global context, it would be a mistake to ignore the fact that innovation can drive the EU's competitiveness through productivity growth. Spurring innovation has a direct effect on what is produced, making goods better and cheaper whilst also ensuring that the production process is efficient. This improvement in the ratio of production output to input is referred to as productivity. Hence, it is a measure of efficiency. Enterprises are competitive when their productivity grows consistently and enables them to reduce the unit costs of their outputs. In turn, if this happens in traded sectors it can allow EU companies to compete on global markets without relying on government support.

Productivity growth and sustainability can reinforce each other. Productivity can also help overcome the trade-off between environmental policy and long-term growth when coupled with appropriate action, such as investment in pollution abatement (Basu and Jamasb, 2019). Boosting productivity growth needs refocusing the use of available resources and investments on more efficient production activities and systems, which must also be environmentally friendly in order to ensure a sustainable growth path (Kalff et al., 2019). Hence, increasing the efficiency of the production process can be compatible with sustainable production and support the sustainable transition. This raises the issue of ensuring a proper decoupling between economic activity and the negative externalities related to the production process. R&I can play a key role here. Productivity gains, and the related economic benefits in terms of value added and jobs, can also be directly generated by more competitive sustainable activities. For example, in Europe, the value added and employment of the environmental sector has increased rapidly compared to the rest of the economy, together with a steady increase in labour productivity (Box 3.1-1). The International Labour Organization (2018) shows an overall positive employment impact from the action taken in the energy transport and construction sectors to limit global warming to 2 °C. By 2030, the estimated job creation, driven by the high demand for labour from renewable energy sources, is around 18 million jobs globally. Under the same logic, it can be shown that the stringency of environmental policies is accompanied by higher levels of eco-innovation and economic competitiveness (European Environment Agency, 2020).

Figure 3.1-1 Sectors most affected by the transition to sustainability in the energy sector (in million jobs)



Source: ILO (2018). World Employment and Social Outlook 2018 – Greening with jobs

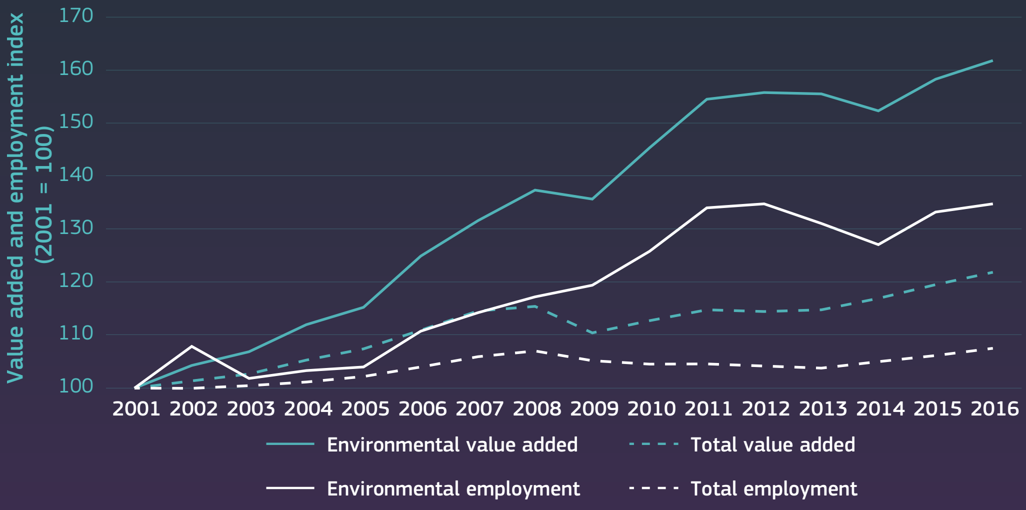
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter31/figure-31-1.xlsx

BOX 3.1-1 A sustainable transition

Europe has engaged in a transition towards a sustainable growth model, in line with the 2030 Agenda for Sustainable Development. Among the multifaceted dimensions of a sustainable development path, the creation of an economic and social model within the natural limits of our planet plays a key role, calling for a better use of resources and a transition towards a low-carbon and climate-nature Europe (European Commission, 2019).

Such a transition also requires a change in the way the production process takes place, including greater relevance and weight for those activities aimed at the prevention and maintenance of the stock of natural resources and a reduction in environmental degradation. Figure 3.1-2 presents the growth of employment and gross value added in activities devoted to environmental protection – the prevention, reduction and elimination of environmental degradation – and resource management – the preservation and maintenance of the natural resources stock. The trend reveals that **the EU has embarked on a sustainable development path, with a steady increase in the weight of the 'environmental sector' in terms of both employment and gross value added, as well as productivity**. Indeed, these activities are growing faster than the overall economy, with a steady and positive trend being in place since 2001.

Figure 3.1-2 Growth of the environmental sector in the EU28(1), 2001-2016



Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on Eurostat (online data code: env_ac_egss2 and env_ac_egss1)

Note: Data are normalised to 100 in 2001.

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Furthermore, productivity growth brings benefits to consumers through higher wages for workers. At the same time, businesses become more profitable, which also benefits investment and jobs. The question is to what extent these (technological/digital) productivity gains benefit society as a whole and what share is captured by a small number of dominant firms. This deserves further investigation, although the dominant market power of a few extremely productive large players could raise distributional questions (ILO, 2018).

R&I is crucial for the EU's productivity. For a long time, economic theory has highlighted the role of technical progress in productivity growth and the key role innovation systems play in this (Solow, 1957; Romer, 1986; Romer, 1990). Innovation has two roles in stimulating productivity (Hall, 2011). First, R&I can increase firms' efficiency through process innovation and improve the goods and services they produce. This raises their demand and reduces production costs. Second, firms that innovate are also likely to grow more, and new entrants with better products should displace existing inefficient firms. Overall, this contributes to increasing aggregate productivity: new ideas help to generate greater (or the same) output with the same (or less) input, for both companies and the whole economy. This, in turn, should positively affect wages and business profitability. Similarly, once a new technology is produced, its diffusion throughout the economy is a key productivity driver: higher adoption rates reduce the gap between leaders and laggard companies (and regions) and eventually positively affect aggregate performance (Andrews et al., 2016; Anzoategui et al., 2019).

BOX 3.1-2 Investments in intangible assets, innovation and productivity performance

Cincera, M. (ULB), Delanote, J. (EIB), Mohnen, P. (UNU-MERIT), Santos, A. (ULB) and Weiss, C. (EIB)

Investment in intangible assets has increased rapidly over the past few decades, mainly driven by changes in industrial market structure, with several important implications for how firms operate[1]. While the manufacturing sector is becoming more oriented towards services and customers, an increasing number of tasks in the services sector are automated thanks to artificial intelligence and robotisation. In this context, information and communications technologies (ICT) affect firms' organisational structure and commercial strategies by providing them with new ways of selling products and services (e.g. e-commerce) or giving fast and easy access to data (e.g., information about customers). Technological change is also affecting the structure of the labour market, creating a need for new jobs in the ICT sector and changes in the demand for workers' skills.

EU firms are facing new challenges. Digitalisation and globalisation are putting pressure on existing market positions competition. Investment in intangible assets – such as R&D, intellectual property rights (patents, trademarks, and design), software and data, and staff training – has gained relevance in overcoming these market pressures. Intangible investment has a positive effect on the propensity to innovate (Figure 3.1-3) and firm productivity (Figure 3.1-4).

Firms located in central and eastern Europe tend to invest less in intangible assets, have a lower propensity to innovate and are less productive. In contrast, firms in west and north Europe have higher levels of intangible investment and productivity.

Manufacturing firms have a higher propensity to innovate than services – for a similar level of intangible investment, they are more likely to introduce new products, processes or services. At the same time, firms in the manufacturing sector tend to be less productive, even though they display a higher average intangible investment intensity than those operating in the services sector.

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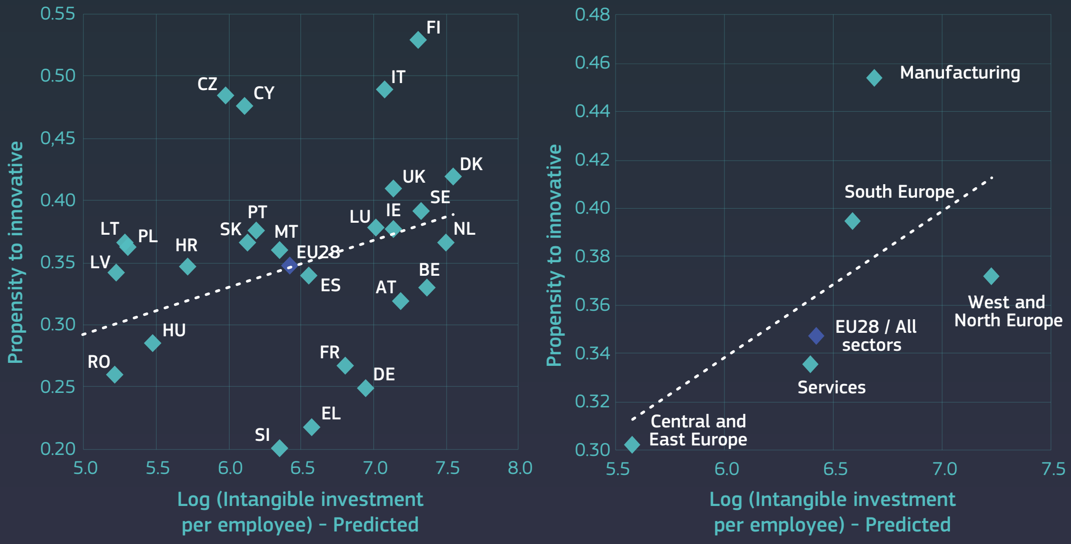
[1] Haskel, J. and Westlake, S. (2017), Capitalism without capital: The rise of the intangible economy, Princeton, NJ: Princeton University Press.

Figure 3.1-3 Intangible investment and innovation



Science, research and innovation performance of the EU 2020

Source: EIB Investment Survey (EIBIS waves 2016 to 2018)

Note: The log of intangible investment per employee was estimated using an OLS regression, controlling for selection bias (decision to invest), obstacles to investment activities, competition index in the sector, firm production capacity utilisation and firm characteristics. Intangible investments include R&D expenditures (including the acquisition of intellectual property); software, data, IT networks, and website activities; acquisition of new skills through the training of employees; organisation and business process improvements (such as restructuring and streamlining).

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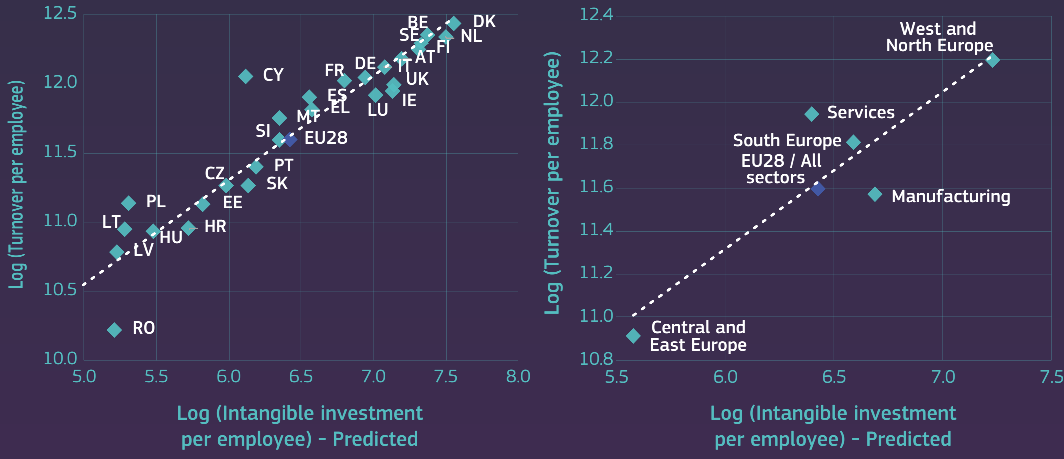
Figure 3.1-4 Intangible investment and productivity relationship



Science, research and innovation performance of the EU 2020

Source: Based on the EIB Investment Survey (EIBIS waves 2016 to 2018)

Note: The log of intangible investment per employee was estimated using an OLS regression, controlling for selection bias (decision to invest), obstacles to investment activities, competition index in the sector, firm production capacity utilisation and firm characteristics. Intangible investments include R&D expenditures (including the acquisition of intellectual property); software, data, IT networks, and website activities; acquisition of new skills through the training of employees; organisation and business process improvements (such as restructuring and streamlining).

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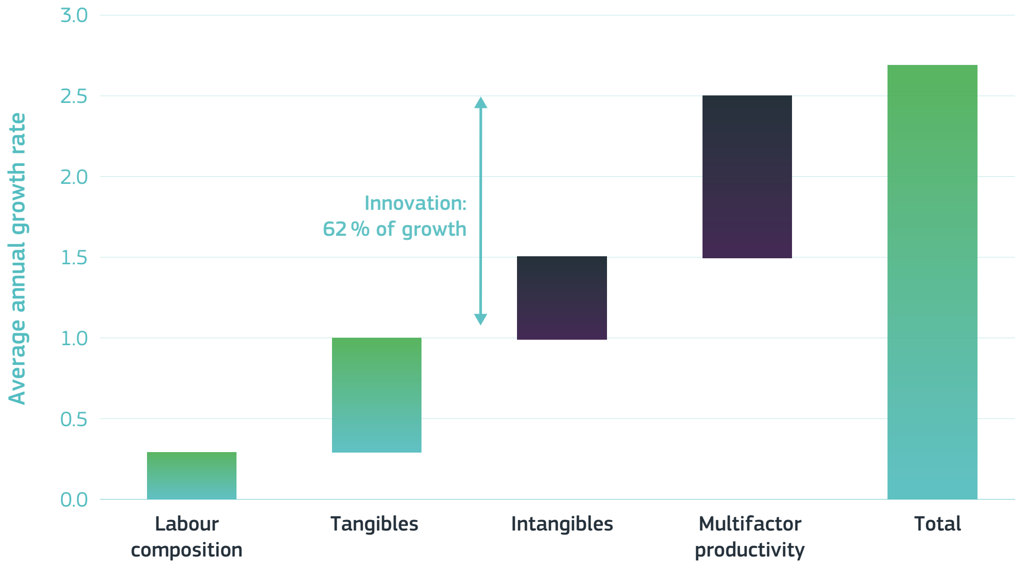
The positive relationship between R&I (and other intangible assets) and productivity has been observed and studied extensively in the literature (see Box 3.1-2 for a recent illustration). While the estimated impacts of R&I on productivity and economic growth vary depending on the methodology used and the period, countries and industries analysed, typical findings confirm the above economic rationale, revealing that R&I and intangible investments do explain a relevant share of productivity performance. Recent evidence also suggests that the decline in R&D and adoption investments contribute to explaining the productivity slowdown preceding the last economic crisis and in its aftermath, respectively (Anzoategui et al., 2019). To quantify the contribution of R&I and intangible investments to productivity and economic growth, the most notable findings suggest that[2]:

- **Before the crisis, almost two thirds of economic growth in Europe from 1995 to 2007 were derived from R&I**, broadly defined as TFP and intangible investments, including R&D, as reported in Figure 3.1-5 (Bravo-Biosca et al., 2013).

Figure 3.1-5 Contribution to European economic growth – percentage per annum (1995-2007)



Source: Bravo-Biosca et al. (2013)

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter31/figure-31-5.xlsx

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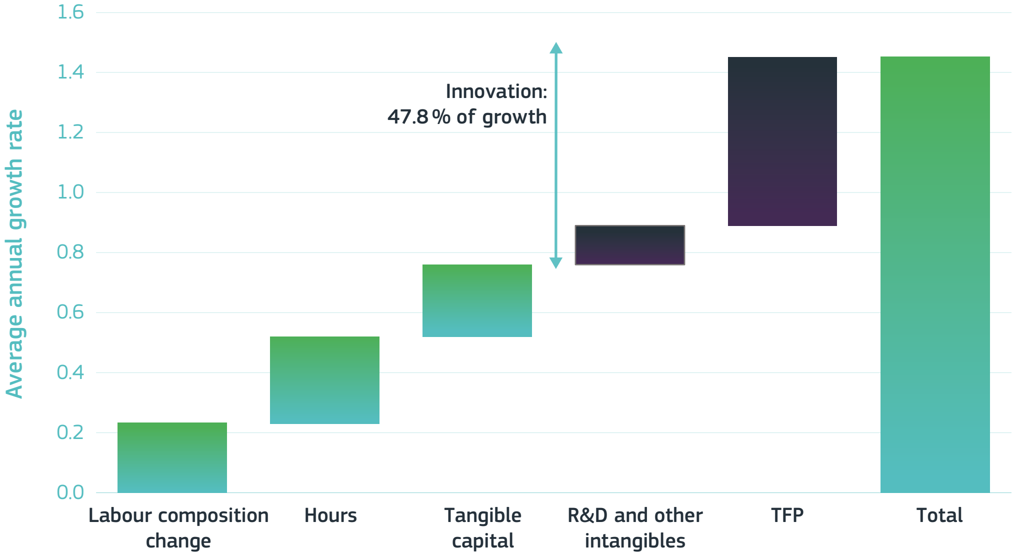
[2] Growth accounting is a standard approach to estimating the contribution of capital, R&D and other intangible (and tangible) components to labour productivity growth, following the seminal work by Solow (1957). TFP is usually considered as the proxy of technological change, while different specifications of the estimation model allow the role of specific factors to be traced back, such as, for instance, ICT capital, R&D, economic competences, etc. The search for the contribution by intangibles has increased in recent years due to the increasing availability of reliable data.

- **After the crisis, from 2010 to 2016, almost half of the economic growth in Europe derived from R&I**, still defined as TFP and intangible investments, including R&D, obtained using the most recent EU KLEMS data 2019 (Figure 3.1-6). Unlike the precrisis estimates by Bravo-Biosca et al. (2013), the contribution of R&I declined slightly due to the significant increase in the role of hours worked, which had been rather minimal in the previous period.

Figure 3.1-6 Contribution to European economic growth (value added) – percentage per annum (2010-2016)



Science, research and innovation performance of the EU 2020

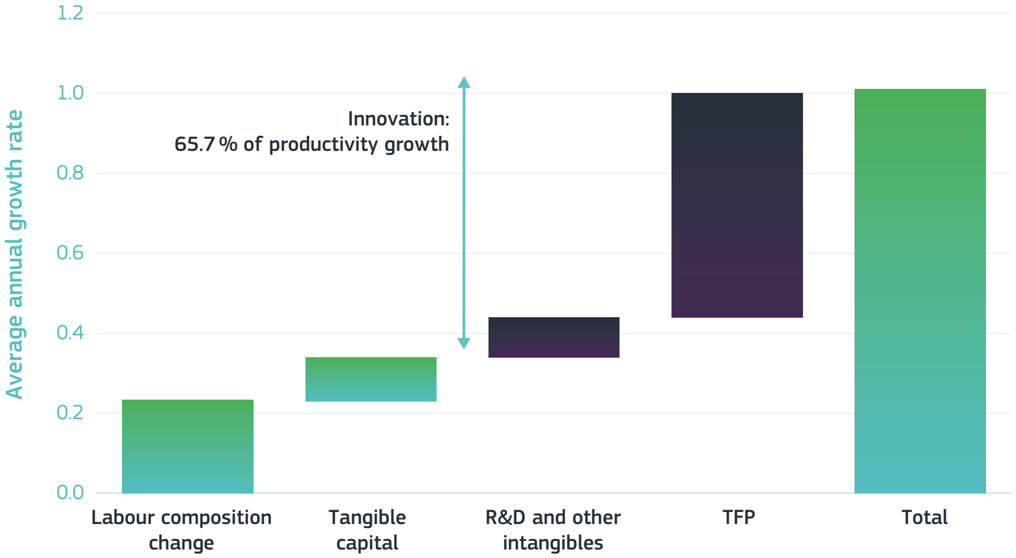
Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on EU KLEMS 2019 (Analytical Database)

Note: Data covers 19 EU Member States: BE, CZ, DE, DK, EE, ES, FR, IT, LV, LT, LU, HU, NL, AT, RO, SI, SK, FI and SE.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter31/figure-31-6.xlsx

- **R&I contributed to nearly two thirds of labour productivity growth in Europe from 2010 to 2016**. If the focus is on labour productivity growth, then the contribution of R&I, as defined above, is equal to about 65.7 % of total productivity growth, signalling its key role as productive-enhancing investments even in the aftermath of the crisis. The results are shown in Figure 3.1-7, presenting the same growth-accounting exercise replacing value-added growth with labour productivity growth.

Figure 3.1-7 Contribution to European labour productivity growth – percentage per annum (2010-2016)



Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on EU KLEMS 2019 (Analytical Database)
Note: Data covers 19 EU Member States: BE, CZ, DE, DK, EE, ES, FR, IT, LV, LT, LU, HU, NL, AT, RO, SI, SK, FI and SE.
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter31/figure-31-7.xlsx

- **The significance of economic competences and intellectual property products has increased in the last two decades**, becoming key intangible assets together with R&D and software and database. While R&D has been and continues to be a relevant factor for economic and productivity growth, economic competences and intellectual property products (including design) have become key drivers of growth across the globe, including in the EU. It is worth noting the decline over time of the contribution of ICT capital (Figure 3.1-8).

- An increase in 10% in R&D investment is associated with gains in productivity between 1.1% and 1.4%, as shown in the meta-analysis by Donselaar and Koopmans (2016)[3].

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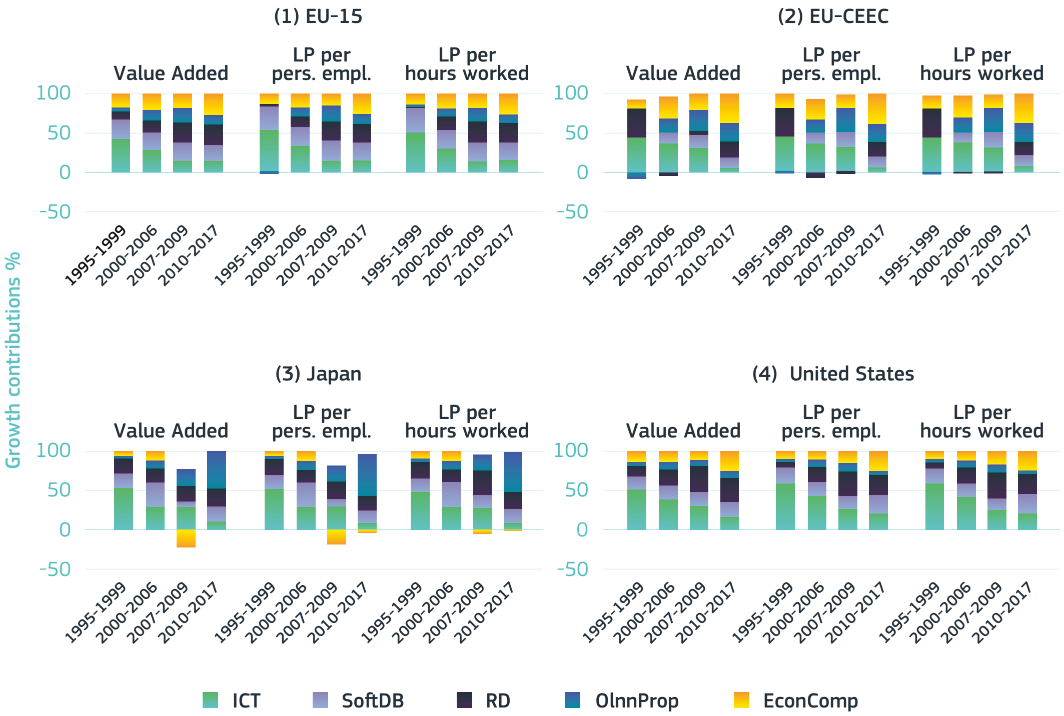
[3] It should be noted that a 10 % increase in R&D investment corresponds to a 0.2 % increase in GDP terms (i.e. R&D investment over GDP). This implies that, assuming no change in the number of hours worked, an increase in R&D investment of 0.2 % of GDP would result in an increase of 1.1 % of GDP, five times larger.

Figure 3.1-8 Contribution of ICT capital and intangible to value added and productivity growth



Science, research and innovation performance of the EU 2020

Source: EU KLEMS 2019

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter31/figure-31-8.xlsx

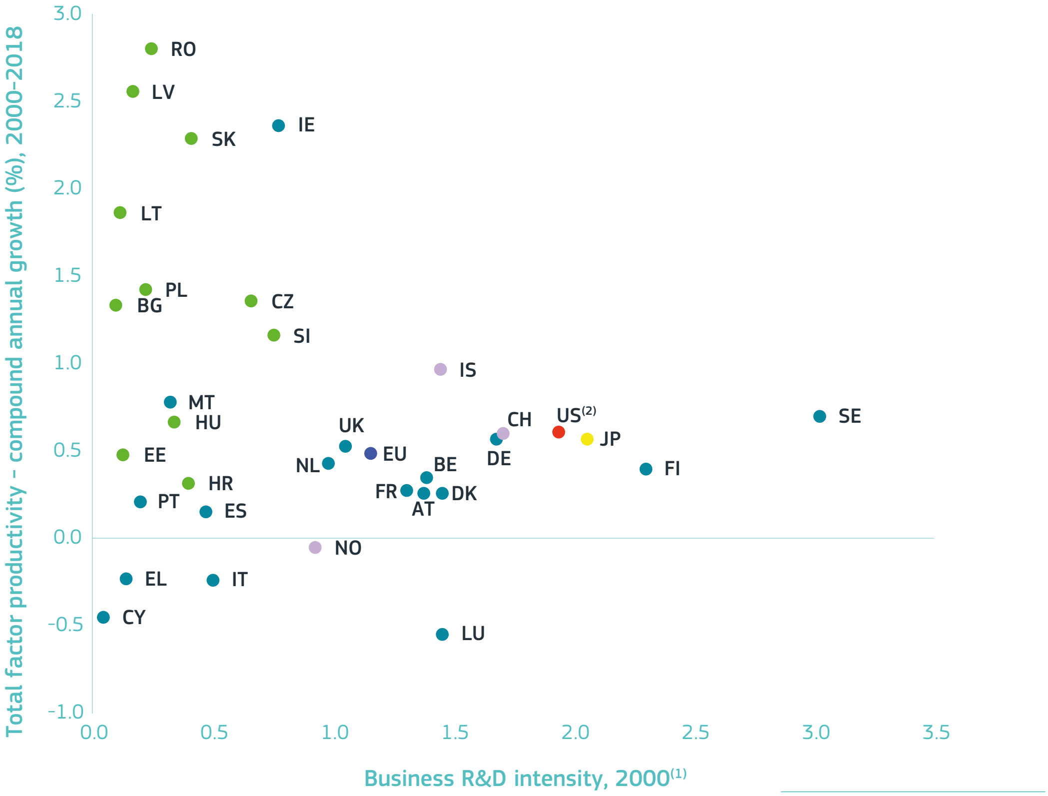
BOX 3.1-3 Total factor productivity and labour productivity

Labour productivity measures the amount of value added produced per work hour and is very often considered to be a good measure of the economy's overall efficiency. Increasing labour productivity can traditionally be associated with the ability to raise the returns to the production factors, notably capital, labour and technology.

Total factor productivity is a measure of the efficiency in the combination of production factors such as labour and capital to generate economic output.

Productivity growth is closely associated with the ability to foster innovation creation and diffusion in high-prosperity countries, but not in lower-performing countries (Figure 3.1-9). There are many factors explaining productivity growth, including well-functioning institutions, better infrastructure and high levels of education. However, and despite the intrinsic difficulties to map the contribution of all these factors, countries with high-income show a strong and positive correlation between TFP growth and business R&D (BERD), as their ability to innovate and technological advancement are main drivers for productivity growth. However, this is not true for lower- and middle-income EU countries where other factors can drive productivity growth, such as improvements in the business environment. In order to avoid a middle-income trap and ensure a long-term virtuous path, central, eastern and south-eastern (CESEE) countries in Europe need to move towards a more innovation-driven model (not just relying on foreign direct investment and technology uptake). The current situation in these countries does not favour the creation of high-skill jobs in the economy and reduces opportunities for high-skilled labour, which is reflected in low unemployment and high job-vacancy rates in the area (Correia et al., 2018).

Figure 3.1-9 Total factor productivity – compound annual growth, 2000-2018 and business R&D intensity, 2000



Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on Eurostat (online data code: rd_e_gerdtot) and European Commission - DG Economic and Financial Affairs

Notes: (1)SE, NO: 2001; HR, AT: 2002; MT: 2004. (2)US: Business expenditure on R&D (BERD) does not include most or all capital expenditure. (3)Countries in green correspond to CESEE countries.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter31/figure-31-9.xlsx

2. Productivity slowdown: a productivity paradox

Despite the rise in digital technologies over the last decade, promising large productivity gains, productivity growth has been sluggish, holding back more robust economic growth in Europe and other advanced economies. This is referred to as a **productivity paradox** which flags long-term risks for the competitiveness of European economies. The rise in digital technologies and their convergence with the physical world, in what some have called the Fourth Industrial Revolution, is transforming our economies and societies. Automation, big data, the Internet of Things and artificial intelligence are all digital technologies that are coming of age, promising new and more efficient business processes and products, which would bring significant gains in productivity growth in our economy. However, economic growth in Europe, and in other advanced economies, has been held back by very low levels of productivity growth that have remained almost flat for over a decade.

While the slowdown is also true in other major economies, over the last decade, productivity growth in the EU has been particularly poor compared to global competitors (Figure 3.1-10). From 2008-2018, TFP growth in the EU was less than half what it was over the period 1995-2007. While it was also low in other advanced economies, such as the United States and Japan, which only managed growth rates below 1 %, the slowdown in productivity growth was particularly acute in the EU. Labour productivity growth rates in the EU also tend to decline over time. While labour productivity per working hour in the EU increased on average by 2.1 % (1.9 % per worker) per year in the period 1995-2000, in the decade 2000-2010 this fell to 1.2 % (0.9 %) per year then decelerated further to 1.0 % (0.8 %) from 2010 to 2018[4]. Box 3.1-4 explores TFP dynamics at the sectoral level for a few Member States.

This productivity slowdown is also observed systematically at Member-State level[5] (Figure 3.1-11). Over the last decade, low EU growth was mainly driven by declines in Greece, Luxembourg and other Member States with values close to -1 %. On the other hand, Ireland, Slovakia, Latvia and Poland presented the highest TFP growth rates over the last decade.

Compared to the United States, almost all EU countries present lower labour productivity. Only Ireland, Luxembourg, Belgium and Denmark report similar or higher labour productivity. Central and eastern countries show the lowest performances in terms of labour productivity. Overall, the gap in labour productivity growth between the EU and the United States is about 12 % (see Figure 3.1-12).

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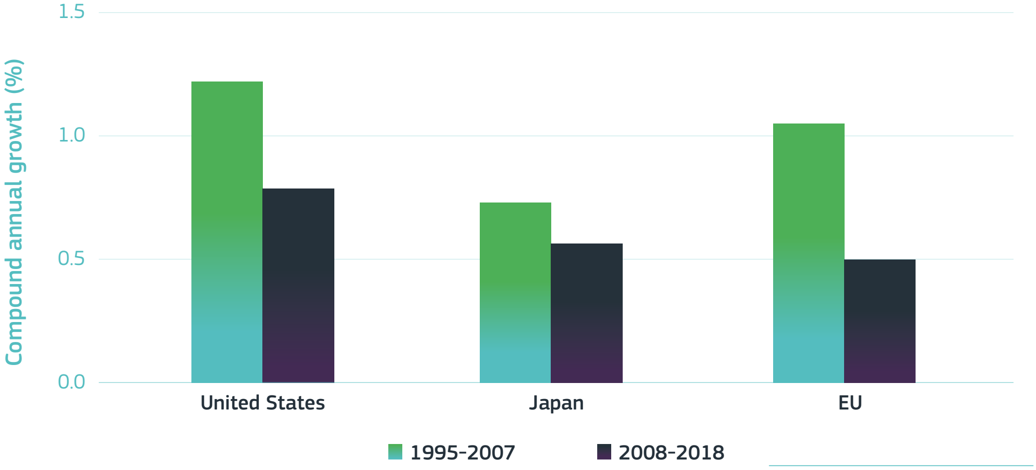
[4] Source: DG Regio.

[5] Except for Ireland, although productivity growth levels in Ireland should be analysed with caution due to a statistical break following a revision in the calculation of GDP that led to a GDP growth rate of 26 % in 2015.

Figure 3.1-10 Total factor productivity – compound annual growth, 1995-2007 and 2008-2018

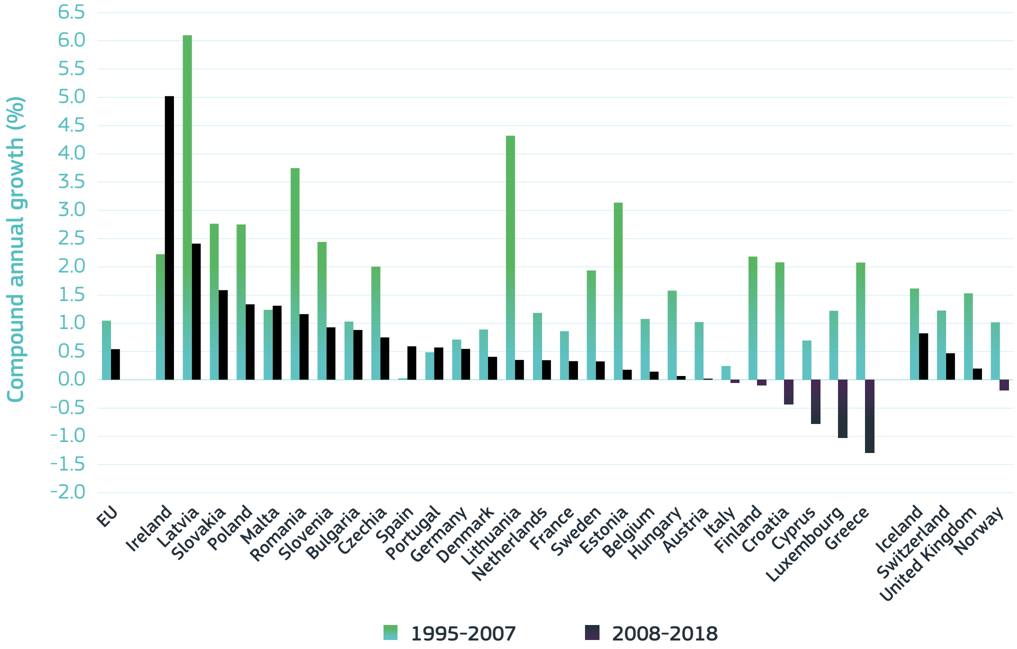


Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit, based on Eurostat and European Commission - DG Economic and Financial Affairs

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter31/figure-31-10.xlsx

Figure 3.1-11 Total factor productivity – compound annual growth, 1995-2007 and 2008-2018

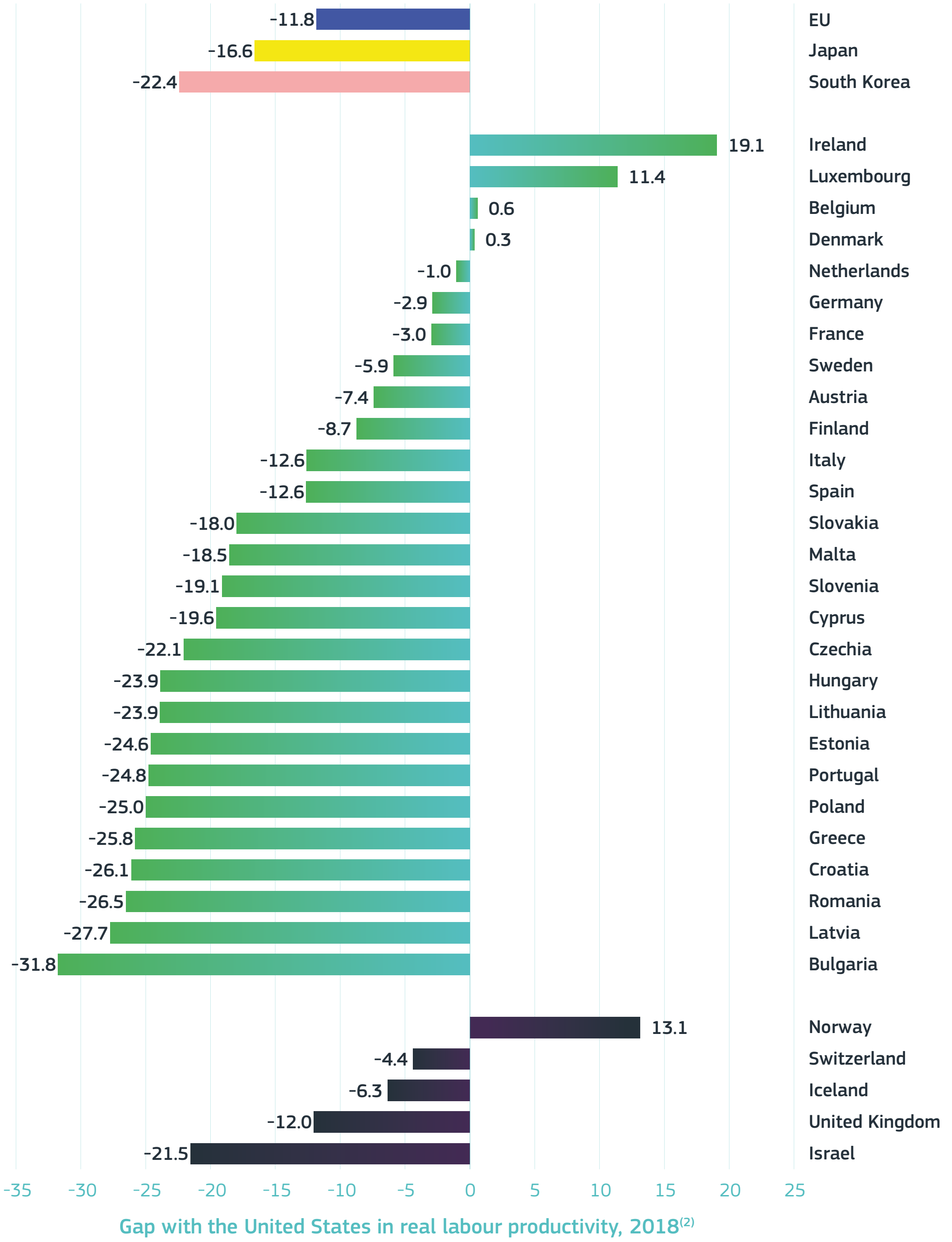


Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on Eurostat and European Commission - DG Economic and Financial Affairs

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter31/figure-31-11.xlsx

Figure 3.1-12 The gap in real labour productivity (GDP per hour worked[1]) between each country and the United States, 2018



Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on European Commission - DG Economic and Financial Affairs, OECD

Notes: [1]GDP per hour worked in PPS€ at 2010 prices and exchange rates. [2]IS, NO, CH, IL, JP, KR: 2017.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter31/figure-31-12.xlsx

BOX 3.1-4 TFP trends at the sectoral level

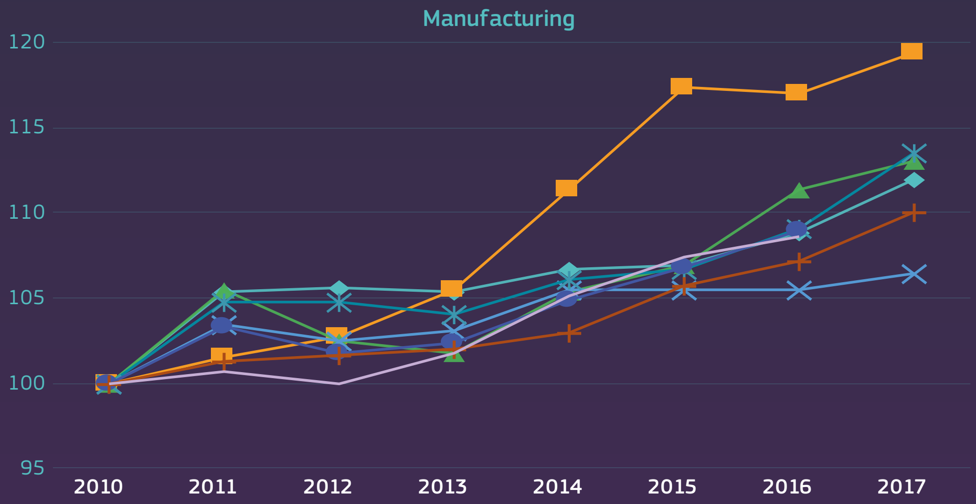
Jeoffrey Malek Mansour - Belgian Science Policy Office (Belspo)

Higher labour productivity can be achieved if more or better capital is used (capital deepening), or if the combined efficiency with which labour and capital are used (i.e. TFP) is improved. As such, TFP is thus a fundamental driver of global productivity and is linked to technological progress in an economy. Figure 3.1-13 shows the evolution of TFP over the post-crisis period (2010-2017) for the EU19[6] and a number of reference countries and across three aggregate sectors: manufacturing, market services[7] and non-market services[8].

It appears that, on average for EU19 countries, TFP has known divergent evolutions across these 3 macro-sectors: while it increased steadily in the manufacturing industries (+9 %), its progression was more moderate in market services (+4 %) and even declined slightly in non-market services (-1 %).

With respect to these averages, individual countries have evolved differently and a variety of trends can be observed. In the manufacturing sector, TFP growth has proved particularly vigorous in Belgium but rather sluggish in France and Italy. Germany, the Netherlands and Austria have remained close to the EU19 average. On the contrary, Germany and the Netherlands have performed particularly well in the market-services sector while France, Belgium and Italy have stagnated and have proved to be the worst-performing economies in our sample. Concerning the non-market-services sector, countries' performance is even more adverse, in particular for Italy and Austria (-2 %), Belgium (-3 %) and more spectacularly Spain (-7 %). Conversely, TFP in Germany, France and the Netherlands has increased by 1 to 1.5 % over the same period in non-market services.

Figure 3.1-13 Total factor productivity by sector and selected EU countries, 2010-2017



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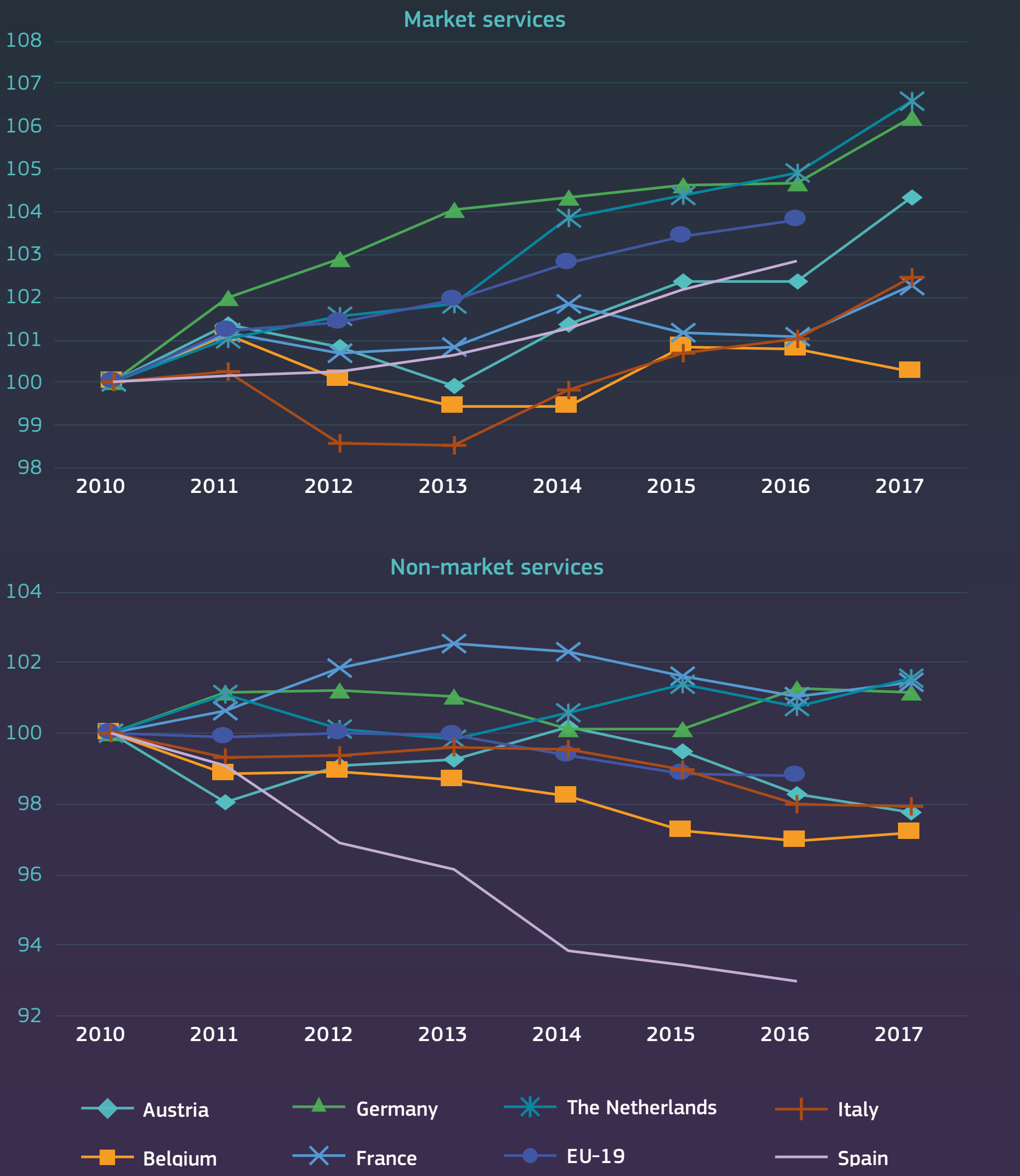
[6] AT, BE, CZ, DE, DK, EE, ES, FI, FR, HU, IT, LT, LU, LV, NL, RO, SE, SI, SK.

[7] Market services are proxied by NACE sectors (sections) G to N: wholesale and retail trade; Transportation and storage; Accommodation and food service activities; Information and communication; Financial and insurance activities; Real estate activities; and Professional, scientific, technical, administrative and support service activities.

[8] Non-market services are proxied by NACE sections (sections) O to Q, i.e. public administration, defence, education, human health and social work activities.



Source: Authors' own computations based on EUKLEMS, 2019 release

Note: TFP is set at 100 in 2010.

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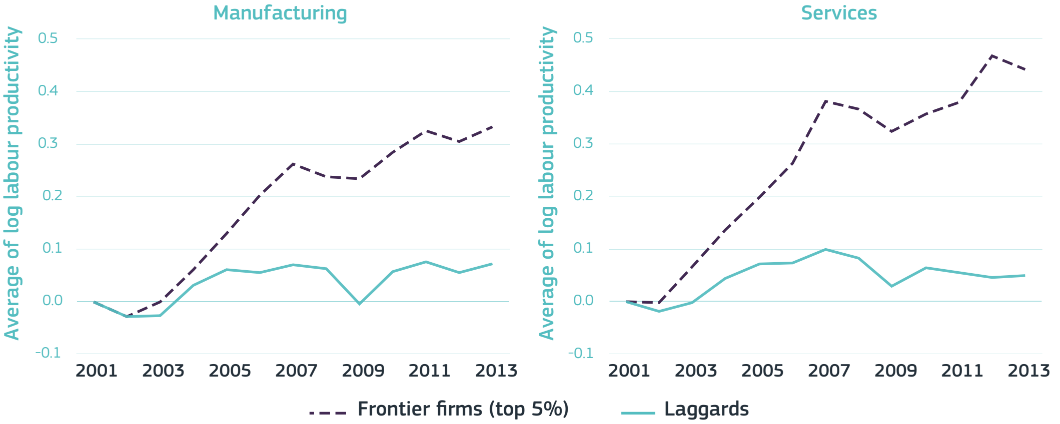
3. A growing productivity gap and a lack innovation diffusion

The productivity paradox points to deep changes in innovation dynamics. These changes relate to the rise of several breakthrough innovations led by **new global technological champions that are creating and shaping entirely new markets**. However, they are also linked to the **slowdown in innovation diffusion**, which is holding back a stronger uptake of innovations across companies, sectors and regions. The convergence of digital technologies with the physical world has enabled the rise of many important breakthrough innovations. At the same time, it has rendered the innovation process more complex as companies need to master different technologies and new business models. This, coupled with the rise in network effects, has led to a slowdown in innovation diffusion across firms, regions and sectors, preventing the benefits of innovation from being disseminated fully across the economy.

This slowdown in innovation diffusion has been observed since the beginning of the 2000s. A small number of leading firms (in particular, platform-economy companies, see Box 3.1-5) have championed strong productivity growth rates, while a 'fat tail' of laggard firms have depicted disappointing productivity growth rates that translate into low aggregate productivity growth. These differences are found across sectors, although there are some intra-sectoral differences, notably with lower overall growth rates in the business service sector. This widening of the productivity gap may explain why a rapid technological change and productivity slowdown can be observed at the same time. This has strong implications not only for productivity growth but also for rising inequality patterns. Wage inequality has increased both within and between firms, suggesting that increasing between-firm inequality does not simply reflect the flow of similar workers into similar firms but that the ones at the top of the wage distribution are seeing even higher rewards (OECD, 2019).

Figure 3.1-14 Labour productivity gap between global frontier firms and other firms, 2001-2013



Source: Andrews et al. (2016)

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BOX 3.1-5 The rise of platform-economy companies

In the past two decades or so, digital technologies have enabled some of the most impressive breakthrough innovations in our economy, which have revolutionised entire industries and markets. The rise of the so-called platform-economy companies, such as Alphabet, Facebook, Amazon, Alibaba, Uber or Netflix, has deeply transformed how we search for things, communicate with each other, buy products, move within cities or consume entertainment. Many of these firms have been able to grow at an unprecedented pace to become global economic behemoths by market capitalisation, transforming entire industries and markets. At the same time, these companies do not seem to improve the quality of employment as they tend to offer less-stable contracts and fewer prospectives for career development (EPSC, 2019).

One sign of this lack of innovation diffusion is the increasing industry concentration (see also Chapter 2 - Changing innovation dynamics in the age of digital transformation). This is one development that indicates that technological change or globalisation is enabling the most productive firms to expand (Autor et al., 2017), although it has recently also raised questions about the lack of competition and the formation of quasi monopolies. Evidence shows that, between 2000 and 2014, three quarters of European industries saw a **concentration increase in market performance** in the order of 4 percentage points for the average European industry (Bajgar et al., 2019).

In parallel, as a result of persisting rigidities that affect the well-functioning of the markets, 'zombie' firms[9] **continue to 'capture' capital and labour resources** that could otherwise be redirected towards innovative, more productive activities, thereby hindering Europe's innovation performance (see also Chapter 3.3 - Business Dynamics and its contribution to structural change and productivity growth). The misallocation of resources, including credit, barriers to entry and inefficient product and labour markets ease the survival of less-productive firms which would otherwise have exited the market. Consequently, the economy is characterised by a wider distribution of productivity among firms, with a larger gap between the laggards and the most-productive companies. This also means that a more efficient allocation of resources across companies, allowing less productive firms to exit and productive firms to grow, would enable significant growth.

Inequalities between firms are also driven by sectoral dynamics, with the uptake of digital technologies over the past two decades varying significantly across different sectors of the economy. Some sectors have benefited more from the uptake of advanced digital technologies and have adapted their products, services and business models accordingly. On the other hand, other sectors seem to have lagged behind. These disparities could be broadened with the rising applications of artificial intelligence. Promising developments in artificial intelligence can go far beyond labour

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[9] Zombie firms are defined as those companies with a low ratio of operating income to interest expenses (less than one third for three consecutive years in McGowan et al., 2017), suggesting that they do not make enough profit to pay debt obligations on bank loans.

BOX 3.1-6 Chapter 10 – The bottom also matters: policies for productivity catch-up in the digital economy

This chapter provides an overview of recent and ongoing analysis of these issues and discusses **policies that affect the catch-up of laggards in the context of digital transformation**.

First, the chapter introduces **productivity divergence** in the context of the global phenomenon linked to digital transformation and the knowledge economy. Then, it examines **trends in productivity divergence and business dynamism**, respectively, with a **focus on the bottom of the productivity distribution**. Beyond common trends, a few examples highlight **cross-country and cross-sector heterogeneity**. The descriptive sections conclude with company and sector characteristics and discussions about the possible explanations behind the documented trends at the bottom, including the role of openness.

The final analytical section provides a framework and summarises the main results of the analysis on the **role of policies on the speed of laggards catching up**.

Read more in Chapter 10.

Figure 3.1-15 Average productivity by performance group relative to the 'typical firms' group multifactor productivity

Science, research and innovation performance of the EU 2020

Source: Authors' own computations based on the EIB Investment Survey (EIBIS waves 2016 to 2018)

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automation with impacts on business models and innovation activity. The differences observed between firms with strong digital capability and a well-designed AI adoption strategy could reinforce the differences in uptake, enabling these companies to raise profit margins or increase the efficiency of their R&D operations. Overcoming that gap requires, among others, policies to improve the conditions to speed up knowledge creation and diffusion via more investments in intangible assets and skills, and innovation-friendly regulation that supports transformative technological change across sectors.

Ensuring the EU's competitiveness and prosperity will require a boost in productivity. The gap in productivity performance between highly productive firms at the frontier and the rest points to a clear lack of innovation diffusion in Europe. As Member States approach higher levels of prosperity, the adoption of an innovation-based model is crucial to avoid the middle-income trap that this lack of diffusion can exacerbate, especially for Member States in the CESEE. Overcoming that gap requires policies to improve the conditions to speed up knowledge creation and diffusion via increased investments in intangible assets and skills, innovation-friendly regulation that supports transformative technological change across sectors, stronger science-business links, adequate conditions for the creation, scaleup and orderly exit of firms, access to risk capital, and efforts to raise the capacity and quality of national research and innovation systems.

4. Conclusions

R&I are key engines for Europe's productivity growth, driving long-term competitiveness and economic performance. Innovative investments make the production process more efficient and improve produced goods and services. Provided supportive framework conditions are in place, innovative companies can flourish and the process of creative destruction will make room for new entrants with better products, displacing existing inefficient and less-innovative companies.

After the last economic crisis, from 2010 to 2016, nearly two thirds of labour productivity growth in Europe derived from R&I, broadly defined. The contribution of different intangible investments has changed over time, reflecting the evolving innovation dynamics, including the increasing role of digitisation and AI and the rise of global technological champions creating and shaping entire markets. In particular, economic competences and intellectual property products have emerged as key intangible assets, together with R&D, software and databases.

In this context, the increasing concentration of R&I activities highlights the need to foster the diffusion of innovation creation and its uptake in order to spread the benefits across countries, regions and companies. This is particularly important for economies in the southern periphery of the EU, which have been unable to keep pace with the innovation leaders, and for the CESEE countries in order to ensure a continued (and sustainable) growth model in the long term. Innovation diffusion and knowledge absorption are also crucial to close the gap between a few leading top companies and the rest.

Productivity growth can and needs to drive the sustainability transition. As productivity growth entails more (equal) output with the same (fewer) resources, such an improvement in the efficiency of production systems is necessary to reduce the impact of production on the planetary boundaries. Similarly, innovation diffusion and its uptake can ensure that the benefits of productivity growth are widespread across companies, sectors and places, contributing to meeting the social dimension of the sustainability transition.

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CHAPTER
3.2

STRUCTURAL CHANGE

KEY FIGURES

50 %
share of knowledge-intensive sectors in EU employment

16 %
increase in the shares of knowledge-intensive services in the EU in the period 2000-2016

17 %
labour productivity growth driven by productivity gains within sectors in the EU in the period 2000-2016

What can we learn?

- A higher weight of knowledge-intensive sectors **correlates with higher R&I investments and productivity performance**.
- **Knowledge-intensive services have a weight of more than 40 %** and constitute the main bulk of employment shares in the EU.
- **Structural change is not favouring enough knowledge-intensive sectors in the EU**, reducing productivity growth patterns. This trend is particularly relevant in some Member States.
- **While a generalised transformation towards knowledge-intensive services has been observed, intra-EU differences persist**. In particular, some countries have been moving away from medium-high-tech and high-tech manufacturing while the catching up by others (most notably the central, eastern and south-eastern Europe - CESEE economies) is driven by greater specialisation in medium-high-tech manufacturing.
- **Differences in productivity performance also exist within sectors** and contribute to explain the productivity gap between the EU and the United States.

What does it mean for policy?

- **Mobilise national and European resources towards knowledge-intensive activities** as a lever to increase Europe's ability to invest in R&I and its productivity prospects.
- An **EU industrial strategy** is key to counter the deindustrialisation trends in the EU and to **increase long-term EU competitiveness while meeting the need for a transition towards a climate-neutral and sustainable economy**.

While R&D is the engine of long-term productivity growth, the capacity of an economy to invest in R&D is shaped by its economic structure. Europe is slowly emerging from a period of sluggish economic growth since the aftermath of the last economic crisis. While high heterogeneity can be observed across Member States and their regions, low or null productivity growth has been identified as one of the key causes behind the weak economic performance, which is a challenge Europe must face in order to achieve greater and widespread prosperity. As acknowledged in the economic literature and described previously (see Chapter 3.1 - Productivity puzzle and innovation diffusion), investments in knowledge and innovation, measured most notably by R&D expenditure, are a fundamental lever to improve the competitiveness of an economy and its capacity to create value. However, while in general terms higher investments in R&D increase the innovation potential of economies and their productivity, several factors affect the production of knowledge and its diffusion. This chapter and Chapter 3.3 explore two of them, defined as structural as they determine – *ceteris paribus* – the overall capacity of an economic system to innovate and invest in R&D. These two elements are: i) the structural composition of an economy and its change; and ii) the dynamism of the business sector. As will be shown below, knowledge-intensive sectors are 'naturally' characterised by higher R&D intensity and they tend to innovate more. Therefore, economies specialising in knowledge-intensive activities experience the highest levels of productivity and the largest productivity growth. This will be the subject of this chapter. Furthermore, innovative companies are more likely to emerge in countries where the business environment is more dynamic, i.e. where there is a larger share of new companies entering the markets, as they contribute to boosting competition, introducing new business models and upgrading the economic structure. This topic will be analysed in Chapter 3.3.

1. Economic structure shapes economies' R&D intensity and labour productivity

Countries that have been able to change the structure of their economy by increasing their specialisation in knowledge-intensive sectors will become more productive, leading to greater prosperity in the long term. This section analyses the economic structure of the EU and its Member States and investigates its dynamics in recent years. The focus is on those sectors characterised by a higher intensity of research and innovation activities as they are the main drivers of productivity gains and are of fundamental importance for innovation and greater levels of prosperity.

To measure the degree of knowledge across different sectors, the analysis makes use of R&D intensity, i.e. the share of R&D investment in a sector's total value added. Being the most-used indicator, it is easily comparable across different countries and is a reasonable proxy for knowledge and innovation creation. Hence, the analysis below will use and compare four main knowledge-intensive macro-sectors: high-tech manufacturing, medium-high-tech manufacturing, high-tech knowledge-intensive services and (non-high-tech) knowledge-intensive services. Here, these four macro-sectors are referred to as knowledge-intensive activities or sectors.

BOX 3.2-1 Classification of manufacturing industries and knowledge-intensive services

The definition of manufacturing industries and knowledge-intensive services follows the aggregation by Eurostat according to technological intensity and based on NACE Rev.2[1]. Beyond the four knowledge-intensive macro-sectors, the remaining activities are used for the analysis later in this chapter and the corresponding classification is presented below.

High-tech manufacturing includes the manufacture of: basic pharmaceutical products and pharmaceutical preparations (C21) and of computer, electronic and optical products (C26).

Medium-high-tech manufacturing includes the manufacture of: chemicals and chemical products (C20), electrical equipment (C27), machinery and equipment (C28), motor vehicles, trailers and semi-trailers (C29), and the manufacture of other transport equipment (C30).

Medium-low-tech manufacturing includes both the medium-low and the low-technology manufacturing industries. These include the manufacture of: coke and refined petroleum products (C19), rubber and plastic products (C22), other non-metallic mineral products (C23), basic metals (C24), fabricated metal products, except machinery and equipment (C25), the repair and installation of machinery and equipment (C33), the manufacture of food products (C20, beverages (C11), tobacco products (C12), textiles (C13), wearing apparel (C14), leather and related products (C15), wood and wood and cork products except furniture, articles of straw and plaiting materials (C16), paper and paper products (C17), the printing and reproduction of recorder media (C18), the manufacture of furniture (C31) and other manufacturing (C32).

Knowledge-intensive services include water transport (H50), air transport (H51), information and communication (J), financial and insurance activities (K), professional, scientific and technical activities (M), employment activities (N78), public administration and defence, compulsory social security (O), education (P), human health and social work activities (Q), and arts, entertainment and recreation (R). They do not include services with high technological content which are classified separately as high-tech knowledge-intensive services.

High-tech knowledge-intensive services include motion picture, video and television programme production, sound recording and music publishing activities (59), programming and broadcasting activities (60), telecommunications (61), computer programming, consultancy and related activities (62), information service activities (63), and scientific research and development (72).

Other services include services not belonging to any of the above categories (including G, I, L, S, T and U).

Agriculture, hunting and forestry, mining and quarry (B) and construction (F) are classified as *Rest of the economy*.

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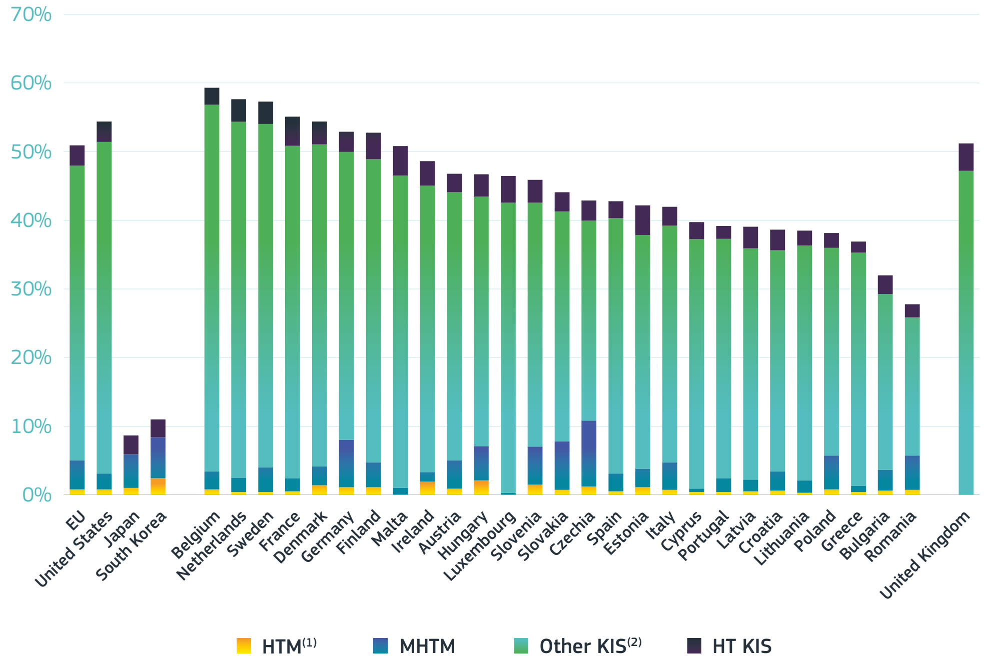
[1] See https://ec.europa.eu/eurostat/documents/3859598/5902521/KS-RA-07-015-EN.PDF

The structural composition of the EU's economies is a key factor in explaining why most Member States fall short in reaching high R&D intensity, with most of them remaining below 3%. The Lisbon Agenda sets the R&D intensity target for the EU at 3%. However, only a few Member States have met this target, while the EU as a whole is a long way off and will not be able to meet it by 2020 (see Chapter 5.1 - Investment in R&D). Countries more specialised in knowledge-intensive sectors tend to be characterised by higher R&D intensity, driven by larger shares of R&D over value added in the business sector (BERD). Indeed, activities belonging to high-tech and medium-high-tech manufacturing and high-tech and the other knowledge-intensive services are intrinsically more innovative and require more resources to be invested in intangible assets. Figure 3.2-1 presents the structural composition of European economies, measured by the share of employment per sector[2].

Figure 3.2-1 Employment shares in high tech manufacturing, medium-high tech manufacturing and knowledge intensive services, 2016(3)



Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on Eurostat (online data code: nama_10_a64_e) and OECD

Notes: (1)Data missing for MT and LU. (2)Data incomplete for JP and KR. (3)EU, KR: 2015.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter32/figure-32-1.xlsx

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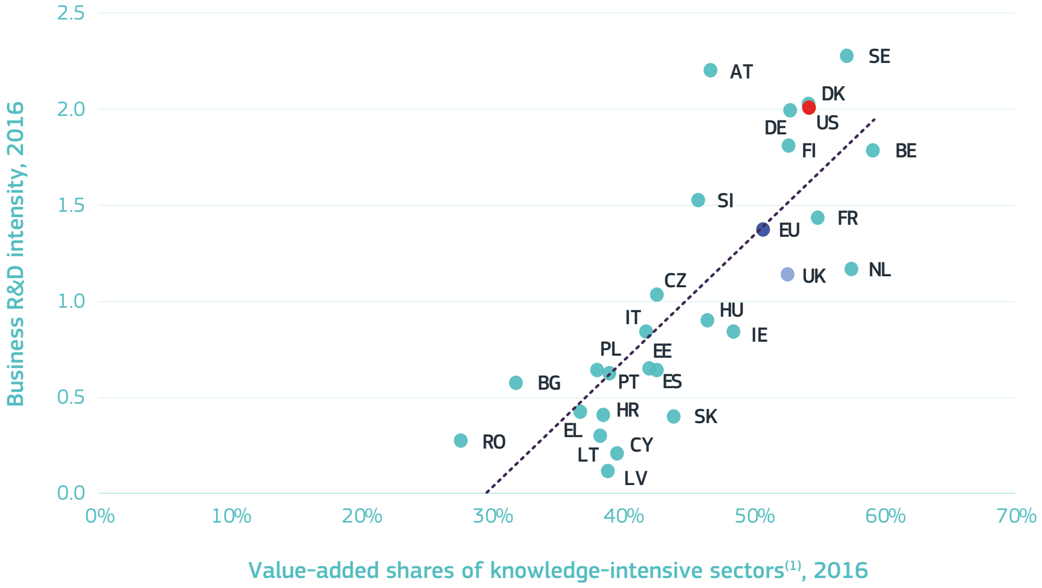
[2] A similar graph can be produced using value-added shares. Employment shares are used to be consistent with the analysis in the rest of this chapter.

The European economic structure is similar to that observed in peer countries, adding up to more than half the total employment in knowledge-intensive sectors. Figure 3.2-1 shows that the EU, like any modern economy, is characterised by the predominance of services, representing more than 70% of total activities. In particular, knowledge-intensive services have a weight of more than 40% and constitute the main bulk of employment shares in the EU. When considering high-tech knowledge-intensive services only, their share is around 3% of total employment, even though, as for high-tech manufacturing, they are characterised by the highest productivity levels, as shown below. The economic structure of the EU is similar to that of the United States, which have a smaller share of medium-high-tech manufacturing and a higher specialisation in knowledge-intensive services. It is worth noting that South Korea stands out among the peer countries for high-tech and medium-high-tech manufacturing, with a significantly higher weight at 8.4%.

Within Europe, significant heterogeneity can be observed across the Member States. First, there are economies with a fairly high share of knowledge-intensive sectors, above 50%, and with the highest value (Belgium) falling slightly below 60%. On the other end of the distribution, there is a group of countries recording a total below 40%, mainly due to significantly lower shares of knowledge-intensive services. This group mainly includes eastern European economies and countries from southern Europe, following different paths over time. Indeed, the former are economies that are building their knowledge-based sectors, while the latter are countries facing difficulties to upgrade their economic structure, such as, for instance Italy, Greece and Portugal. Second, while Europe tends historically to be specialised in medium-high-tech manufacturing, there are a few countries with relatively higher shares. These are mainly central, eastern and south-eastern economies that have developed a large base in these sectors in recent decades, most notably in the automobile sector, driven by the location of production from other countries, such as, for example, from Germany. As will be shown below, this process has mainly involved production, while R&D intensity has not increased that much. It should be noted that Germany, Austria and Italy are three countries with a significant and long-standing specialisation in medium-high-tech manufacturing.

The larger the weight of knowledge-intensive sectors, the higher the capacity to invest in R&D and innovate. Given the above scenario, it is possible to investigate the relationship between R&D intensity and the weight of knowledge-intensive sectors which eventually determines how much an economy can invest in R&I. Figure 3.2-2 plots business R&D intensity and the sum of the employment shares of medium-high-tech and high-tech manufacturing and knowledge-intensive services. The private sector is the main performer in R&D investment, accounting for around 65% of total R&D investment in the EU and 72% in the United States. The figure reveals a clear positive relationship: countries with a larger total share of knowledge-intensive sectors are also those with larger R&D intensities. Empirical evidence suggests that differences in structural composition do explain most of the EU-United States business R&D gap, and that this is true even when accounting for the role of company size and the share of young innovative firms in the two economies (Cincera and Veugelers, 2013). Among knowledge-intensive activities, high-tech and medium-high-tech manufacturing are key engines for R&D investments in the business sector, as a relevant share occurs in industry (European Commission, 2018; Coad and Vezzani, 2017). It is interesting to observe that, while there is a positive correlation between the share of knowledge-intensive manufacturing activities and business R&D intensity, there are a few exceptions (Figure 3.2-3). This is notably the case in some CESEE economies, which have the highest specialisation in knowledge-intensive manufacturing – especially in the medium-high-tech sectors – but relatively lower R&D intensity. As mentioned above, this is due to the delocalisation of production from abroad which does not come with the relocation of R&D activities (Correia et al., 2018).

Figure 3.2-2 Business R&D intensity and sum of employment shares in knowledge intensive sectors, 2016[(2)(3)]



Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on Eurostat (online data code: nama_10_a64_e) and OECD

Notes: (1)Knowledge-intensive sectors include high-tech manufacturing, medium-high-tech manufacturing and knowledge-intensive services. (2)Data missing for MT and LU. (3)EU: 2015.

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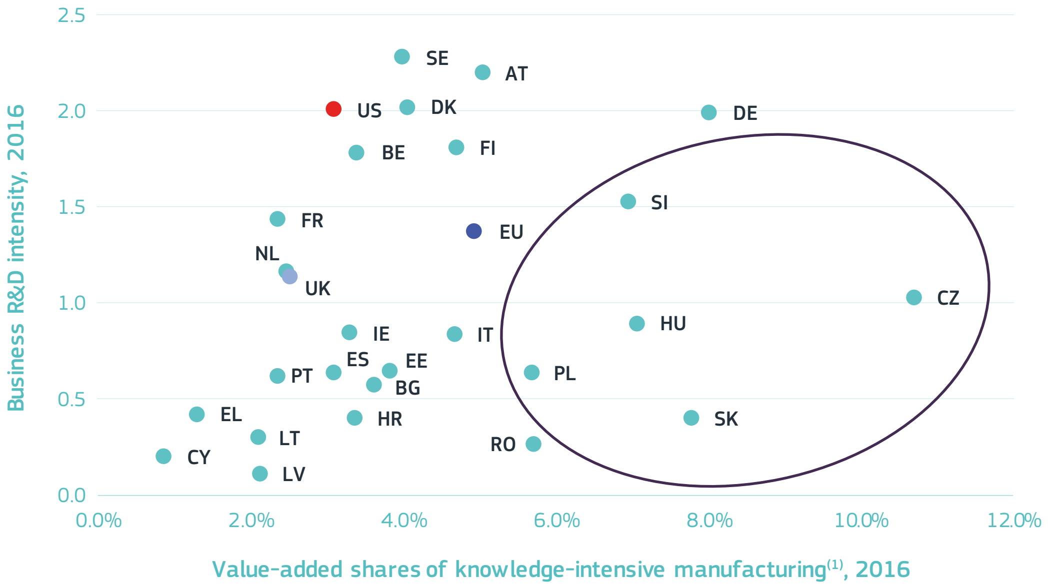
Figure 3.2-3 Business R&D intensity and employment shares in high-tech and medium-high-tech manufacturing, 2016[2][3]



Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on Eurostat (online data code: nama_10_a64_e and rd_e_gerdtot), OECD

Notes: [1]Knowledge-intensive manufacturing includes high-tech manufacturing and medium-high-tech manufacturing. [2]Data missing for MT and LU. [3]EU: 2015.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter32/figure-32-3.xlsx

Higher shares of knowledge-intensive sectors are correlated with better economic performance, as investments in R&D and innovative activities are larger in those sectors. The high level of R&D intensity and the larger innovation propensity in knowledge-intensive sectors are fundamental drivers of labour productivity. New firms with innovative and more efficient business models or introducing breakthrough innovations to the market tend to develop more easily in these sectors. Similarly, they are more likely to adopt innovative products or processes due, for instance, to network effects and the technological proximity to those sectors where the original innovation was developed[3]. Therefore, it follows that there is significant correlation between economic performance and an economy's economic structure: higher shares of knowledge-intensive sectors in the economy bring higher productivity which, among others, is a driver of prosperity in the medium-long term.

The most productive EU economies tend to have a higher specialisation in knowledge-intensive sectors, while a significant gap between the EU and the United States persists, revealing an overall better performance. In Figure 3.2-4, total labour productivity[4] is used to measure countries' economic performance and is plotted against

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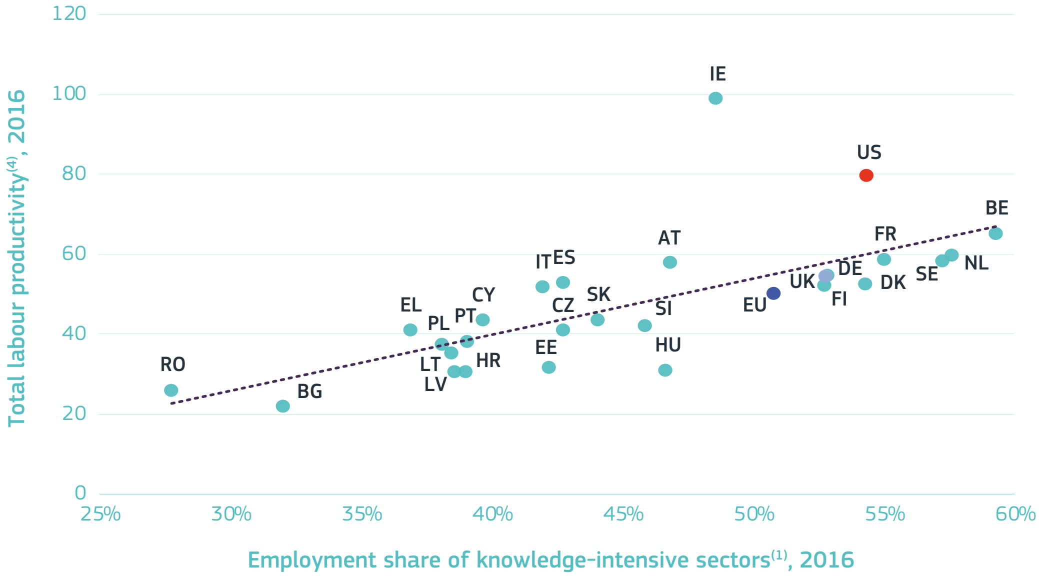
3 See, for instance, Xiao et al. (2018) on the concept of related variety for industrial diversification in Europe.

4 In what follows, labour productivity is given by value added at constant prices (2010) over the number of workers.

Figure 3.2-4 Total labour productivity and the employment share of knowledge-intensive sectors, 2016[2][3]



Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on Eurostat and OECD data

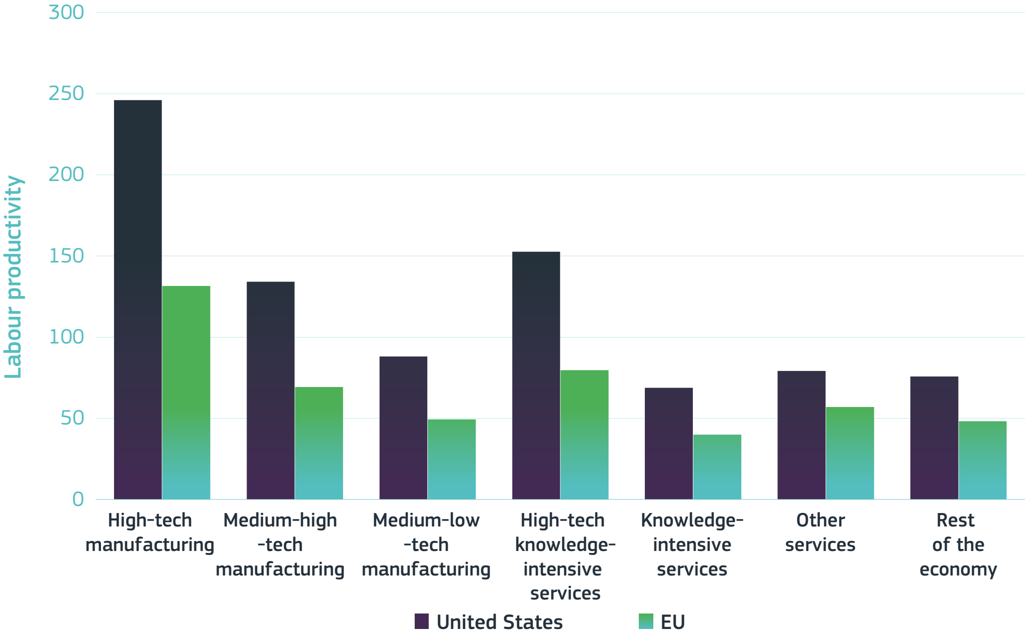
Notes: (1)Knowledge-intensive sectors include high-tech manufacturing, medium-high-tech manufacturing and knowledge-intensive services. (2)Data missing for MT and LU. (3)EU: 2015. (4)In thousand PPS€ at constant 2005 prices and exchange rates per worker.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter32/figure-32-4.xlsx

the sum of the shares of knowledge-intensive services, high-tech and medium-high-tech manufacturing in total employment. The graph reveals a positive relationship: labour productivity increases with the weight of knowledge-intensive sectors in the economy. A group of leading EU economies with productivity and specialisation in knowledge-intensive activities higher than the EU average can be observed on the right of the graph. A large group of countries follow, with employment shares and productivity levels (with the exception of Italy, Austria and Spain) below the EU average. Most countries lie around the dashed line representing the average trend, while a few exceptions can be identified. First, Ireland, with the highest labour productivity across countries, is also significantly higher than might be expected, given the share of knowledge-intensive sectors. While the data used in this chapter do not allow any conclusions to be drawn, this could be because Ireland is the European hub of international companies with strong innovation performance and generating high value added. Second, the United States is the second most productive economy, having higher labour productivity than countries with a similar economic structure. The relevance of high-tech knowledge-intensive services and the large numbers of unicorns, startups and multinational giants at the innovation frontier – e.g. in the Internet of Things and the digital economy – contribute to explain the United States' good performance. It is also worth noting that the United States experiences higher labour productivity across all sectors in the economy (see Figure 3.2-5). Finally, mention should be made of the group of CESEE economies previously highlighted. While their R&D intensity is relatively low compared to their economic structure, their labour productivity seems consistent with the observed trend, as suggested by the dashed line. While this corroborates that their growth model has paid off to date, previous analyses have suggested a shift towards more R&D and that intangible investment could be beneficial to sustain productivity growth and prosperity in the future (Correia et al., 2018).

Knowledge-intensive activities are the most productive sectors, although differences exist across countries. Knowledge-intensive sectors have the highest productivity levels in the economy. However, differences in performance do exist, with some sectors being more productive in some countries compared to others. These within sector differentials depend on countries' characteristics, specific activities within sectors and other factors, including policy, and contribute to shaping overall total productivity and the distribution of countries observed in Figure 3.2-4. Figure 3.2-5 compares labour productivity across sectors in the EU and the United States. High-tech manufacturing is the most productive sector, significantly ahead of the others. High-tech knowledge-intensive services and medium-high-tech manufacturing come next, the former showing productivity levels significantly higher than the other services, including knowledge-intensive ones. Most importantly, the figure highlights the productivity gap between the EU and the United States. Sectoral productivities

Figure 3.2-5 Labour productivity[1] by sector, EU (2015) vs. United States (2016)



Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on Eurostat and OECD data

Note: (1)Thousand PPS€ at constant 2005 prices and exchange rates per worker.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter32/figure-32-5.xlsx

are higher in the latter in every sector, and the differential is particularly significant in high-tech, medium-high-tech manufacturing and high-tech knowledge-intensive services, where labour productivity is almost double the levels observed in the EU.

So far, this chapter has shown that European countries are heterogeneous in the composition of their economic structure and, as such, they do differ in their capability to invest in R&D and in their economic performance. Furthermore, differences in terms of labour productivity also exist within the same sectors, as shown by the comparison between the EU average and the United Sates.

Given the above scenario, it is interesting to see how countries evolve over time: first, how their sectoral specialisation has changed, i.e. whether they have been moving towards activities with higher knowledge intensity or the opposite trend has been taking place. This is usually defined as structural change. Second, it is interesting to note the impact of this transition on labour productivity dynamics. Has the change of economic structure had a positive impact on labour productivity growth, i.e. is the EU experiencing a growth-enhancing structural change? What has been the main driver of labour productivity growth in the EU since the 2000s? The analysis below focuses on these questions.

2. The contribution of structural change to productivity growth in the EU is limited

The economic structure of countries changes slowly over time. To observe the sectoral dynamics and their direction, this section takes a medium-term perspective by considering the period 2000-2016. Furthermore, a narrower time span is taken into account to identify the structural trend in the aftermath of the last economic crisis, focusing on the years after 2008. While movements are going to be smaller in such a shorter period, this allows for an analysis of how change has taken place in the post-crisis period, as well as seeing whether or not the trend has been affected by the recession. Figure 3.2-6 shows how structural change has affected knowledge-intensive sectors, reporting the cumulative growth rate in the period 2000-2016 for knowledge-intensive services (Panel A) and manufacturing (Panel B).

Overall, a clear trend towards knowledge-intensive services can be observed for all countries. The increase in their share averages 16 % for the EU, higher than in the United States (9 %) but around half the shift noted in the Japanese economy (32 %). The increase is higher for high-tech knowledge-intensive services, at 22 % for the EU and 23 % for Japan, while the growth rate is significantly lower (3.2 %) for the United States.

However, this process is accompanied by a transformation in the opposite direction in relation to manufacturing: employment shares declined for both high-tech and medium-high-tech manufacturing activities. While the weight of the former decreased at a faster pace than the latter, the lower initial values contribute to the larger variations, due to the potential impact of single shocks on the overall economy. Increased specialisation in services, including those intensive in knowledge, is a common feature of modern economies. However, excessive deindustrialisation may have negative consequences because of the relevance of industry for innovation and productivity prospects. This is particularly true for the deep transformation industry is currently undergoing, at the crossroads between the physical and digital world, which is radically changing the way production takes place and business models work and change. The need to boost the competitiveness of the EU and its industry, while meeting the requirements of social, environmental and economic sustainability, are among the key policy challenges facing Europe today[5].

Structural change is also heterogeneous across Member States. Whilst most countries have experienced a fall in their employment shares in high-tech manufacturing, a few have increased their specialisation. These include some CESEE countries (Poland, Romania, Czechia and Latvia), together with Cyprus, Greece and Denmark. A similar scenario holds for medium-high-tech manufacturing where a positive growth rate in employment shares can be observed mainly for the previously mentioned CESEE economies, including the high increase in specialisation in Estonia and Latvia. It is worth noting that the major EU economies have been shifting away from the sector, including those countries with an historical specialisation, such as Germany (-7.5 %), Belgium (-42 %), France (-36 %) and Italy (-12 %).

The main trends reported in Figure 3.2-6 are also confirmed for the period 2008-2016, although a few differences are worth mentioning. Romania experienced a negative shift away from high-tech manufacturing, which means that the positive shift towards the sector observed above took place in the period before the crisis. A similar trend occurred in Hungary in medium-high-tech manufacturing. Portugal has increased its specialisation in all knowledge-intensive activities, reversing the negative trends reported above. The positive shift in high-tech manufacturing (+7.1 %) is particularly noteworthy[6]. Similarly, Latvia has experienced increased specialisation in high-tech manufacturing (+29 %). Finally, the negative shift from knowledge-intensive manufacturing in Germany and Spain has been relatively contained compared to the overall trend observed since 2000, flagging an ongoing effort to reverse the deindustrialisation trend. This is particularly significant in the Spanish case, where the negative shift declined from -38.1 % to -0.6 % and from -36.5 % to -5 % in high-tech and medium-high-tech manufacturing, respectively. Finally, South Korea, unlike the EU, Japan and the United States, has been increasing its specialisation in medium-high-tech manufacturing since the crisis, which is the only such case among the major economies included in the analysis, highlighting the peculiarity of the South Korean economic process.

Countries that have increased their share in knowledge-intensive sectors have experienced better productivity performance. As shown in Figure 3.2-4, there is a positive correlation between knowledge-intensive sectors and economic performance. This is also true in dynamic terms: countries expanding the weight of knowledge activities tend to enjoy higher labour productivity growth. The relationship is shown in Figure 3.2-7. A process of structural change favouring knowledge-intensive sectors means that economic activity is displaced towards activities with higher productivity and innovation potential, consequently benefitting the total

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[5] See also https://ec.europa.eu/growth/industry/policy_en

[6] It should be noted that some time may be needed for value-added shares to react to movements in employment from one sector to another. Therefore, considering value-added shares rather than employment shares may provide different figures as, for instance, in the case of Portugal and Italy whose changes in value-added shares have been negative and slightly positive, respectively. Since the scope of this section is to highlight structural trends, the focus is mainly on employment, while value added is used to build labour productivity figures

Figure 3.2-6 Percentage change in employment share in knowledge-intensive sectors$^{(1)}$, 2000-2016$^{(3)}$

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on Eurostat and OECD data

Notes: (1)Data missing for MT, LU and HR. (2)Data incomplete for JP. (3)EU: 2015.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter32/figure-32-6.xlsx

productivity of a country. Panel A shows the correlation between the cumulative increase in the employment share of knowledge-intensive sectors and productivity growth in the period 2000-2016. The figure reveals different groups of countries behaving differently, some where the positive relationship is steeper – i.e. Bulgaria, Slovakia, Poland, Ireland, Latvia and Lithuania together with Romania – and others where it is less straightforward, remaining rather flat. The positive correlation becomes clearer when using value-added shares rather than employment shares, as shown in Panel B, suggesting how the increase in production in those sectors plays a key role in driving productivity gains. The CESEE economies stand out as having the biggest shifts towards knowledge-intensive sectors and the largest increases in labour productivity, together with Ireland.

A key message to be drawn from the above figures is that structural change in the EU as a whole has not privileged knowledge-intensive activities, which have increased their share by just 5% since 2000. Furthermore, this average change has been driven mainly by a few countries, as shown in Figure 3.2-7.

The above analysis suggests that: 1) knowledge-intensive sectors tend to be more productive than traditional ones; therefore 2) knowledge-oriented economies have higher labour productivity levels; and 3) they enjoy higher growth rates if their economic structure changes to favour knowledge-intensive sectors.

The rest of this chapter estimates the contribution of structural change to total labour productivity growth in the EU and peer economies, disentangling it from the role of productivity gains within sectors. In particular, labour productivity is broken down into:

- increases (decreases) due to the shift in employment shares from sectors where productivity growth is lower (higher) to sectors where it is higher (lower);
- increases (decreases) due to productivity gains (losses) within the same sector driven by efficiency gains, such as, for instance, following productivity-enhancing innovations.

The methodology is explained in more detail in Box 3.2-2[7].

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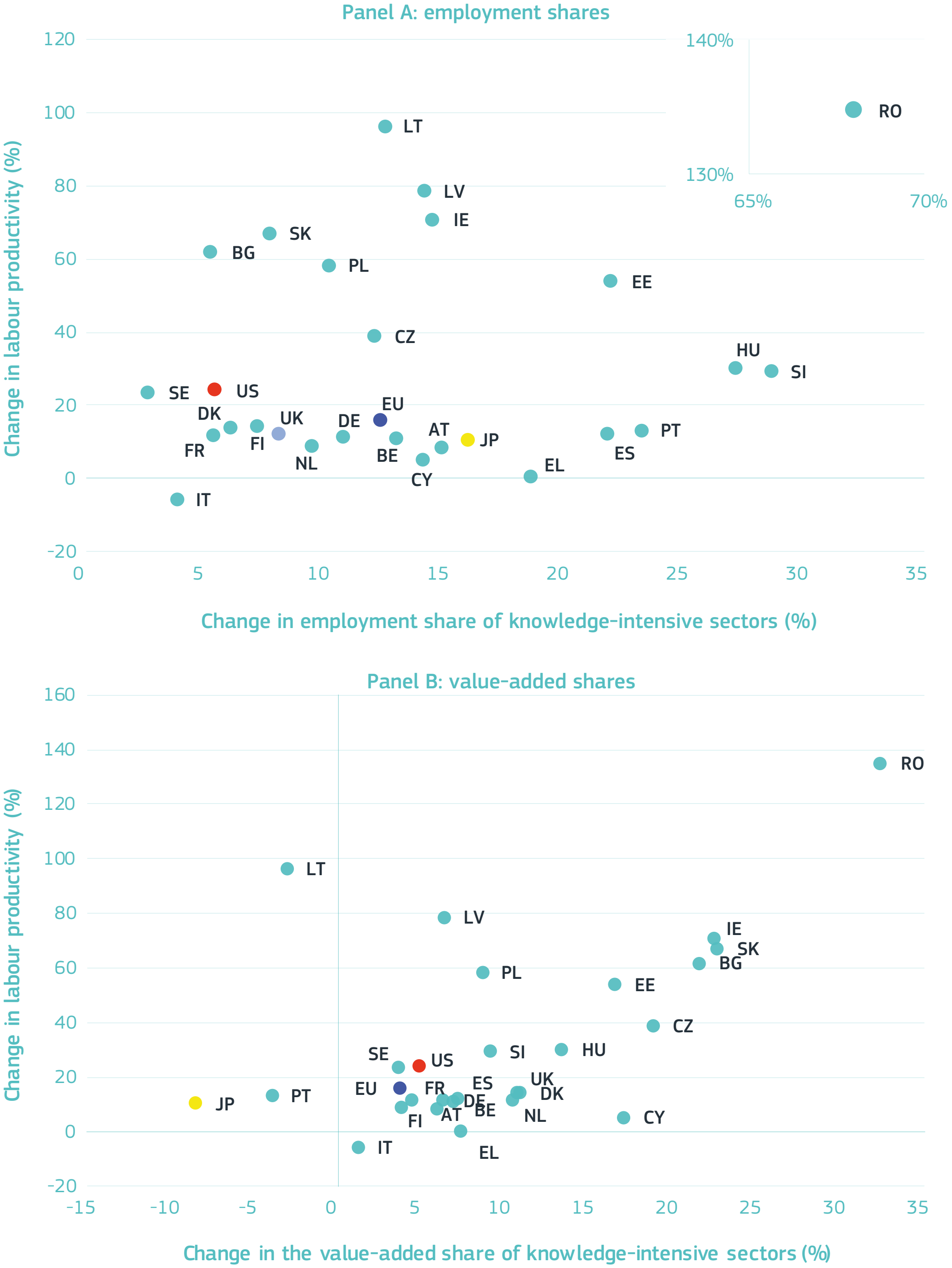
[7] There are different ways to break down labour productivity growth into its sources. This chapter follows the approach as in Cimoli et al. (2011) and Martino (2015), among others.

Figure 3.2-7 Change in the share of knowledge intensive sectors and labour productivity growth, 2000-2016[(1)(2)(3)(4)]



Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on Eurostat and OECD data

Notes: (1)Knowledge Intensive sectors includes High-Tech Manufacturing, Medium-High-Tech Manufacturing and Knowledge-Intensive Services. (2)Data missing for KR, MT and LU. (3)Data on knowledge-intensive services for JP are not complete for some subsectors, hence changes are reported for the available subsectors. (4)EU: 2015.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter32/figure-32-7.xlsx

BOX 3.2-2 Decomposition of labour productivity growth

In this chapter, the analysis of the sources of labour productivity growth follows a standard approach in the economic literature, based on the algebraic decomposition of the growth rate into three components. While different approaches do exist, the analysis is based on Equation (1):

Equation 1

$$\triangle y/y_0 = \sum_i [\underbrace{(\triangle y_i L_0)/y_0}_{PrG} + \underbrace{(\triangle L_i y_0)/y_0}_{ShEff} + \underbrace{(\triangle y_i \triangle L_i)/y_0}_{DynEff}]$$

where *L* and y are employment shares and labour productivity for each sector *i* respectively, the subscript $_0$ indicates the first year, while Δ measures the change in a variable from the first to the last year. Note that the computed labour productivity growth rates are cumulative for the period – they are not yearly growth figures.

Total labour productivity growth is the sum of the three components for every sector in the economy.

The first term of Equation (1) defines productivity gains (*PrG*) in each sector, given by increases (reductions) in productivity keeping employment constant, and are given by increased (reduced) efficiency, such as, for instance, due to technical progress within the sector in case of positive growth. The second and third terms make up the structural change component of labour productivity growth, being the sum of changes in employment shares – the pure share effect (*ShEff*) – and interaction between changes in both employment shares and labour productivity – the dynamic effect (*DynEff*). The *ShEff* term provides information on the direction of structural change, i.e. informs on which sectors employment has been flowing to. The *DynEff* term refers to the interaction between structural change and productivity dynamics. Indeed, this term is positive, i.e. structural change is positively contributing to total productivity growth, if employment shares are either shifting towards sectors with rising labour productivity or moving away from sectors where productivity is declining. The sum of the last two components indicates whether the structure of the economy is shifting towards activities with higher productivity growth. Note that, by construction, this term is also positive in cases where employment shares in a knowledge-intensive sector are declining if labour productivity growth in that sector is negative. Therefore, the *PrG* component provides fundamental information to complement the contribution of structural change. This is the case in Italy, for instance, where the contribution of structural change in medium-high-tech manufacturing is slightly positive, driven by negative productivity gains and the loss of employment shares. Of course, the key elements here are rather the declining productivity and reduced employment share in a knowledge-intensive sector, which are both detrimental to the competitiveness of the Italian economy.

For simplicity, the total economy is divided into seven macro-sectors, three of which are knowledge-intensive: i.e. 1) knowledge-intensive services; 2) high-tech knowledge-intensive services; 3) high-tech manufacturing; and 4) medium-high-tech manufacturing. The remaining are the more traditional ones: i.e. 5) medium-low-tech manufacturing; 6) other market services; and 7) the rest of the economy. While simple, such a classification allows the contribution of each sector to be traced to total productivity growth to see whether structural change has been contributing to it positively or negatively.

As from the 2000s, structural change towards knowledge-intensive sectors has not been the main driver of labour productivity growth in the EU, while the performance of knowledge-intensive sectors is low – although positive – compared to the United States. South Korea is the only economy where structural change has favoured medium-high-tech manufacturing. Figure 3.2-8 summarises the breakdown of total labour productivity growth into its structural change and productivity gains components, by sector, for the period 2000-2016. This enables the total contribution of each sector (last column) and of structural change and productivity gains, respectively (last row), to be highlighted.

While labour productivity has grown by 15.67 % in the EU since 2000, the growth rate would have been higher if structural change had favoured more the sectors with higher productivity gains. As shown in Panel A, this is particularly true for the industrial sectors with high knowledge intensity, i.e. high-tech and medium-high tech manufacturing. However, a closer look at the figure reveals that the most negative components of structural changes are in non-knowledge-intensive sectors, most notably medium-low-tech manufacturing and the rest of the economy. This is linked to the high productivity gains in those sectors during the reference period, suggesting that the loss of employment shares has reduced the total labour productivity growth and added to the negative contribution of structural change (-1.19 %).

A key challenge faced by the EU is that knowledge-intensive sectors have the lowest productivity gains, despite the higher labour productivity levels, as presented in the second column of Figure 3.2-8. Conversely, the other market services and the rest of the economy are by far the main sectors in which labour productivity has been growing the most while the loss of employment shares in the latter is actually reducing the overall growth figures. Since these sectors are less knowledge-intensive, these positive productivity gains suggest an increase in efficiency, hinting at the application of productivity-enhancing technologies to traditional activities.

While structural change has made a similar contribution to productivity growth in both the United States and the EU, productivity gains in knowledge-intensive activities in the former have been systematically larger. As in the European case, structural change contributes negatively to labour productivity growth (-3.2 %), as it does in knowledge-intensive manufacturing, flagging a more intense deindustrialisation trend such as in the EU. However, the productivity gains in high-tech and medium-high-tech manufacturing are higher at above 2 %, and they manage to counterbalance the loss in employment shares. The productivity performance in medium-high-tech manufacturing in the EU is higher due to a smaller decline in the employment shares, driven mostly by the CESEE economies. Knowledge-intensive services are the main drivers of productivity growth in both economies, because of positive productivity gains together with sustained increases in their employment shares. Even in this case, it is worth noting the difference in performance: while labour productivity growth has grown by just around 2.4% in the EU, the United States has experienced an increase over 10%, which also includes the high-tech knowledge-intensive services, outperforming by far any other sector in their economy. It should also be noted that, in both economies, high-tech knowledge-intensive services have had a relatively low growth rate – negative in the case of the EU – despite having the second highest labour productivity level, as shown above.

Figure 3.2-8 **Labour productivity growth decomposition: structural change and productivity gains, 2000-2016**

Panel A: EU

	Structural change	Productivity gains	Total
High-tech manufacturing	-0.62%	0.95%	0.33%
Medium-high-tech manufacturing	-0.87%	1.75%	0.88%
Medium-low-tech manufacturing	-3.01%	2.55%	-0.45%
Knowledge-intensive services	5.37%	2.53%	7.90%
HT-knowledge-intensive services	0.97%	-0.12%	0.86%
Other market services	2.48%	4.16%	6.64%
Rest of the economy	-5.40%	4.92%	-0.48%
Total	**-1.19%**	**16.87%**	**15.67%**

Panel B: United States

	Structural change	Productivity gains	Total
High-tech manufacturing	-2.18%	2.31%	0.13%
Medium-high-tech manufacturing	-2.11%	2.10%	-0.01%
Medium-low-tech manufacturing	-3.36%	2.53%	-0.83%
Knowledge-intensive services	4.61%	8.78%	13.39%
HT-knowledge-intensive services	0.22%	1.68%	1.90%
Other market services	0.32%	7.34%	7.65%
Rest of the economy	-0.73%	2.29%	1.56%
Total	**-3.23%**	**26.82%**	**23.80%**

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on Eurostat and OECD data
Note: EU data is until 2015.
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter32/figure-32-8.xlsx

The post-crisis period reveals higher productivity growth in knowledge-manufacturing activities in both the EU and United States, although well below the figures for South Korea. The low performance of the EU's knowledge-intensive services is confirmed. Figure 3.2-9 reports the decomposition of labour productivity growth for the post-crisis period, including data which are also available for Japan and South Korea. Figures for the EU and United States confirm the trend observed for the whole period, but with two main differences. First, productivity growth in the industrial sectors in the United States is higher, due to a slowdown in the pace of structural change away from those sectors. Second, productivity gains in the EU's knowledge-intensive services have been very low (+0.21 %) and negative in the high-tech ones (-0.23 %). Growth in the sector has been entirely driven by the increase in employment shares (+2.69 % in knowledge-intensive services and +0.49 % in the high-tech ones) which, in turn, explains 70 % of total productivity growth (3.18 % out of 4.54 %). On a more positive note, productivity gains in high-tech manufacturing, while relatively low, appear to have been mainly concentrated in the post-crisis period (+0.64 % between 2008-2016 compared to +0.95 % for 2000-2016). As regards Japan and South Korea, while data availability does not allow the complete picture to be drawn, it is worth noting the loss of productivity in knowledge-intensive services in both countries, despite increased specialisation within the sector, which has not favoured the high-tech services. As already mentioned above, South Korea stands out for being the only economy with positive figures in knowledge-intensive industries, showing productivity gains significantly higher than in peer countries. It is also the only country where structural change contributes significantly to productivity growth in medium-high-tech manufacturing (1.2 % out of 2.47 % growth in the sector) and its contribution in high-tech manufacturing is almost non-negative (-0.2 %). Finally, South Korean total labour productivity growth (+14 %) is almost double that in the United States (+8 %) and more than three times higher than in the EU (+4.5 %).

Figure 3.2-9 Labour productivity growth decomposition: structural change and productivity gains, 2008-2016

EU

	Structural change	Productivity gains	Total
High-tech-manufacturing	-0.28%	0.64%	0.35%
Medium-high-tech manufacturing	-0.20%	1.11%	0.91%
Medium-low-tech manufacturing	-1.35%	1.00%	-0.35%
Knowledge-intensive services	2.69%	0.21%	2.90%
HT-knowledge-intensive services	0.49%	-0.23%	0.26%
Other market services	0.58%	1.18%	1.76%
Rest of the economy	-2.47%	1.20%	-1.28%
Total	**-0.55%**	**5.09%**	**4.54%**

Japan

	Structural change	Productivity gains	Total
High-tech manufacturing	-0.95%	-0.45%	-1.40%
Medium-high-tech manufacturing	-1.52%	1.05%	-0.46%
Medium-low-tech manufacturing	-0.48%	2.80%	2.32%
Knowledge-intensive services	2.93%	-4.48%	-1.54%
HT-knowledge-intensive services	0.09%	0.00%	0.08%
Other market services	-0.03%	-6.23%	-6.26%
Rest of the economy	NA	NA	10.59%
Total	**NA**	**NA**	**3.33%**

United States

	Structural change	Productivity gains	Total
High-tech manufacturing	-0.57%	0.81%	0.24%
Medium-high-tech manufacturing	-0.39%	0.80%	0.42%
Medium-low-tech manufacturing	-0.84%	0.49%	-0.35%
Knowledge-intensive services	1.51%	3.24%	4.75%
HT-knowledge-intensive services	0.34%	0.41%	0.75%
Other market services	0.06%	3.32%	3.38%
Rest of the economy	-0.77%	-0.24%	-1.02%
Total	**-0.66%**	**8.89%**	**8.17%**

South Korea

	Structural change	Productivity gains	Total
High-tech manufacturing	-0.20%	1.53%	1.33%
Medium-high-tech manufacturing	1.20%	1.27%	2.47%
Medium-low-tech manufacturing	-0.01%	1.55%	1.54%
Knowledge-intensive services	6.59%	-2.86%	3.73%
HT-knowledge-intensive services	0.76%	-0.62%	0.14%
Other market services	-1.68%	5.47%	3.79%
Rest of the economy	NA	NA	1.04%
Total	**NA**	**NA**	**14.05%**

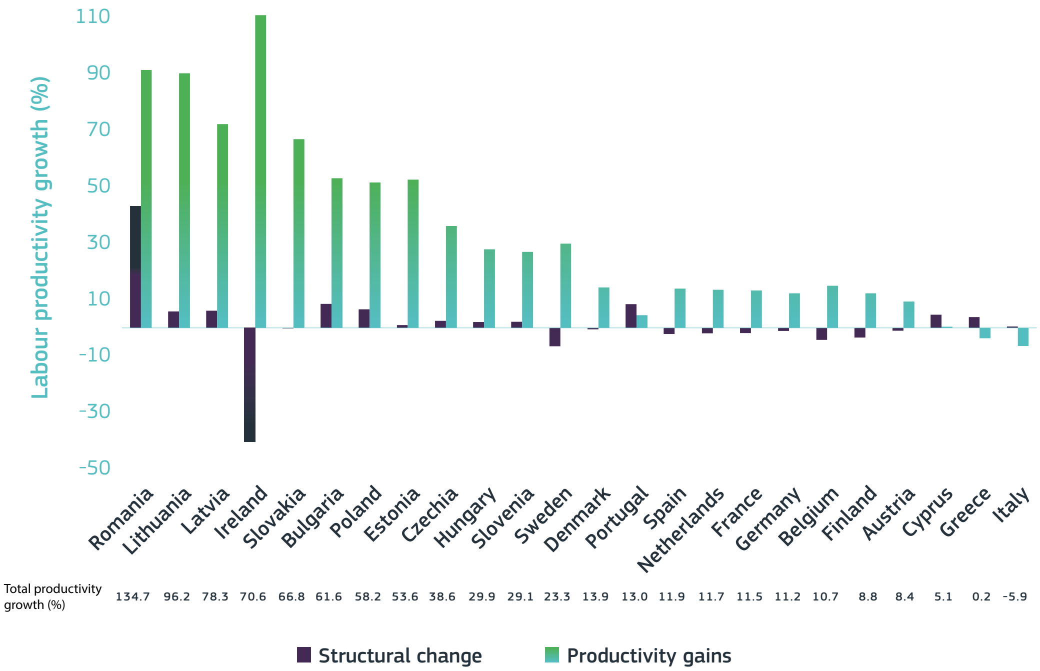
Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on Eurostat and OECD data

Note: Data for Japan and South Korea is not complete for some subsectors, hence changes are reported only for the available subsectors. EU data is until 2015.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter32/figure-32-9.xlsx

Figure 3.2-10 shows the contribution of structural change and productivity increases within sectors to total productivity growth for EU Member States in the period 2000-2016. Values represent the total sum of the two dimensions across sectors, while countries are ordered by total productivity growth. Most of growth has been driven by productivity gains, which is true for all economies. Structural change is a positive but still minor source of growth, mainly for the CESEE economies, together with Portugal, Cyprus and Greece. For the remaining countries, its contribution is negative, and almost null for Italy. Romania and Ireland are two notable outliers since structural change contributes to around half of labour productivity growth in the former while reducing it by around one third in the Irish case.

Figure 3.2-10 Contribution of structural change and productivity gains to total labour productivity growth in EU Member States, 2000-2016[(1)]



Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on Eurostat data

Note: [(1)]Data missing for HR, MT and LU.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter32/figure-32-10.xlsx

BOX 3.2-3 Firm size distribution and sectoral labour productivity[8]

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Differences in productivity between countries might also arise in the face of heterogeneous productivity across production units. In this box, we exploit the observation that, despite sectoral differences, there is an overall positive relation between firm size and labour productivity and hence different firm-size distributions could have an impact on aggregate productivity. We develop a decomposition analysis that splits the sectoral productivity in Member States relative to the EU[9] aggregate into differences in both the firm-size distribution and in the productivity level within each firm-size class.

Methodology

The analysis relies on data from Structural Business Statistics (SBS) for five firm-size classes (less than 10 people employed, 10-19, 20-49, 50-249 and 250 or more) within eight NACE sections: C (manufacturing), F (construction), G (trade), H (transportation and storage), I (accommodation and food services), J (information and communication), M (professional activities) and N (administrative and support activities).

For instance, if employment in a country was more concentrated in larger firms compared to the EU aggregate, given that larger firms are associated on average with higher productivity, the *size distribution effect* would be positive. However, at the same time, if average productivity for larger firms in this country was lower than peers in the EU aggregate, the *size class* productivity effect would be negative.

Finally, to provide an overall picture, we aggregate results at the country level. A third component is then added to account for differences in the weight of sectors and the fact that productivity is higher in certain sectors than others (e.g. manufacturing compared to trade activities). We refer to this component as the sectoral composition effect.

The decomposition is as follows[10]:

$$LP_{c,j} - LP_{EU,j} = \sum_i a_{c,j,i} \times LP_{c,j,i} - \sum_i a_{EU,j,i} \times LP_{EU,j,i} =$$

$$\sum_i (a_{c,j,i} - a_{EU,j,i}) \times \left(\frac{LP_{c,j,i} + LP_{EU,j,i}}{2}\right) \textit{[size distribution effect]} +$$

$$\sum_i (LP_{c,j,i} - LP_{EU,j,i}) \times \left(\frac{a_{c,j,i} + a_{EU,j,i}}{2}\right) \textit{[size class productivity effect]}$$

where:

$a_{c,j,i}$ = employment share of firm size class i in sector j of country c

$LP_{c,j,i}$ = labour productivity of firm size class i in sector j of country c

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[8] Based on the homonymous chapter included in Bauer et al. (2020).

[9] The EU aggregate not including the UK.

[10] Labour productivity is calculated by the ratio of value added and the number of people employed. Value added is measured in purchasing power parity-adjusted euros using GDP-based price levels.

Cross-country comparison

In general terms, country differences in productivity levels within each firm-size class play the most important role by large and mainly explain the divergence across Member States (Figure 3.2-11A), whereas both the sectoral composition effect – i.e. differences in sectoral employment shares – and the firm-size distribution effect play a more limited role.

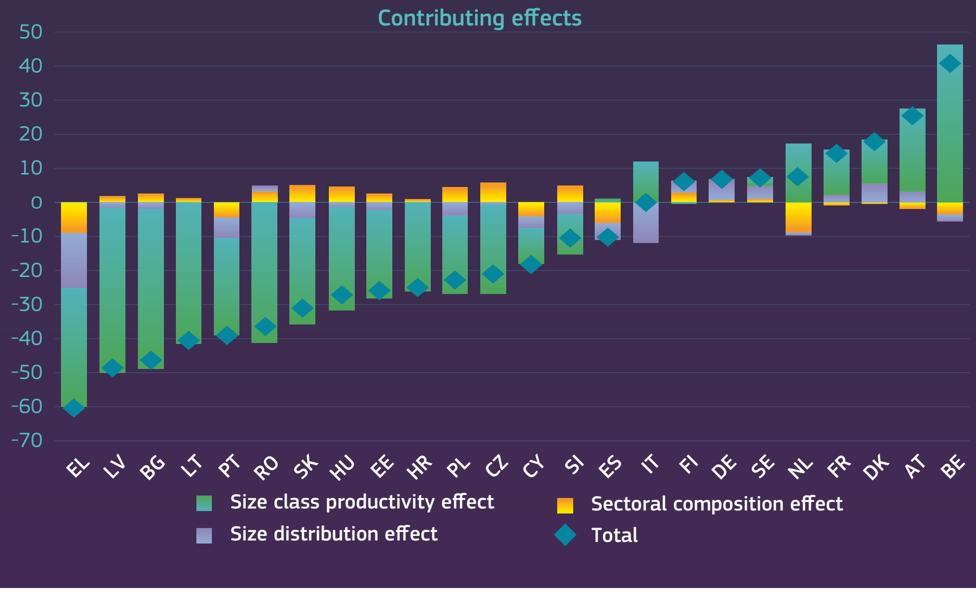
However, for a few countries, having a firm distribution tilted towards smaller firms would seem to be significantly detrimental for productivity performance. This is particularly the case for Greece, where it accounts for a quarter of the productivity difference with respect to the EU benchmark, and Italy, where it fully offsets the positive contribution from the 'pure' productivity effects. It is also worth highlighting the case of Spain, in which the size distribution effects and the sectoral composition effects explain 50-50 the productivity gap.

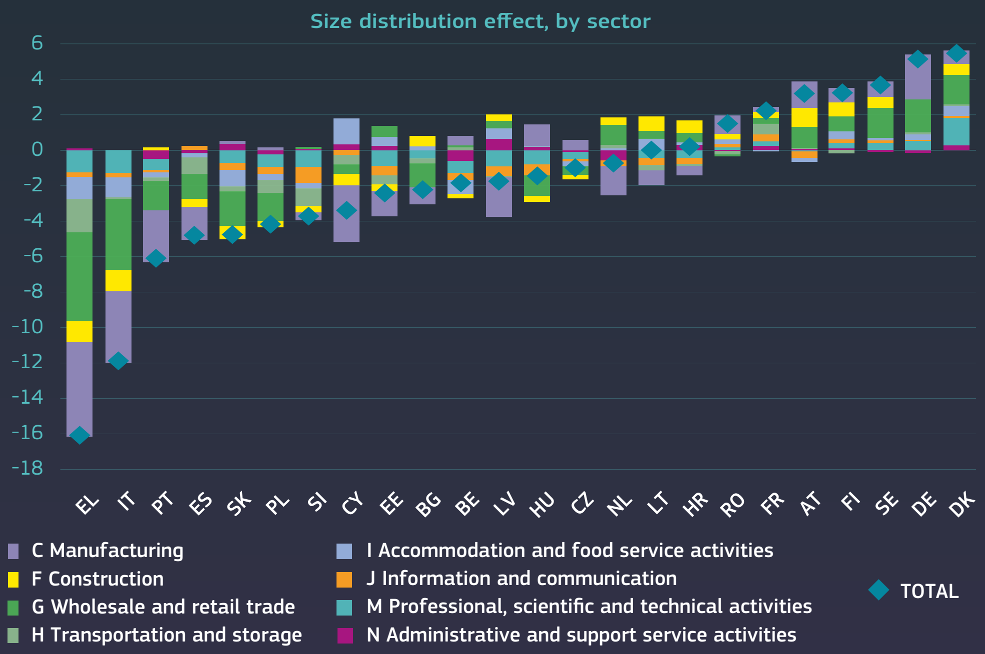
Figure 3.2-11B decomposes the size distribution effect in Figure 3.2-11A by sector. Contributions to size distribution effects are on average higher than their employment share for manufacturing (C), ICT services (J) and professional activities (M), suggesting a more important role for firm size shaping productivity relative to other economic activities.

Sectoral contributions seem to move in the same direction within most countries, particularly for those where the size effect is larger. Nevertheless, there are some noticeable exceptions: e.g. Czechia and Hungary which are largely involved in central European value chains, show positive size distribution effects in the manufacturing sector but negative in some service activities, while the opposite happens in the Baltic countries.

To summarise, while the dispersion of firm-size distributions across Member States plays a limited role overall in explaining productivity gaps within the EU, there are some specific cases in which this effect is significant and might deserve policy action. In particular, the related literature points to the importance of the institutional framework in shaping firm-size distributions, judicial and government efficiency being a supportive factor for increasing firm size.

Figure 3.2-11 Percentage difference in labour productivity relative to the EU28, 2016





Source: Authors' own computations based on SBS data

Note: Malta and Luxembourg are not included due to lack of data.

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Recent dynamics

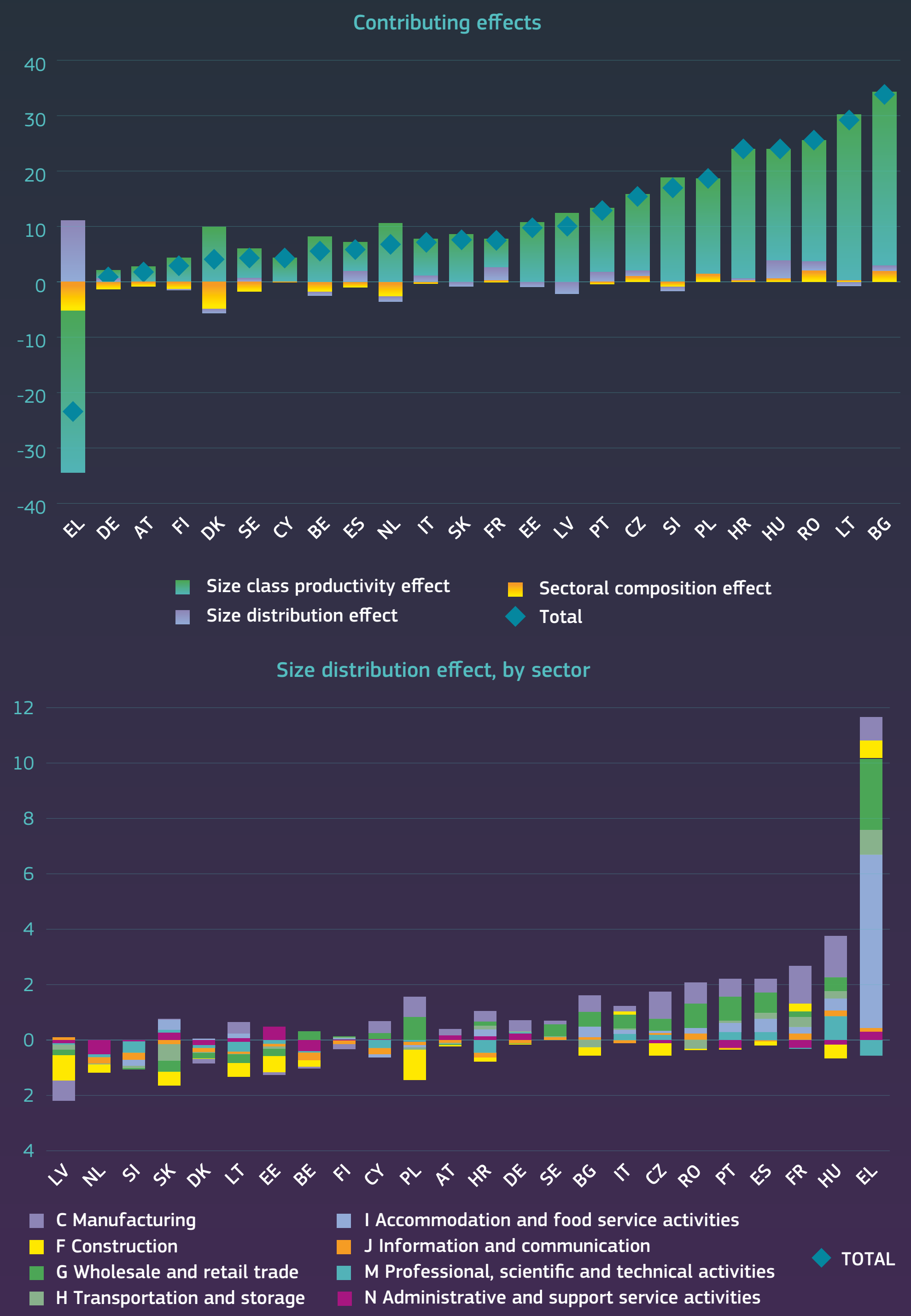
Labour productivity increased in recent years (2012-2016/17) across all countries, most notably in those Member States with lower levels compared to the EU benchmark (Figure 3.2-12A), Greece being the only exception. These developments supported a convergence process driven mainly by an increase in productivity levels across all firm-size classes, supported in some cases and to a much lesser extent by a sectoral shift towards economic activities with higher productivity levels (e.g. in Bulgaria, Romania and Poland).

Overall, changes in firm-size distribution played a limited role in shaping productivity growth but made a significantly positive contribution in those countries where size distribution had previously been identified as having a detrimental effect, namely Greece, Spain, Portugal and Italy. In policy terms, it might be worth investigating whether such a declining share of employment in smaller firms is associated with the aftermath of the crisis (i.e. being less resilient than bigger firms) or/and the result of structural reforms supporting larger enterprises.

Figure 3.2-12B decomposes the size distribution effect in Figure 3.2-12A by sector. On average, this factor made a positive contribution to productivity growth in manufacturing (C), retail trade (G) and accommodation and food services (I), while proving negative for construction (F) and ICT services (J), showing different sectoral patterns following the crisis.

On a country basis, within those recording a significant shift in employment towards larger firms, developments were driven in particular by accommodation and food services in Greece, while in other countries, manufacturing (e.g. in Hungary) and trade (e.g. in Portugal and Spain) played a relatively more important role.

Figure 3.2-12 Percentage change in labour productivity, 2012-2016/2017



Contributing effects

Size distribution effect, by sector

Source: Authors' own computations based on SBS data

Note: Malta and Luxembourg are not included due to lack of data.

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3. Conclusions

The structure of an economy shapes its capacity to invest in R&D and to innovate. The EU and peer modern economies are characterised by the predominance of knowledge-intensive services, accounting for more than 40% of total employment and being the backbone of economic activity. The weight of knowledge-intensive manufacturing activities is smaller and heterogeneous across the Member States, with some of them being relatively more specialised, most notably in central and eastern Europe.

In recent decades, Europe has gone through a generalised transformation towards knowledge-intensive services, while most Member States have been moving away from medium-high and high-tech manufacturing, with the exception of the CESEE countries. This trend has had a subduing effect on economic dynamics, despite productivity gains within knowledge-intensive manufacturing sectors positively contributing to productivity growth. Overall, structural change is not the main driver of growth, either in the EU or in peer countries, with the exception of South Korea, which suggests that productivity improvements within sectors are the key driving factor.

In a broader context in which a productivity gap between the EU and the United States persists across sectors, the observed structural dynamics contribute to making the case for an **EU industrial strategy to counter the deindustrialisation trends in the EU and to increase its long-term competitiveness while meeting the need for a transition towards a climate-neutral and sustainable economy**.

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CHAPTER

3.3

BUSINESS DYNAMICS AND ITS CONTRIBUTION TO STRUCTURAL CHANGE AND PRODUCTIVITY GROWTH

KEY FIGURES

20%
EU business churn rate

1 in 10
active enterprises in the EU are high-growth enterprises

12%
of EU high-growth enterprises in HT, MHT manufacturing and HT knowledge-intensive services

7%
of 'today's unicorns' are based in the EU

2%
of EU unicorn founders are women

7/30
top global startup ecosystems are in the EU

What can we learn?

- **The decline of business dynamism may hamper productivity growth**.
- **Most jobs created by new firms emerged in less-productive sectors** of the economy albeit some progress over time.
- **Slightly more than 1 in 10 enterprises in the EU are high-growth enterprises;** only a small share is 'high-tech'.
- **EU's scaling-up performance lags behind the United States and China**, including in the presence of tech scaleups and unicorn companies.
- **Unicorns are very geographically concentrated**: in the EU in Germany, in the US in California, in China in Beijing. Looking into **'hidden' radical innovators** broadens the understanding of the state of innovation across the EU and its regions.
- **'EU DNA' unicorns** with headquarters in the United States and the United Kingdom and their (co-)founders tend to keep strong connections 'back home' with benefits also to the country of origin.
- There are considerable **intra-EU differences in entrepreneurial quality and motivation**.
- **The EU has seven ecosystems in the world's 'top 30' startup ecosystems** compared to 12 in the United States and only 3 in China.
- Despite some progress, a **gender gap remains among founders of innovative startups**.
- The **presence of zombie firms** is still problematic in some EU Member States.

What does it mean for policy?

- **Improve overall framework conditions for innovation**, including access to risk finance and deepening the Single Market to ensure the scaling-up of 'made in EU' disruptive ideas, and their permanence in the EU, while maintaining a global outreach.
- **Tackle the startup gender gap**, beyond the classical market failures.
- **Boost the resilience and integration of startup ecosystems to reach greater critical mass**, with a strategic vision that builds upon the EU's industrial strengths and tackles societal challenges linked to the ambitions of the EU Green Deal.
- A **'tech-with-a-purpose' approach** would leverage R&I to create the solutions that match the urgency of the environmental and social challenges of our time.

1. Declining business dynamism may hamper productivity growth

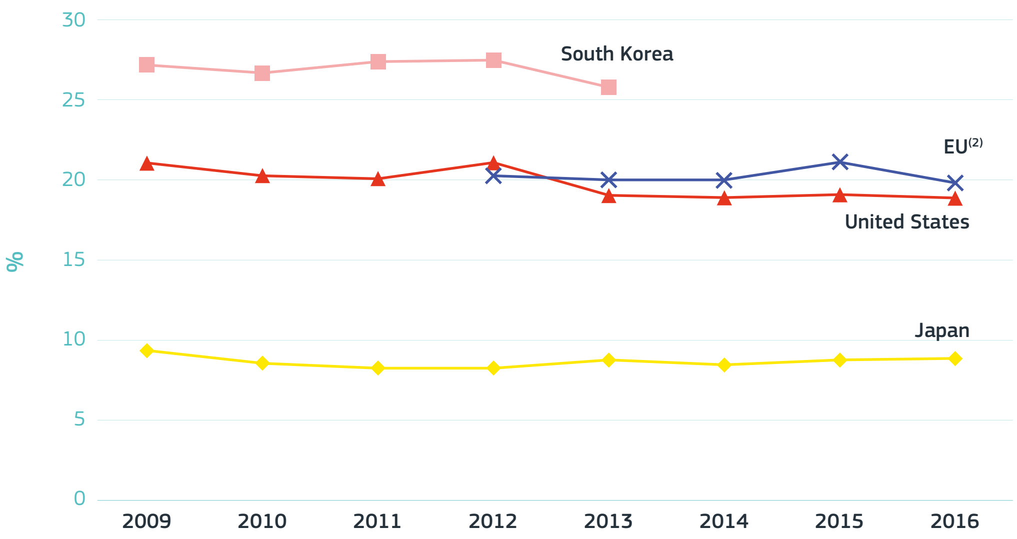
Business dynamism, via the process of creative destruction, can contribute to productivity growth and a more robust economy. An economy's business dynamism can be examined through a set of different measures, such as firm entry and exit rates, churn, and job reallocation rates (i.e. the simultaneous creation and destruction of jobs (Calvino et al., forthcoming)). Economic theory shows that an economy that exhibits higher firm dynamics will in principle be more innovative and productive.

Joseph Schumpeter coined the term 'creative destruction' in 1942. Acemoglu (2008) also refers to the importance of creative destruction for growth. The thesis is that an economy where resources move from less-productive to more-productive businesses within industries will show higher productivity growth (Decker et al., 2016) via a more efficient allocation of resources in the economy. Put differently, it assumes that new businesses will introduce new products and services and challenge older businesses to adapt and compete and will eventually replace them. Bauer (2020) found that higher entry rates improve productivity growth and that net entry contribution is an important driver of productivity. Moreover, Criscuolo et al. (2014) highlight the role of startups in job creation by demonstrating that young firms contribute disproportionately to net employment creation.

In this chapter, we look into recent and longer-term trends across different measures of business dynamism in Europe, benchmarking with other major economies, and we discuss the implications these developments may have for innovation, productivity and growth prospects. In addition, we analyse the state of play of innovative entrepreneurship on the continent as well as some enabling conditions for the success of European entrepreneurs.

In recent years, business dynamism has stagnated and even declined in the EU and/or its international competitors. This may limit its contribution to productivity growth. Figure 3.3-1 depicts the evolution of business churn in the EU and in other major economies between 2009 and 2016, depending on data availability. Business dynamism is highest in South Korea and lowest in Japan. Over time, churn rates seem to have stagnated in Japan and the EU, while in the United States and South Korea a slight decline is more evident after 2012.

Figure 3.3-1 Business churn of employer enterprises (%)[1] by region, 2009-2016



Science, research and innovation performance of the EU 2020

Source: Eurostat (online data code: bd_9fh_sz_cl_r2), DG Joint Research Centre, OECD

Notes: [1]Business churn is the sum of birth and death rates of employer enterprises i.e. enterprises, with at least 1 employee. [2]EU was estimated by DG Research and Innovation.

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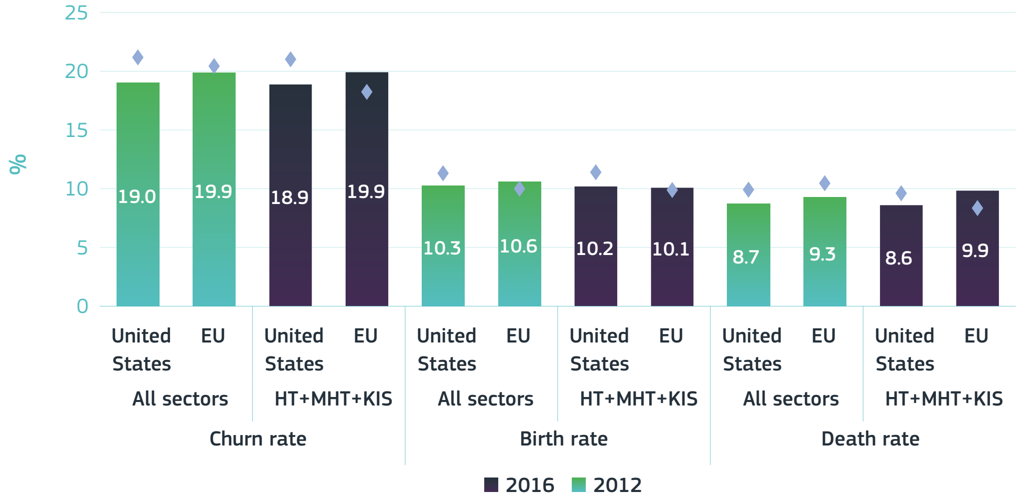
The EU exhibits slightly higher business dynamism than the United States. The combined dynamics in high- and medium-high-tech manufacturing and knowledge-intensive services are similar to those of the overall economy. In 2016, the EU's economy was somewhat more 'dynamic' than the United States, both in all sectors and in high- and medium-high-tech manufacturing (HT, MHT) and knowledge-intensive services (KIS) sectors (Figure 3.3-2). This was mainly due to slightly higher company death rates in the EU. Between 2012 and 2016, there appears to have been a stagnation in EU business dynamism, and a small increase in the HT, MHT and KIS sectors derived from higher death rates in these sectors. The United States experienced a decline in business churn activity between 2012 and 2016 due to a slight contraction in both birth and death rates.

Some EU Member States have seen a decline in business churn activity over recent years, while overall increases were more visible in EU-13 countries. Figure 3.3-3 depicts the evolution of churn rates between 2010 and 2017. Business churn declined in some Member States during this period. Hungary, Poland, Bulgaria, Estonia and Croatia had the highest churn in 2017, while Belgium, Ireland, Greece and Malta showed the lowest business dynamism and have not made any progress compared to 2010. The largest increases were in Hungary (mainly due to much higher company death rates), Poland and Romania. Denmark stands out as a country with high birth rates and relatively low death rates. The United Kingdom and Norway registered increases in business churn, while Turkey experienced the largest decline in the group of associated countries represented in the graph.

Figure 3.3-2 EU-US comparison of churn, birth and death rates, all sectors and in high- and medium-high-tech manufacturing, and knowledge-intensive sectors, 2012 and 2016



Science, research and innovation performance of the EU 2020

Source: Eurostat (online data code: bd_9fh_sz_cl_r2), DG Joint Research Centre

Note: (1)EU was estimated by DG Research and Innovation and excludes Cyprus.

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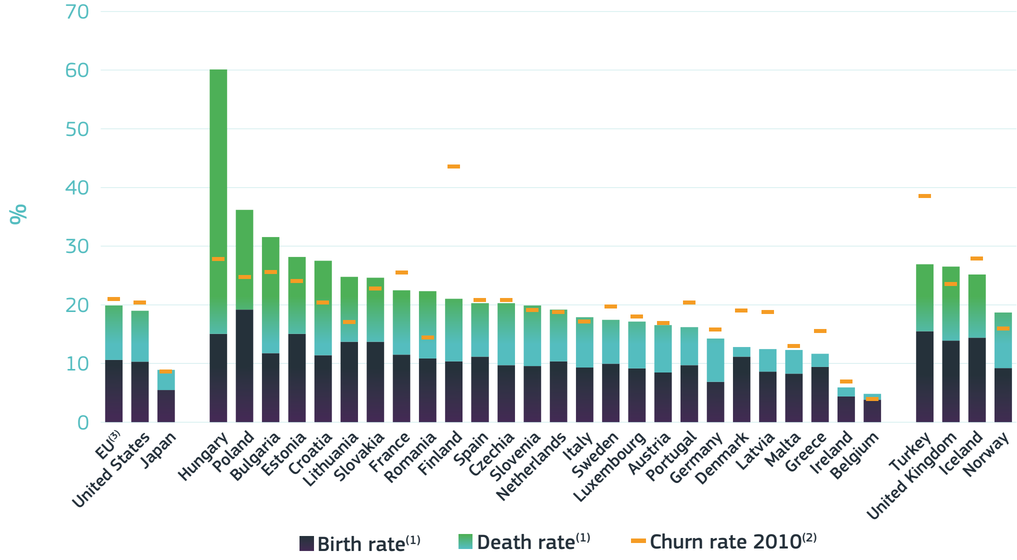
Figure 3.3-3 Churn rate (birth rate plus death rate) of employer enterprises, 2017 and total churn rate 2010(1)



Science, research and innovation performance of the EU 2020

Source: Eurostat (online data code: bd_9fh_sz_cl_r2), DG Joint Research Centre, OECD

Notes: (1) EU, CZ, IE, FR, HU, MT, PL, RO, SK, TR, US, JP: 2016. (2)EU, BE, BG, DK, DE, HR, MT, PL, SK, FI, SE, UK, NO, TR: 2012. IE: 2014 EL: 2015. (3)EU was estimated by DG Research and Innovation and excludes Cyprus.

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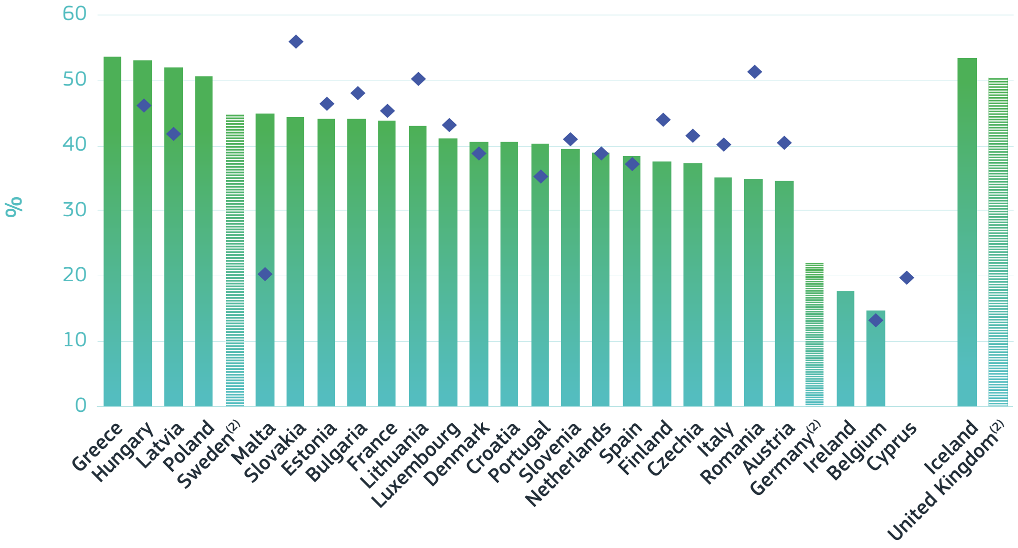
The presence of young companies in EU Member States ranges from more than half in Greece to only slightly over 10 % of employer enterprises in Belgium. Startups (defined here as young companies up to five years old) constitute more than half of employer enterprises in Greece, Hungary and Latvia, and less than one fifth in Ireland, Belgium and Cyprus (Figure 3.3-4). In Iceland and the United Kingdom, startups comprise more than 50 % of enterprises. In most EU Member States (for which either 2009 or the earliest year is available) the share of startups in the economy contracted. The biggest declines were registered between 2009 and 2016 in Romania, Slovakia and Lithuania, while increases were more pronounced in Malta, Latvia and Hungary. Chapter 8 - Framework conditions provides an overview of the framework and market conditions that may partly explain these cross-country differences.

The evolution of enterprise birth rates across the EU reveals a mixed pattern. As expected, the evolution of job creation by new firms correlates positively with birth rates. There are considerable cross-country differences in terms of job creation rates. Employer enterprise birth rates have not yet reached pre-crisis rates in some EU Member States such as France, Luxembourg, Latvia, Romania and Slovenia. On the other hand, in Spain, Lithuania, Estonia, Slovakia and Hungary, birth rates have surpassed those before the crisis. In a few Member States, like Austria, Belgium, Germany, Portugal and Sweden, birth rates seem to be relatively stable. In 2017 (or latest year available), enterprise birth rates ranged from 19 % in Poland to only around 4 % in Belgium and Ireland (Figure 3.3-4). In the United States, following a rise in 2012, birth rates appear to have slightly declined again.

Figure 3.3-4 Share of startups (up to 5 years old) in total employer enterprises, 2009 and 2016



Source: Eurostat (online data code: bd_9fh_sz_cl_r2)

Notes: (1)BE, BG, DK, CY, MT, NL, FI: 2012. FR, SK: 2013. (2)SE, DE and UK do not include the share of employer enterprises that are 5 years old due to data unavailability.

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As expected, the evolution of job-creation rates among new employer enterprise births has more or less followed the evolution of enterprise birth rates. Job creation rates are the highest (above 4%) in Hungary, Greece, Spain, Poland and Slovakia, compared to job-creation rates by the newly created enterprises covered of just 1% or less in Belgium, Germany and Ireland. In the United States, job creation by new firms seems to be declining slightly.

Figure 3.3-5 Employer enterprise birth rates and job creation rates[1] (%), by country

Source: Eurostat (online data code: bd_9fh_sz_cl_r2), OECD (SME and Entrepreneurship Outlook 2019), DG Joint Research Centre

Note: [1] Job creation rate is the ratio of jobs created by employer enterprise births over the number of jobs in employer enterprises.

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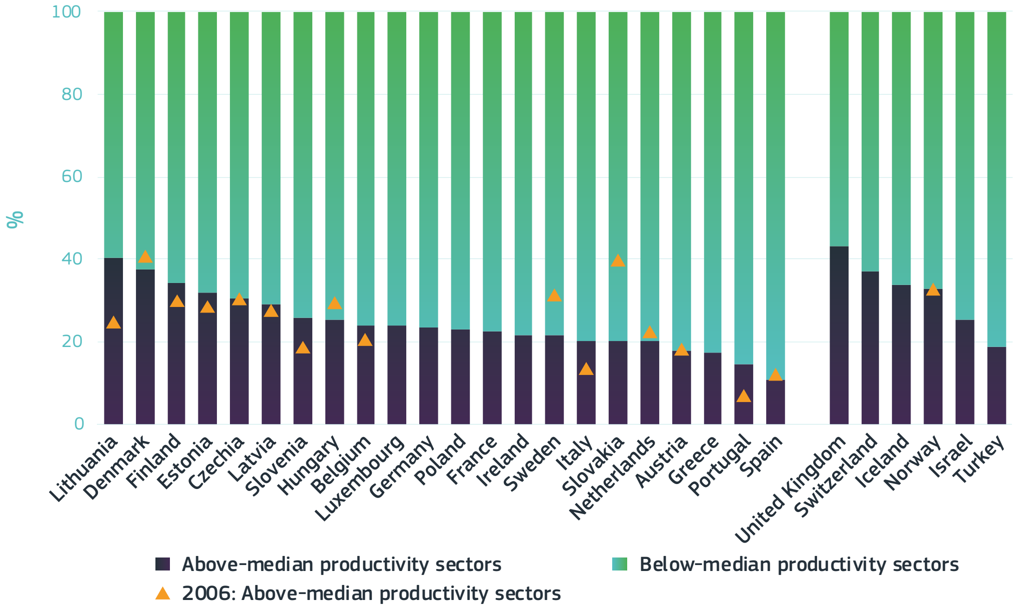
Most jobs created by new firms emerged in less-productive sectors of the economy. However, in some countries, there has been progress towards job creation in more-productive sectors. Figure 3.3-6 depicts the share of jobs created by new firms in above- and below-median productivity sectors in 2016 and compares it with 10 years ago (whenever country-level data is available). Lithuania, Denmark, Finland, Estonia and Czechia registered the highest percentages of new jobs created by new firms in above-median productivity sectors, with 30-40% of new jobs being created in sectors with higher productivity. A similar picture applies to the United Kingdom, Switzerland, Iceland and Norway. On the other hand, over 80% of jobs created by firm births in Spain, Portugal, Greece, Austria and the Netherlands were in lower-productivity sectors.

Nonetheless, since 2006, there has been an increase in the shares of jobs being created by new firms in more productive sectors in some countries. This is the case in Lithuania, Finland, Estonia, Czechia, Latvia, Belgium, Italy, Austria, Portugal and Spain. In the case of Lithuania, this increase almost doubled in percentage points. In other countries, such as Denmark, Hungary, Sweden, Slovakia, and the Netherlands, the contribution to new job creation from more productive sectors appears to have declined.

Overall, considering the link between productivity and wage-setting, it seems that most jobs created by new firms were in lower-productivity sectors and hence, in principle, were lower-paid jobs. As mentioned in OECD (2019), this may provide an explanation for

Figure 3.3-6 Percentage of jobs created by firm births in above- and below-median productivity sectors(1), 2016(2) and comparison with 2006 share for above-median productivity sectors



Source: OECD SME and Entrepreneurship Outlook 2019

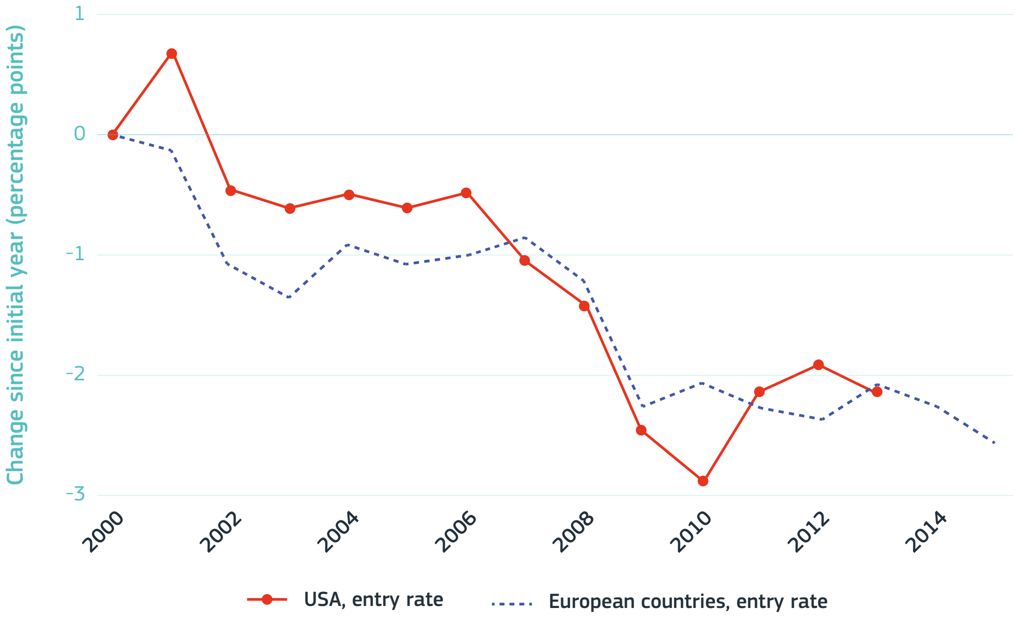
Notes: (1)Median productivity (as measured by valued added per person employed) is calculated at the sectoral level (ISIC Rev4) for each country and year. (2)2016 or latest year available.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter33/figure-33-6.xlsx

wage stagnation in many countries, despite the improvement in economic indicators, such as GDP growth and employment rates, since the crisis.

Longer-term analyses based on firm-level data are needed to better understand the evolution and impact of changes in business dynamism in the economy. Research points towards a decline of business dynamism in both Europe and the United States. As mentioned above, according to economic theory, stronger business dynamism can lead to a higher productivity-enhancing reallocation of resources in an economy and consequently can be a source of growth. Decker et al. (2016) showed the decline of business dynamism in the United States as well as a *reduction in high-growth entrepreneurship in the United States in the post-2000 period*. Calvino et al. (forthcoming) use microdata for a set of European countries and the United States to compute firm-level business dynamics within industries. Figure 3.3-7 confirms that since 2000 there has also been a decline in business dynamism, as measured by entry rates, in Europe. Bijnens and Konings (2018) found similar results for Belgium using 30 years of firm-level data.

Figure 3.3-7 Average cumulative changes in entry rates, selected European countries and comparison with the United States, 2000-2015



Source: Calvino et al (forthcoming)

Note: This figure reports within-country-industry trends of entry rates, based on the year coefficients of regressions within country-sector, for the period 2000-2015, conditional on data availability. European countries include BE, ES, IT, NL, AT, PT, SE, FI, UK, NO. Each point represents cumulative change in percentage points since 2000.

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However, understanding the direct causes and impact of declining business dynamism since 2000 is a complex exercise. Disentangling the impact of the slowing pace of job reallocation and entry rates on innovation and productivity, with certainty, can be a challenging task. For example, Decker et al. (2018) argue that to get the full picture about the slowing business dynamism it is important to consider the hypothesis that *changes in the business model within sectors may imply less need for a high pace of business formation and reallocation dynamics to achieve productivity growth*. Hence, existing firms may continue to be productive because of process, organisational and business model innovation. In fact, Aghion et al. (2016) showed that *innovation by existing firms contributed more to productivity growth than did innovation by entering firms*. Akcigit and Ates (2019) found that the explanation for declining business dynamism in the United States may lie in a decline in knowledge diffusion.

Business dynamics in digital sectors have received closer scrutiny in the literature due to concerns over market concentration in the digital sectors (Andrews et al., 2018). Calvino et al. (forthcoming) found that the higher the digital intensity of the sector, the larger the decline in entry and job reallocation rates (see Chapter 2 - Changing dynamics of innovation in the age of digital transformation). On finding a similar picture, Decker et al. (2016) concluded that there has been a decline in the contribution from reallocation to productivity growth since 2000, which has been particularly true in the high-tech sector.

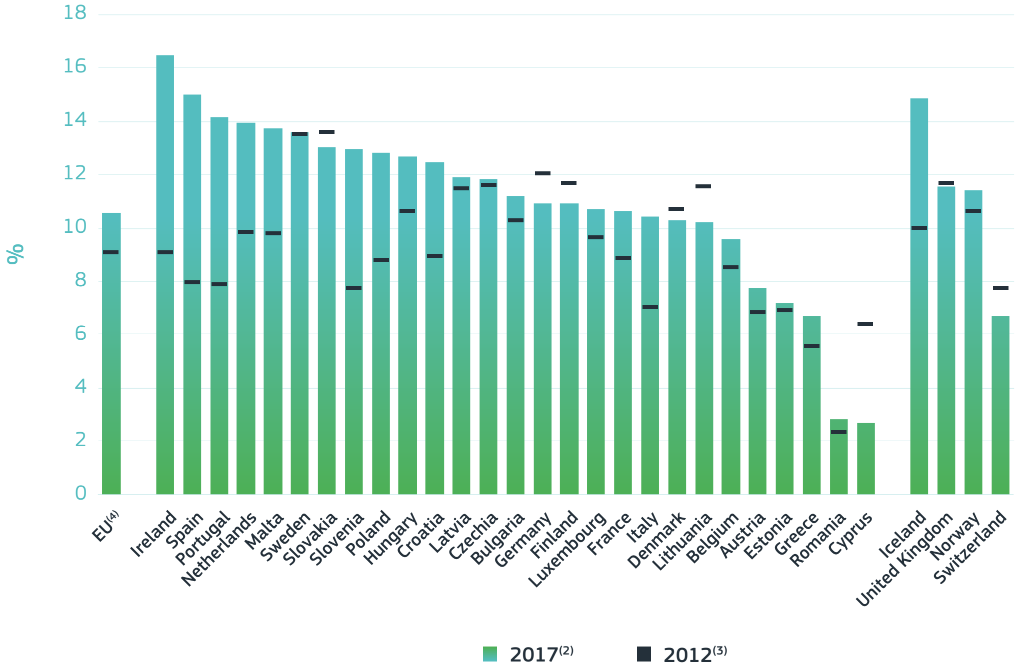
Calvino et al. (forthcoming) shed more light on the impact of changes in the competitive environment on business dynamism measured by entry rates and job reallocation rates. On the impact of the business cycle, they find that it *plays an important role but the observed declines in dynamism do not seem to be a cyclical phenomenon only*. Furthermore, greater efficiency in contract enforcement and business regulations was found to be associated with stronger business dynamism. The authors also identified a negative association between the administrative burden on startups and entry rates. These aspects are further explored in Chapter 8 - Framework conditions.

2. Europe’s scaling-up performance needs revamping

Slightly more than 1 in 10 enterprises in the EU are high-growth companies. In many EU Member States, the representation of high-growth firms in the economy has increased. High-growth enterprises can be measured either in terms of employment or turnover growth. Since data are more commonly available for employment, this is the criteria we have applied – a high-growth enterprise has at least 10 employees and an average annualised employment growth of 10% or more per annum over a three-year period – which also follows the definition of Eurostat and the OECD. Grover Goswami et al. (2019) from the World Bank found that *high-growth firms are not only powerful engines of job and output growth but also create positive spillovers for other businesses along the value chain*. Daunfeldt et al. (2014) show that high-growth firms contribute disproportionately to new job creation. In the European Innovation Scoreboard, the European Commission (2019) also includes an indicator for employment in fast-growing innovative enterprises, following the rationale that the spread of these high-growth enterprises in the most innovative sectors can potentially lead to structural change (see Chapter 6.3 – Innovation output and knowledge exploitation and valorisation).

Overall, the share of high-growth enterprises in Europe has increased between 2012 and 2017 (Figure 3.3-8). In 2017, in the EU, 10.6 % of the companies were recognised as high-growth enterprises. The share of high-growth firms ranged from nearly 17 % in Ireland to slightly less than 3 % in Cyprus. Between 2012 and 2017 (or 2016 depending on data availability), the largest increases occurred in Ireland, Spain and Portugal[1], while absolute declines were most pronounced in Cyprus, Lithuania and Germany[2].

Figure 3.3-8 Share of high-growth enterprises(1) in total active enterprises with at least 10 employees, 2012 and 2017



Source: Eurostat (online data code: bd_9pm_r2)

Notes: (1)Enterprises with at least 10 employees at the beginning of their growth and having an average annualised growth in number of employees greater than 10 % per annum, over a three-year period. (2)EU, CY, CH: 2016. (3)FI: 2013. EL, CH: 2014. (4)EU was estimated by DG Research and Innovation.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter33/figure-33-8.xlsx

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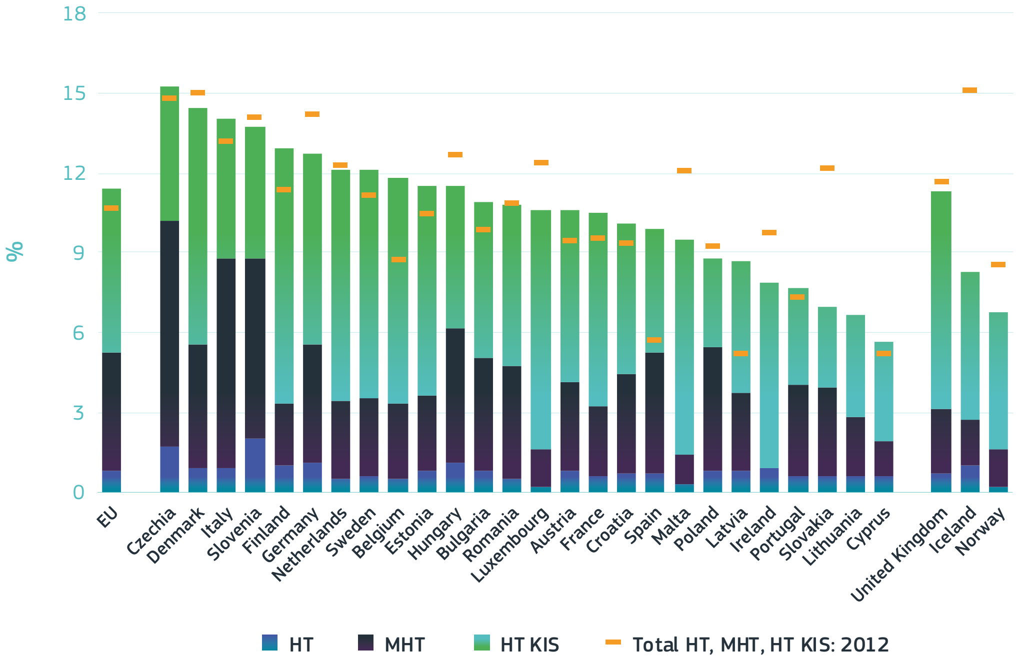
[1] This may reflect business cycle fluctuations.

[2] For more on high-growth firms see as well https://publications.jrc.ec.europa.eu/repository/handle/JRC119788

Less than 12 % of all high-growth enterprises in the EU are in high-tech, medium-high-tech manufacturing and high-tech knowledge-intensive services, although there has been an increase in recent years. Figure 3.3-9 shows that most high-growth enterprises do not occur in high-tech, medium-high-tech manufacturing and high-tech knowledge-intensive services (KIS). In fact, their share ranges from around 15 % in Czechia to 6 % in Cyprus. There are also intra-EU differences in terms of the representation of high-tech KIS and high-tech and medium-high-tech manufacturing, which also reflects countries' economic structure. For example, in central, eastern and south-eastern European countries, such as Czechia, Slovenia, Hungary, Slovakia and Poland, medium-high-tech manufacturing accounts for almost half of the shares. On the other hand, in Ireland, Luxembourg, the Netherlands, Belgium, Sweden and France, high-tech KIS make the greatest contribution, of at least 70 %. High-tech KIS also play an important role in the United Kingdom, Iceland and Norway. High-tech manufacturing has the lowest share in all countries.

Figure 3.3-9 Share of high-growth enterprises[1] in high-tech (HT) and medium-high-tech (MHT) manufacturing, and high-tech knowledge-intensive services (HT KIS) in total high-growth enterprises, 2017 and 2012 without breakdown



Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit, based on Eurostat (online data code: bd_9pm_r2)

Note: [1]Enterprises with at least 10 employees at the beginning of their growth and having an average annualised growth in number of employees greater than 10 % per annum, over a three-year period.

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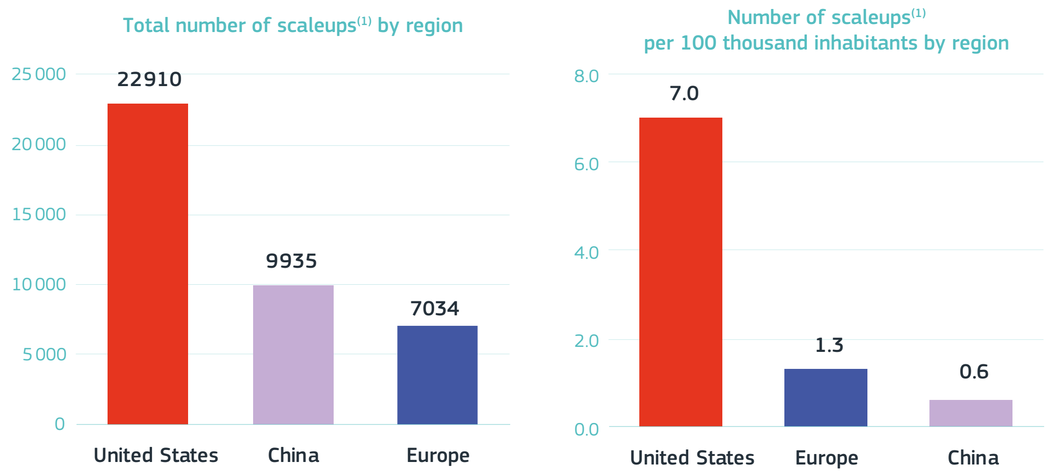
An alternative way to look into high growth concerns the amount of funding raised. Europe lags considerably behind the United States as regards the presence of tech scaleups. A scaleup is defined by Mind the Bridge (2019) as a tech company that has raised more than EUR 1 million in funding. Figure 3.3-10 compares the absolute and relative presence of these companies in Europe, the United States and China. Europe has a lower number of tech scaleups than the United States and China and, when standardised by population, it still lags behind the United States. As of 2018, there were 1.3 scaleups per 100 000 inhabitants in Europe compared to seven scaleups in the United States.

Figure 3.3-10 Total number of scaleups(1) and number of scaleups per 100 000 inhabitants, as of 2018



Source: Mind the Bridge - Tech Scaleup Europe 2019 Report

Note: (1)A scaleup is a tech company (i.e. a company - operating in Tech & Digital industries, founded in the New Millennium, with at least one funding event since 2010.Biotech, Life Sciences and Pharma, Semiconductors are currently not included in the scope of research) which has raised more than EUR 1 million in funding, as defined by Mind the Bridge (2019). (2) Europe includes EU Member States, and 18 other European countries (LI, NO, CH, RS, ME, BA, MD, XK, AL, IS, UA, BY, MK, UK, SM, MC, AD, VA). Removing the Top 5 non-EU Member States reduces the number of scaleups in the European aggregate substantially, to 4295.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter33/figure-33-10.xlsx

France, Germany and Sweden represent half of all tech scaleups in the EU. Figure 3.3-11 examines the distribution of tech scaleups within the EU. Just five EU Member States – France, Germany, Sweden, Spain and the Netherlands – account for nearly two thirds of all scaleups identified in the EU[3]. Furthermore, the number of UK and Israeli tech scaleups is higher than any EU Member State.

When it comes to transformational entrepreneurship with a global outreach, the EU trails behind the United States and China. For example, for each private

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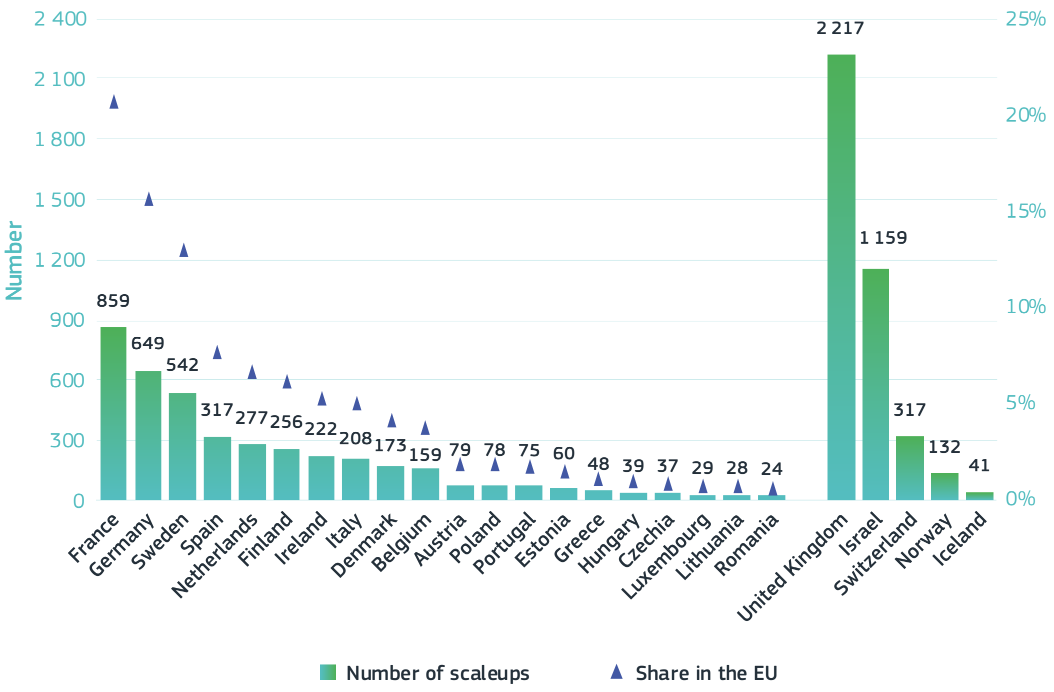
[3] These are mostly the largest Member States in terms of population, firms and GDP, so it would be expected that they also account for more tech scaleups as well (size effect).

unicorn in the EU, there are seven in the United States and four in China. As mentioned by the European Commission (2018), the term 'unicorn' was first coined by Aileen Lee in 2013[4] following the emergence of a 'rare' group of companies that was experiencing spectacular growth and had reached a post-money valuation of more than USD 1 billion.

As of January 2020, there are 439 companies worldwide with private unicorn status. Of those, nearly half (or 215) are based in the United States, around a quarter in China (or 101), and 7 % (or 29) are in the EU (Figure 3.3-12). This gap is also evident when looking into the geographical distribution of the total valuation of private unicorns: US unicorns account for 49 %, Chinese unicorns for 29 %, and EU unicorns are only 4 % of the total. When standardising the number of unicorns per million population, the gap relative to both the United States and China remains although the EU's performance comes very close to China[5].

Figure 3.3-11 Total number of scaleups(1) and share in the EU (%), as of 2018



Source: Mind the Bridge - Tech Scaleup Europe 2019 Report

Notes: (1)A scaleup is a tech company which has raised more than EUR 1 mn in funding. (2)EU average was calculated with the available countries.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter33/figure-33-11.xlsx

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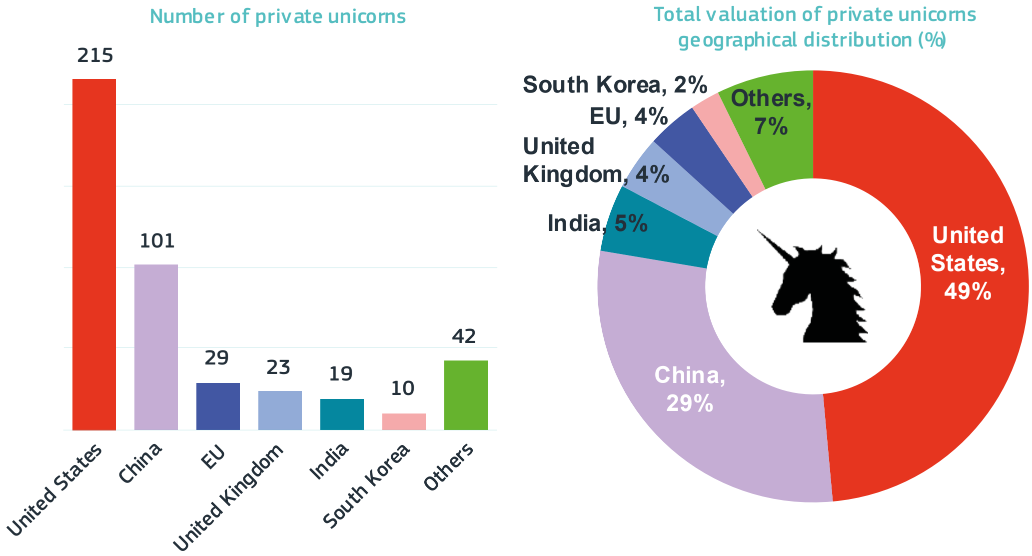
[4] https://techcrunch.com/2013/11/02/welcome-to-the-unicorn-club/

[5] Using population data for 2018 from the World Development Indicators, we find the following results for unicorns per million population: United States (0.7), China (0.07) and EU (0.06).

Figure 3.3-12 Private unicorns[1], January 2020



Science, research and innovation performance of the EU 2020

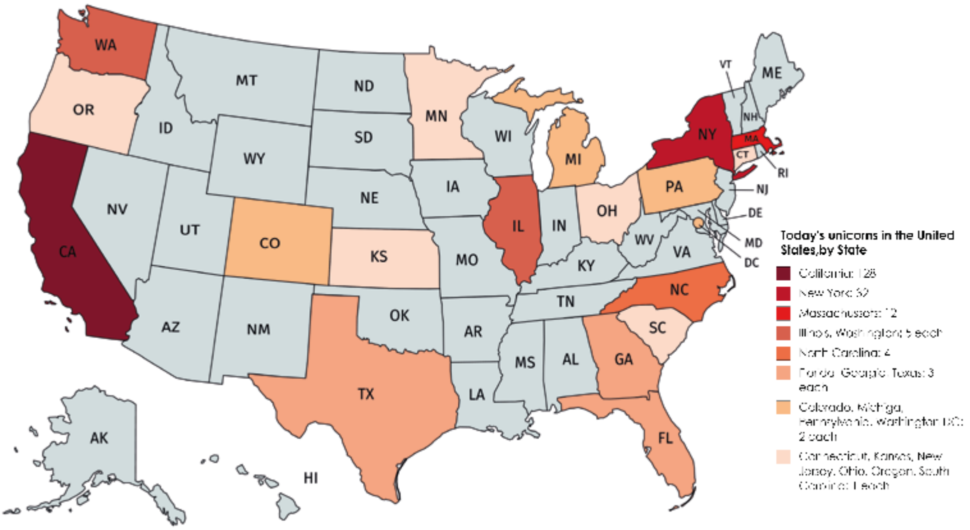
Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit, based on CB Insights-Unicorn tracker, accessed on 24 January 2020

Note: [1]A private unicorn is a private company with a post-money valuation (i.e. 'after funding') valuation of more than USD 1 billion. Even though Kaseya and Collibra are not counted as private unicorns in CB Insights database, after checking Crunchbase and Linkedin company data a decision was made to include them as they are based in the EU. Image © martialred, #125077712; 2019. Source: stock.adobe.com

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter33/figure-33-12.xlsx

'It's all about California'. The United States is home to most unicorns worldwide but they are highly concentrated in just three states – California, New York and Massachusetts. Together, these three states account for 82% of the country's current unicorns, with California alone being home to 60% of all US private unicorns (Figure 3.3-13). New York comes next with 31, followed by Massachusetts with 12 private unicorns. Of the 50 states, 20 (less than half) have at least one private unicorn. In California, San Francisco stands out thanks to the city's strong tech ecosystem which includes, for example, an experienced network of venture capital investors, a vibrant tech community and a pool of tech talent.

Figure 3.3-13 Today's 'unicorn land' in the United States



Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit, based on CB Insights-Unicorn Tracker, accessed on 6 January 2020. Created with mapchart.net©

Note: Today's unicorns are private unicorns at the date of extraction of the data. A private unicorn is a private company with a post-money valuation (i.e. 'after funding') of more than USD 1 billion.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter33/figure-33-13.xlsx

'Unicorns: a tale of concentration'. The spatial concentration of unicorns is not only visible in the United States but also in the EU and China. Unicorns are usually 'born' in well-connected hubs where risk finance and talent are also more widely available. Unicorn companies are very capital-intensive and usually connected to global markets from the start (i.e. 'born-global' companies). For this reason, they tend to emerge in the top entrepreneurial cities where the network of investors, partners and academia is well established. Figure 3.3-14 shows the attractiveness of Germany, France and Sweden (in particular, Berlin, Paris and Stockholm) in the EU as together they account for 66 % of the EU's current unicorns. Moreover, as mentioned above, California (and notably San Francisco) is home to more than half of all US private unicorns and, together with the states of New York and Massachusetts, they represent 82 % of the US unicorn landscape. The high spatial concentration of unicorns in top urban centres also holds for China, with the municipality of Beijing currently home to almost half of all Chinese unicorns. Cumulatively, 82 % of Chinese private unicorns are based in Beijing, Shanghai and the province of Guangdong.

Unicorns are mostly present in fintech, internet software and services, e-commerce and, more recently, in artificial intelligence. Figure 3.3-15 displays the top 15 sectors where private unicorns can be found. Slightly more than half are in the top five sectors, i.e. fintech, internet software and services, e-commerce, artificial intelligence and health.

Figure 3.3-14 Top hubs of 'today's unicorns' by region, and share in the region (%)

Region	**Top unicorn hubs**	**Share (% of 🦄 in region)**
🇪🇺	**Top Member State: Germany**	**41 %**
	Top 3 Member States: Germany, France, Sweden/Spain	72 %
🇺🇸	**Top state: California**	**60 %**
	Top 3 states: California, New York, Massachusetts	82 %
🇨🇳	**Top province/municipality: Beijing municipality**	**46 %**
	Top 3 provinces/municipalities: Beijing, Shanghai, Guangdong	81 %

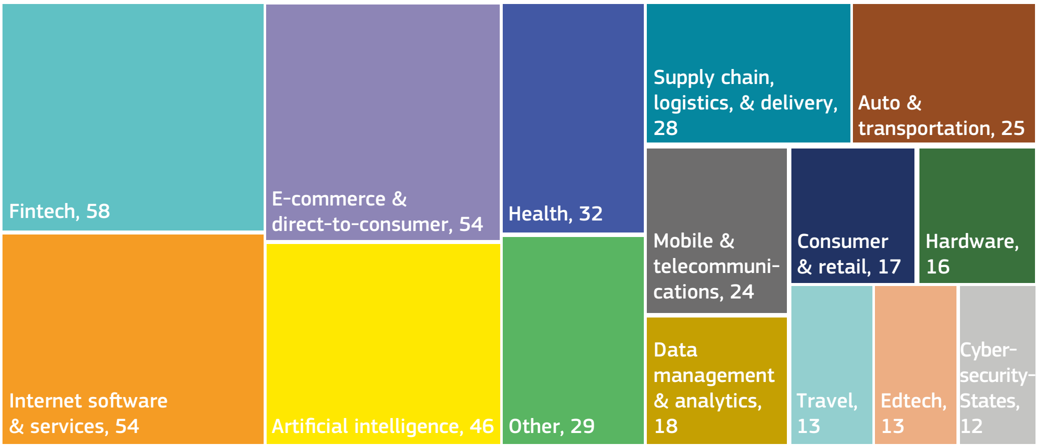
Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit, based on CB Insights-Unicorn Tracker, accessed on 6 January 2020

Note: Today's unicorns are private unicorns at the date of extraction of the data. A private unicorn is a private company with a post-money valuation (i.e. 'after funding') of more than USD 1 billion.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter33/figure-33-14.xlsx

Figure 3.3-15 Top 15 sectors[(1)] of private unicorns[(2)], January 2020



Science, research and innovation performance of the EU 2020

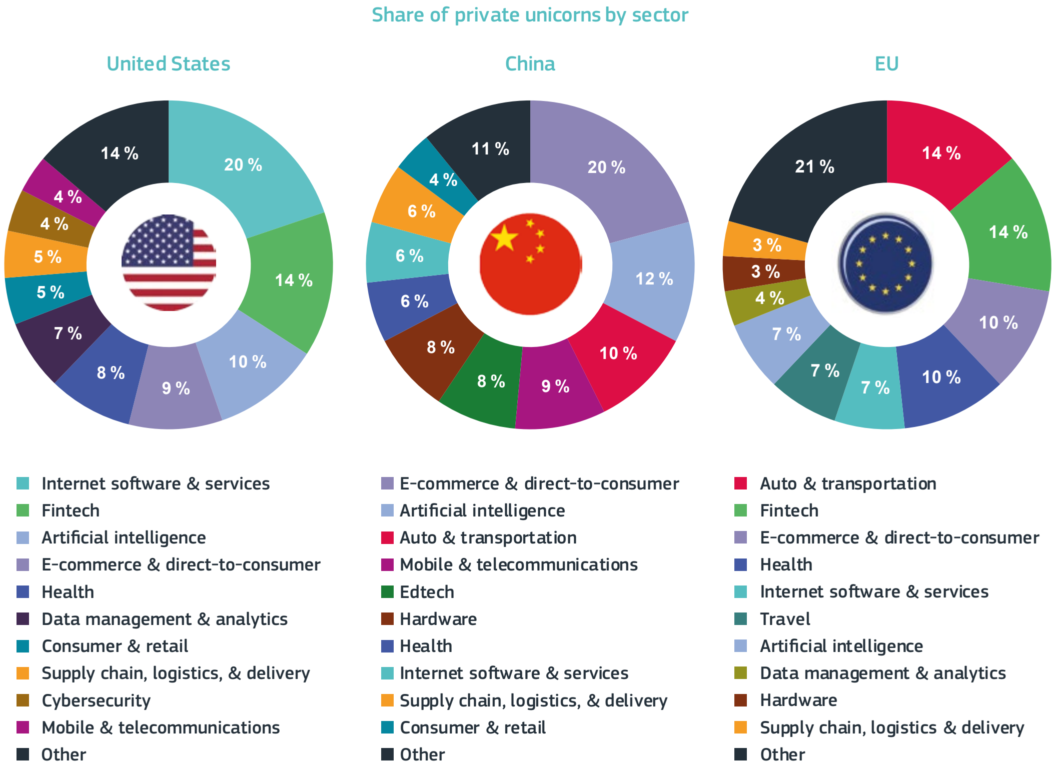
Source: Calculations based on CB Insights-Unicorn tracker, accessed on 21 January 2019

Notes: (1)Sectors were defined according to CB Insights classification. (2)A private unicorn is a private company with a post-money valuation (i.e. 'after funding') of more than USD 1 billion.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter33/figure-33-15.xlsx

Figure 3.3-16 looks at the **sectoral distribution of private unicorns in the EU, United States and China**, with the same colours identifying the different sectors. The 29 EU private unicorns seem to be mainly present in auto and transportation (14%), fintech (14%), e-commerce (10%), health (10%), internet software and services (7%), and travel (7% each). In the United States, internet software and services (20%), fintech (14%), AI (10%), e-commerce (9%) and health (8%) are the 'top five' sectors accounting for slightly more than 60% of the country's current unicorns. The sectoral representation is somewhat different in China, where e-commerce (20%), AI (12%), auto and transportation (10%), mobile and telecomm (9%), educational technology, and hardware (8% each) have the largest weights, representing close to 70% of the current Chinese unicorn landscape.

Figure 3.3-16 Top 10 sectors of private unicorns (%) by region, January 2020



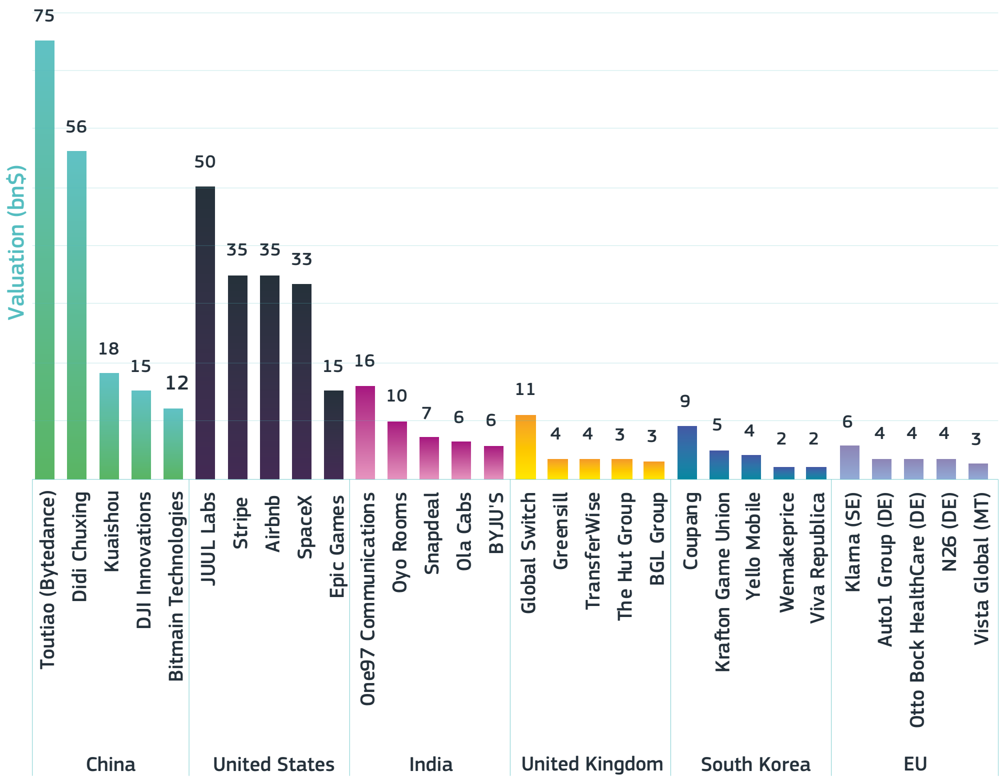
Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit, based on CB Insights-Unicorn tracker, accessed on 21 January 2020

Note: A private unicorn is a private company with a post-money valuation (i.e. 'after funding') of more than USD 1 billion.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter33/figure-33-16.xlsx

The gap between the EU and the United States and China becomes even more evident in the top most-valuable unicorns. The 'top five' private unicorns ranked by valuation in USD billion by region are presented in Figure 3.3-17. It can be seen that the most valuable private unicorns in the EU have significantly lower valuations when compared to other major economies such as the United States, China and India.

Figure 3.3-17 Top 5 private unicorns[1] in terms of valuation (USD bn) by region, January 2020



Science, research and innovation performance of the EU 2020

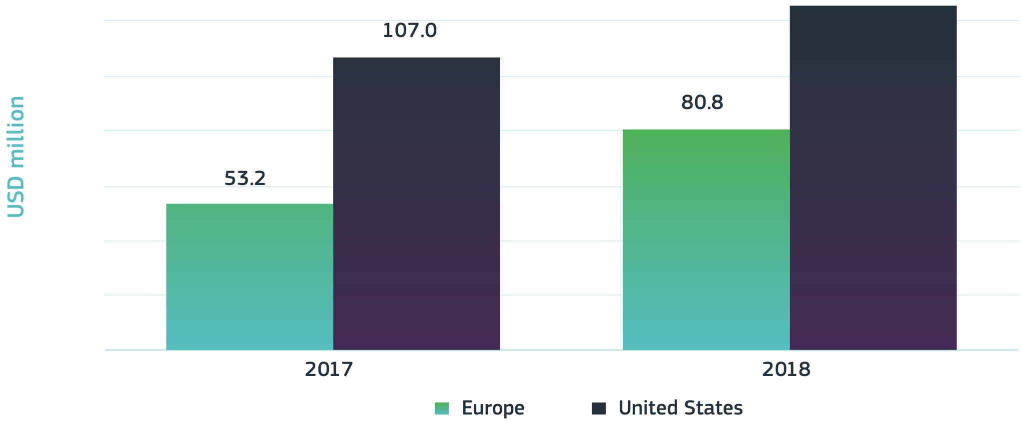
Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit, based on CB Insights-Unicorn tracker, accessed on 21 January 2020

Note: [1]A private unicorn is a private company with a post-money valuation (i.e. 'after funding') of more than USD 1 billion.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter33/figure-33-17.xlsx

Despite the gap in unicorns compared to the United States, European companies seem to have a 'greater efficiency at scaling' prior to reaching unicorn status at USD 1 billion. Figure 3.3-18 indicates that, prior to reaching unicorn status, European companies seem to be more capital efficient, i.e. they manage to reach the USD 1 billion valuation with less available capital. In other words, US unicorns seem to 'burn more cash' when developing their businesses before joining the unicorn club.

Figure 3.3-18 Median funding (in USD million) required prior to reaching private unicorn(1) status



Science, research and innovation performance of the EU 2020

Source: TechCrunch article 16/04/2019 'Unicorns a tale of two continents' based on Pitchbook

Note: The median funding secured prior to (not including) the round in which tech companies in the US and Europe achieved a USD 1 billion valuation during 2017/18.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter33/figure-33-18.xlsx

When adding exited unicorns to the current number of private unicorns, the ratio relative to the United States increases slightly to 1:8 and improves relative to China. The previous figures only considered private unicorns. However, since 2009, there have been other unicorns that were either acquired or are no longer private because they went through an initial public offering (IPO).

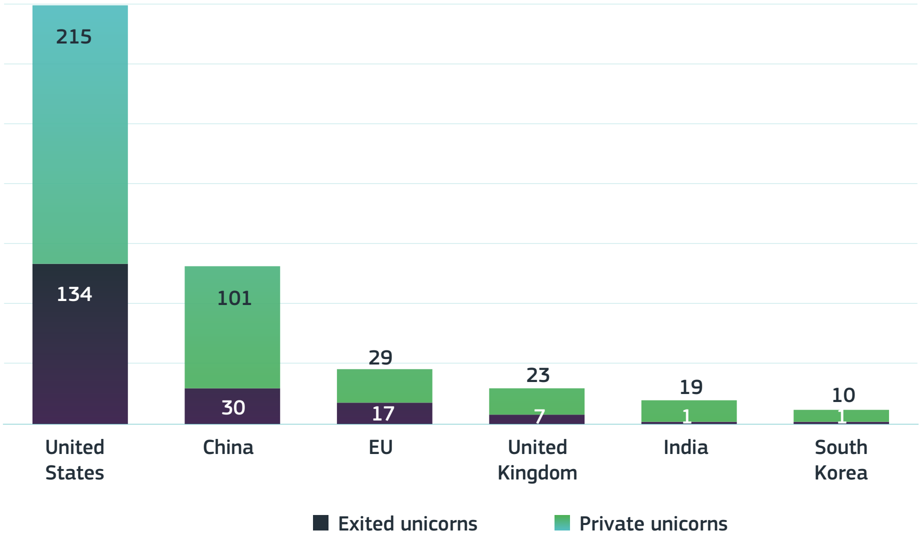
In Figure 3.3-19, we assess whether the gap relative to the United States and China would be smaller if the definition of a unicorn was expanded to include those that went public or were acquired by other companies. Thus, the ratio of EU unicorns to the United States slightly increases to 1:8, while relative to China it improves to 1:3.

In the EU, Germany is home to nearly 40% (or 17) of all unicorns. France and the Netherlands come next with six and five unicorns, respectively. Taking into consideration both private and exited unicorns, Figure 3.3-20 indicates that not all EU Member States have generated at least one unicorn; in fact, that has only happened in half of them. Nevertheless, as is highlighted later in this chapter, there is a group of 'EU DNA' unicorns which, even though they currently have their main headquarters in the United States or the United Kingdom, the (co)-founders have EU nationality and, in some cases, even started the company in a EU Member State.

Germany leads in the creation of unicorns with 5 exited unicorns (HelloFresh, Delivery Hero, Ganymed Pharmaceuticals, Rocket Internet and Zalando) and 12 private unicorns (Auto1 Group, Otto Bock Healthcare, CureVac, N26, NuCom Group, Celonis, About You, Omio, FlixBus, GetYourGuide, Deposit Solutions and wefox Group). France follows with six unicorns – BlaBlaCar, Deezer, Doctolib, OVH, Meero and Criteo – and the Netherlands with five – Adyen, Takeaway.com, Acerta Pharma, Dezima Pharma and Bitfury. The four Swedish unicorns are Spotify, iZettle, Klarna and Northvolt. The most well-known Finnish unicorns are Rovio

Entertainment and Supercell. Cabify and Glovo are the two Spanish unicorns. Ireland is represented by King Digital Entertainment and Kaseya[6]. Nine other EU Member States have produced (or are the headquarters of) one unicorn each: Avast Software (CZ), Sitecore (DK), Bolt (also known as Taxify) (EE), OCSiAl (LU), VistaJet (MT), OutSystems (PT) and Vinted (Lithuania), and Collibra (BE).

Figure 3.3-19 Exited[(1)] and private unicorns[(2)] by region, January 2020



Science, research and innovation performance of the EU 2020

Source: CB Insights-Unicorn Tracker & The Unicorn Exits Tracker, accessed on 21 January 2020

Notes: (1)Exited unicorns since 2009 include private unicorns with one of the following exit strategies: IPO, Acquisition, Corporate majority, Merger, and Reverse Merger. CB Insights tracker includes first exits only. (2)A private unicorn is a private company with a post-money valuation (i.e. 'after funding') of more than USD 1 billion.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter33/figure-33-19.xlsx

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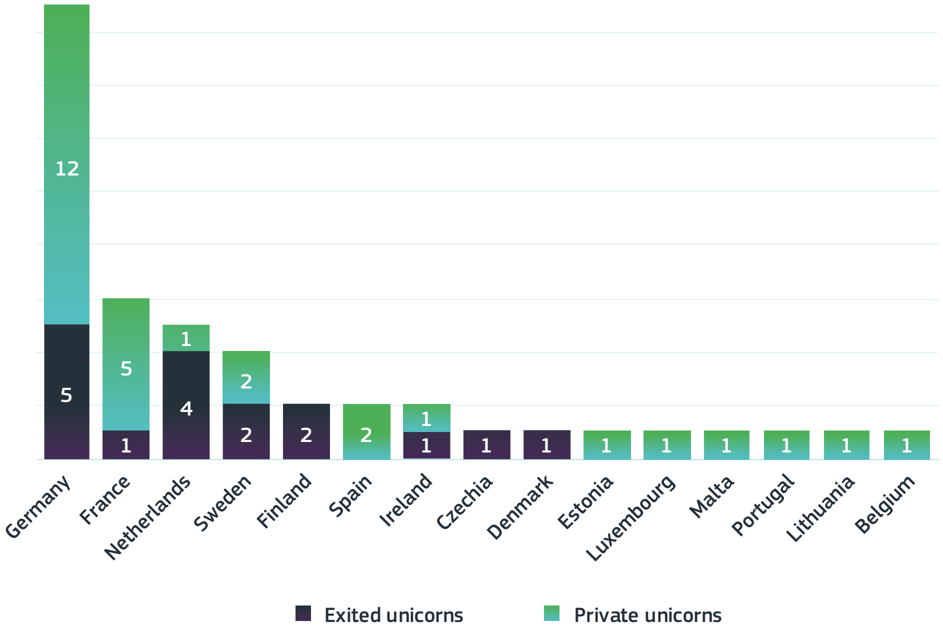
[6] Kaseya was founded in the United States but is now Dublin-based.

Figure 3.3-20 Total unicorns - exited$^{(1)}$ and private$^{(2)}$ - in EU Member States, January 2020



Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit, based on CB Insights-Unicorn Tracker & The Unicorn Exits Tracker, accessed on 21 January 2020

Notes: (1)Exited unicorns since 2009 include private unicorns with one of the following exit strategies: IPO, Acquisition, Corporate majority, Merger, and Reverse Merger. CB Insights tracker includes first exits only. (2)A private unicorn is a private company with a post-money valuation (i.e. 'after funding') of more than USD 1 billion.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter33/figure-33-20.xlsx

From north to south, east to west, there are examples of 'EU DNA' unicorns whose founders have established or moved their headquarters to the United Kingdom or the United States because of access to capital, market size or the intense network of investors and entrepreneurs. Some unicorn founders studied at top US universities and decided to start their companies in the United States. As mentioned before, the criteria typically used to attribute a country to each unicorn is the (current) location of the headquarters[7]. We have compiled a list of unicorns that are global successes and have EU-DNA – i.e. founders with EU nationality and/or who decided to start, or establish, or move their headquarters to the United Kingdom or the United States (Figure 3.3-21). However, this list may not be exhaustive.

For example, Farfetch´s Portuguese founder, Jose Neves, started the online luxury fashion platform in Portugal, with its headquarters currently in the United Kingdom. TransferWise, a fintech business, was created in Estonia by the Estonians Kristo Kaarmann and Taavet Hinrikus before being relocated to the United Kingdom even though their largest office

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[7] According to CB Insights and Crunchbase. Other sources attribute other criteria such as the place where the company reached unicorn status.

with over 800 people is in Estonia[8]. Unity technologies, a game development platform, was founded in Copenhagen in 2005 by David Helgason, Nicholas Francis and Joachim Ante, and is currently San-Francisco-based. The Irish brothers John and Patrick Collision founded Stripe in the United States after studying at Harvard University and the Massachusetts Institute of Technology (MIT). Stripe is currently one of the highest valued private unicorns which builds economic infrastructure for the internet. One of Udacity's co-founders is an immigrant from Germany that started Udacity, an online education company based in the United States. Even though UiPath's headquarters are now in New York, the company keeps a very strong presence in Bucharest, where two Romanian entrepreneurs founded it. The founders of these unicorns typically hold diplomas from top US and European universities, and many of them had previous entrepreneurial activities and experiences.

Figure 3.3-21 **Unicorns with 'EU DNA' in the United States and the United Kingdom**

Unicorn	Type of EU DNA	Short company description	HQ	Valuation (USD bn)[(1)]	Founded in	Number of employees
1. Shazam	Co-founder 🇧🇪 Company born in the UK	App to identify any music playing around you	UK	1**	2000	n.a
2. Just Eat	Founders 🇩🇰 Company HQ relocated from DK to the UK	Access to delivery restaurants and online food orders	UK	6.6*	2001	1 970
3. Tradeshift	Founders 🇩🇰 Company relocated HQ from DK to the US	Cloud-based business network connecting buyers and suppliers	US	1.1	2009	976
4. Unity Technologies	Co-founder 🇩🇰 Founded in CPH, moved HQ to US	Game development platform	US	3	2004	2 605
5. TransferWise	Founders 🇪🇪 Company HQ relocated from EE to the UK	Money transfer service without hidden charges	UK	1.6	2011	1 400
6. Eventbrite	Co-founder 🇫🇷 Co-founder studied at Cornell Univ. Company born in the US	Self-service ticketing platform for events	US	1.5*	2006	1 075
7. Symphony Communication Services	Founder 🇫🇷 Company born in the US	Integrated messaging platform	US	1	2014	346

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[8] https://transferwise.com/community/nextgeneration

Unicorn	Type of EU DNA	Short company description	HQ	Valuation (USD bn)(1)	Founded in	Number of employees
8. Tango	Co-founder 🇫🇷 Co-founder studied at Stanford Univ. Company born in the US	Mobile messaging service	US	1.1	2009	128
9. Oscar Health Insurance	Co-founder 🇩🇪 Co-founder studied at Harvard (MBA) Company born in the US	Health insurance	US	3.2	2012	973
10. Palantir Technologies	Co-founder 🇩🇪 Co-founder studied at Stanford Univ. Company born in the US	Software to connect 'data, technologies, people and environments'	US	11	2004	2 510
11. Udacity	Co-founder 🇩🇪 Company born in the US	Online education company	US	1.1	2011	2 112
13. Ginkgo Bioworks	Co-founder 🇮🇪 Co-founder studied at the MIT Company born in the US	Design custom microbes for customers across multiple markets	US	1	2009	264
14. Intercom	Founders 🇮🇪 Company born in the US	Develop and publish communications technology to monitor user behaviour	US	1.3	2011	882
15. Stripe	Founders 🇮🇪 Founders studied in Harvard and the MIT Company born in the US	Build economic infrastructure for the internet	US	35	2010	2 134
16. Compass	Co-founder 🇮🇹 Company born in the US	Technology-driven real estate platform	US	4.4	2012	n.d.
17. OfferUp	Co-founder 🇳🇱 Co-founder studied at the Univ. of Washington Company born in the US	Online classifieds	US	1.2	2011	326

Unicorn	Type of EU DNA	Short company description	HQ	Valuation (USD bn)$^{(1)}$	Founded in	Number of employees
18. AppNexus	Co-founder 🇳🇱 Company born in the US	Cloud-based software for online advertising	US	2**	2007	n.a
19. Farfetch	Founder 🇵🇹 Company started in PT, HQ in the UK	Online luxury fashion retail platform	UK	2.9*	2007	3 232
20. Talkdesk	Founders 🇵🇹 Company born in the US	Enterprise Contact Center Platform	US	1	2011	704
21. UiPath	Founders 🇷🇴 Company relocated HQ from RO to the US	Design and develop robotic process automation software	US	3	2005	+3 000
22. Letgo	Founders 🇪🇸 Company relocated HQ from ES to the US	Second-hand shopping app to help users buy and sell locally	US	1	2015	321
23. Warby Parker	Co-founder 🇸🇪 Co-founder born in Sweden, raised in San Diego Co-founder studied at UC Berkeley, Wharthon School Company born in the US	Online prescription glasses and sunglasses	US	1.2	2010	1 322

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Source: DG Research and Innovation, Unit for the Chief Economist - R&I Strategy & Foresight, based on multiple sources: Craft (access in December 2019), CB Insights, Crunchbase, LinkedIn profiles, companies' websites, the National Foundation for American Policy (2018), online news and media articles

Note: (1)All unicorns listed in the figure are private and hence the values correspond to post-money valuations. Exceptions are indicated with * concerning exited unicorns via an IPO (valuation corresponds to market capitalisation), and ** concerning exited unicorns that were acquired (valuation corresponds to the exit valuation before the acquisition took place). Information displayed in the figure is not exhaustive, so if corrections are needed please contact the authors. Figure displays unicorns ordered by country alphabetic order.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter33/figure-33-21.xlsx

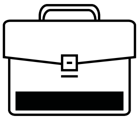
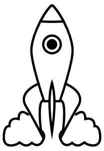
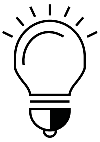
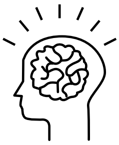
Nevertheless, in general EU DNA unicorn companies and (co-)founders tend to keep strong connections 'back home', which also benefits the country of origin. More generally, the European Commission (2017) investigated the growing phenomenon of dual companies (Onetti and Pisoni, 2016), i.e. high-tech startup companies founded in European countries before relocating their headquarters to outside of the EU, notably the United States. However, they typically maintain a presence (such as R&D labs) in their home country which benefits from positive externalities such as new job creation. The study concluded that 13% of European scaleups follow this 'dual model', and that for 83% of them the United States (in particular Silicon Valley) is the destination, a trend already mentioned in this chapter. For those that relocate within Europe, the United Kingdom is the top choice.

Although there are different reasons for relocating headquarters to the United States or United Kingdom, the most commonly identified are closer proximity to capital markets, an intense and experienced network of investors, and a larger market (see Chapter 8 - Framework conditions). Moreover, the authors' findings suggest that the more mature startup ecosystems (such as Germany, France, Sweden and the UK) show below-average numbers of dual companies (in the 11% to 13% range).

In this context, there are positive externalities to the 'home country' even when headquarters are relocated. This hypothesis holds true in the cases listed below (Figure 3.3-22). Benefits to the country of origin can include employing highly skilled professionals, as in the Tradeshift Frontiers Innovation Lab in Copenhagen or Stripe's new engineering hub in Dublin, participating as angels or seed investors in new startups, such as the founders of Talkdesk and TransferWise, or sponsoring digital education in less-developed regions, like UiPath in Romania, etc.

Some unicorns are highly R&D-intensive and have made it to the top global R&D investors, some despite their young age. Their presence is mainly in software and computer services and on average they have higher market capitalisation than the other top R&D-intensive companies in the sector. They are also less labour-intensive. Only 6 out of the 65 unicorns in the world ranking are from the EU.

Figure 3.3-22 Benefits and positive externalities to the EU country of origin

Type of benefit/positive externality to the home country		Examples from EU DNA unicorns with HQ in the USA and UK
	**Job creation**	**Offices and subsidiary(ies) in the home country[9]:** Farfetch: 1 500+ employees in Portugal Transferwise: 700+ employees in Estonia Letgo: 100+ employees in Spanish subsidiary Stripe: 100+ employees in Ireland UiPath: 700+ employees in Romania
	**Support of the startup ecosystem**	**Advice and mentoring from founders:** OfferUp: Co-founder is a startup advisor in the Netherlands **Seed and early-stage capital:** Talkdesk: Co-founder is an early-stage investor in Portugal Transferwise: Participation in seed capital funding for innovations including in secondary education in Estonia
	**R&D and innovation hubs**	**Launch of tech hubs in the home country:** Tradeshift: Tradeshift Frontiers Innovation Lab in Denmark Farfetch: Plans for a technology and operations campus in Porto Stripe: Engineering hub in Dublin UiPath: Immersion lab in Bucharest Intercom: large R&D team based at its Dublin office
	**Education and research**	**Education and cutting-edge research:** Tradeshift: Sponsors a PhD programme in machine learning in a Danish university UiPath: Foundation supports digital education in Romania Transferwise: Supports NGO Eesti 2.0 and practical mentoring to its students from Transferwise co-founder and others.

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Source: DG Research and Innovation, Unit of the Chief Economist - R&I Strategy & Foresight, based on ORBIS database as of September 2019, companies' websites, online news and media articles

Note: Information on employment was gathered from ORBIS database, accessed on 29-08-2019; Employment data for Farfetch (31/12/2018), Letgo (31/122017), Stripe (31/12/2017), UiPath (31/12/2017). The information displayed in the table is not exhaustive and might be outdated at the time of publication of the report. Should you identify any mistakes in the data please do not hesitate to contact the authors. Images © M.Style, _#125948076; 2019. Source: stock.adobe.com

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter33/figure-33-22.xlsx

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[9] According to CB Insights and Crunchbase. Other sources attribute other criteria such as the place where the company reached unicorn status.

BOX 3.3-1 Zooming in on the top R&D-intensive unicorns

The criteria for being 'highly-R&D intensive' is based on a company's presence in the European Commission R&D Industrial Scoreboard which collects data on the world top 2 500 R&D investors. We start by looking at the spectrum of all unicorns (private and exited) since 2009 which are part of the top global R&D investors. This gives a total of 64 unicorns, up from 40 in the 2018 edition of this report (Figure 3.3-23). Figure 3.3-24 shows that a large majority (80 %) of these very R&D-intensive unicorns can be found in the United States, while only 5 (or 8 %) are in the EU, namely Spotify (Sweden), Yandex[10] (Netherlands), Zalando (Germany), Criteo (France), and AVAST Software (Czechia). As mentioned before, there is a considerable gap between the United States and the EU in terms of the creation of unicorn companies, which is also reflected in this analysis.

Figure 3.3-23 Number of unicorns in the world top R&D investors, SRIP 2018 vs. SRIP 2020

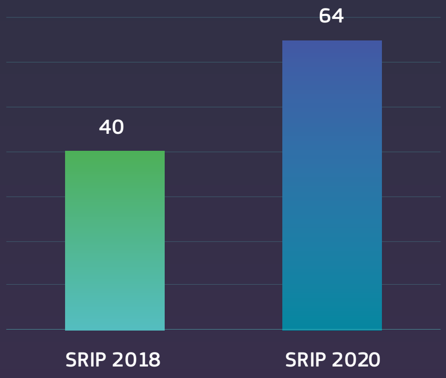
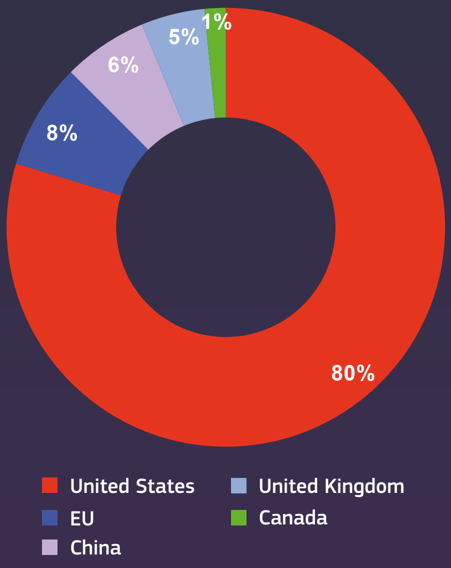


Figure 3.3-24 Geographical distribution of the 65 unicorns in the world top R&D investors



Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit, based on CB Insights - Unicorn and Unicorn Exit Trackers; European Commission (2019), R&D Industrial Scoreboard 2018

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter33/figure-33-23-24.xlsx

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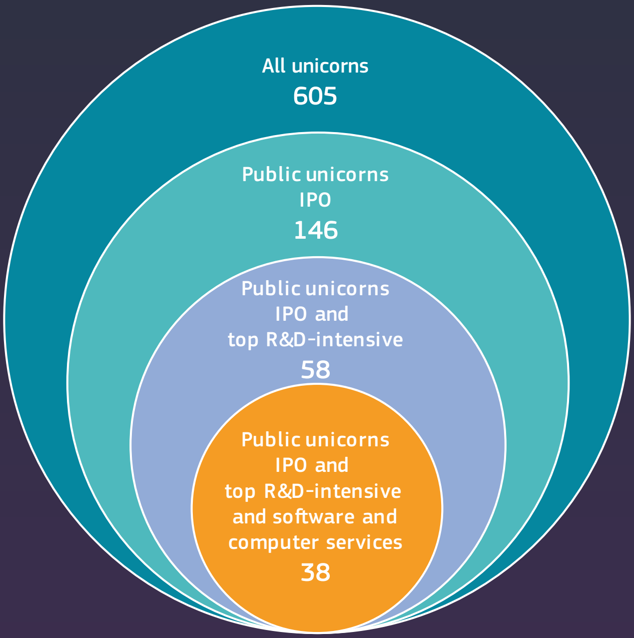
[10] There may be methodological differences in country attribution. For instance, the R&D Scoreboard associates Yandex with the Netherlands, while Crunchbase with Russia

Guzman and Stern (2016) developed a new approach for estimating entrepreneurial quality by linking the probability of a growth outcome (e.g. achieving an IPO or a significant acquisition) as a startup characteristic observable at or near the time of the initial registration of the business. Hence, we focus on unicorn companies that are public and highly R&D-intensive (since acquired companies will not appear in the Scoreboard).

In the next stage, we focus on the software and computer services sector (since this is the sector where we found most unicorns in the R&D Scoreboard). This gives a total of 38 unicorns (Figure 3.3-25) which we then compare with the 268 companies in the R&D Scoreboard in the same sector (although there are definitely some caveats with this analysis).

Figure 3.3-25 Zooming in on the top R&D-intensive unicorns



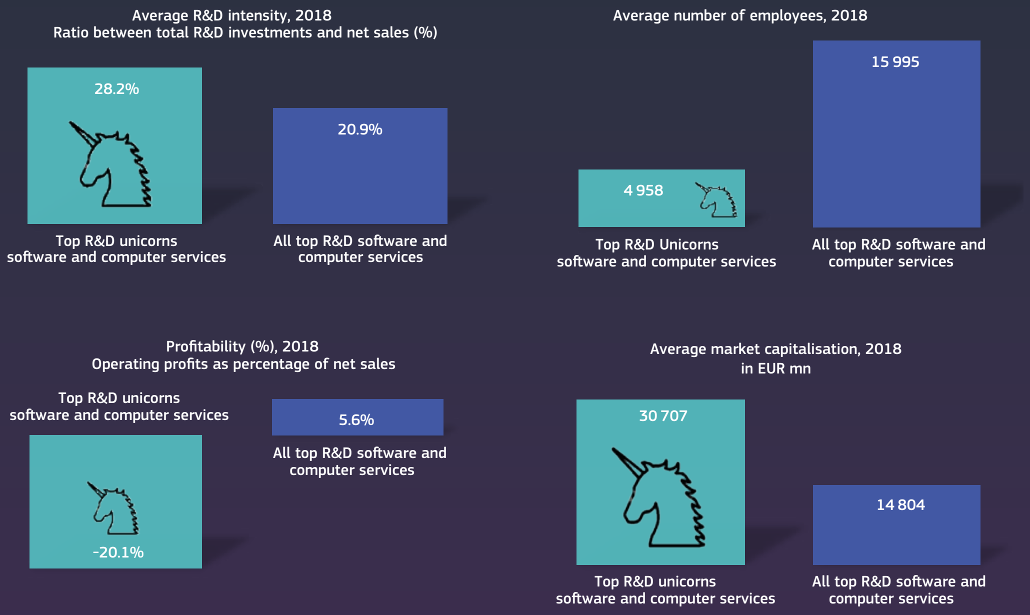
Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit, based on R&D Industrial Scoreboard 2018, and CB Insights Unicorn Tracker (exits)

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter33/figure-33-25.xlsx

Figure 3.3-26 shows the results of this exercise. It seems that, on average, the 'top R&D unicorn investors' are more R&D-intensive, have around four times fewer employees, a negative profitability, and 1.5 times higher market capitalisation than others in the same sector.

Figure 3.3-26 Comparison of the top R&D-intensive unicorns with the top R&D-intensive companies in software and computer services



Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit, based on R&D Industrial Scoreboard 2018, and CB Insights Unicorn Tracker (exits)

Note: Higher standard deviations in R&D intensity and number of employees found for non-unicorns, but higher standard deviations in profitability and market capitalisation found for unicorns. Image © martialred, #125077712; 2019. Source: stock.adobe.com

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter33/figure-33-26.xlsx

Global Innovation Champions are radical innovators that have introduced a 'world-first' product innovation. They broaden our understanding of the state of innovation.

BOX 3.3-2 Beyond unicorns: evidence on European Global Innovation Champions

In search of European Global Innovation Champions', chapter 6 in Vértesy and Damioli (2020).

This pilot work by the Joint Research Centre provides new evidence on radical European innovator companies, in particular on the relatively small share of exporters that introduced a 'world-first' product innovation – referred to here as 'Global Innovation Champions' (GICs). Radical innovators are typically seen as important for shaping the direction of technological change and for job creation (Pianta, 2003; Lucchese and Pianta, 2012). While there is a rich body of literature on the innovative and economic performance of large corporations that account for the bulk of business R&D expenditure (Montresor and Vezzani, 2015; Bogliacino, 2014; Ortega-Argilés et al., 2009), evidence on small- or medium-sized radical innovator enterprises in Europe remains limited.

Yet, analysing European Innovation Survey data shows that about half of the European GICs are small- or medium-sized enterprises (SMEs) that are not part of a corporate group. This suggests a similarity with 'hidden champions', a term introduced by Simon (1996) to describe highly specialised SME world leaders in a niche market, which have been the subject of substantial research (e.g. Audretsch et al., 2018; Witt and Carr, 2013; Simon, 2009; Fryges, 2006). In particular, analogously to hidden champions, GICs might have specific strategies and behaviour that may easily fall under the radar in spite of their relevance for policy.

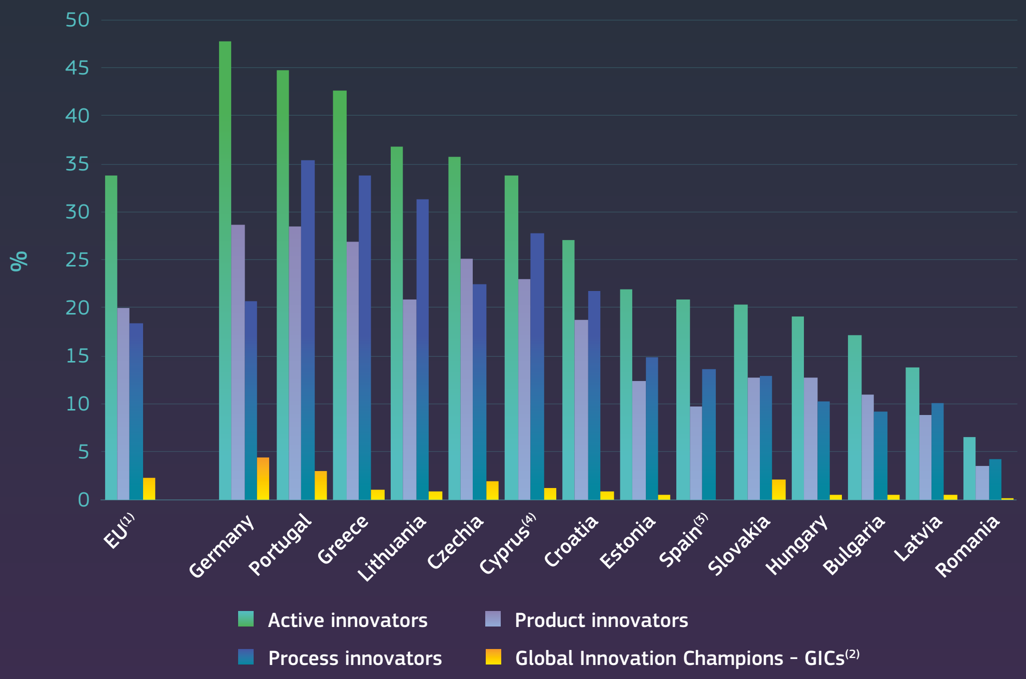
Based on Community Innovation Survey (CIS 2014) data, 1 710 companies were identified as GICs across 12 EU Member States and Norway. This implies that, on average, GICs constitute 3 % of all enterprises, 8 % of active innovators (companies that have introduced or have an ongoing product and/or process innovation) and 13 % of product innovators.

Figure 3.3-27 shows that the share of GICs is particularly high in Germany (4.4 %), and generally quite limited in eastern and Baltic Member States.

Other findings of the analysis:

- **GICs have stronger export performance than other types of innovators**: analogously to the high correlation with product innovations, this is due to the definition of GICs which requires a company to export, besides having introduced a world-first product innovation.
- Although the share of GICs over the population of general and innovative companies is larger for large ones than for SMEs, **the majority (55 %) of GICs are SMEs**.
- **GICs outperform active innovators in most IPR-related activities and MSs**, supporting the idea that the GICs definition identifies technologically intensive radical innovators.

Figure 3.3-27 Share of innovators by type (%), 2014



Science, research and innovation performance of the EU 2020

Source: Figure 14 in Vértesy and Damioli (2020)

Notes: (1)EU was estimated by DG JRC based on data availability for EU Member States. (2)Global Innovation Champions are product innovators that are 'world first' and exporters, and typically leaders in niche markets. (3)CIS questionnaire does not cover 'world first' product innovation in Spain. (4)Breakdown by size not available for Cyprus.

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3. Cross-country variation in entrepreneurial attitudes in the EU: a startup gender gap remains

Four EU Member States are in the 'top 10' in the Global Entrepreneurship Index. However, the intra-EU dispersion of scores is quite significant, especially between the top and the lowest performers. The Global Entrepreneurship Index aims to assess and benchmark the 'health' of entrepreneurial ecosystems across 137 countries. It not only reflects attitudes and propensity towards entrepreneurship, but also the enabling socio-economic conditions underpinning the development of the startup ecosystem. Figure 3.3-28 shows that the top 3 enabling entrepreneurial ecosystems can be found in the United States, Switzerland and Canada. Denmark, Ireland, Sweden and France are in the top 10, while Bulgaria, Croatia and Hungary have the lowest scores at the EU level, quite a long way from the top scores. Overall, there seems to be room in most EU Member States for improving the health of their entrepreneurial ecosystems.

Figure 3.3-28 Global Entrepreneurship Index[1] – top 10 and positioning of EU Member States, 2018

Rank	Country	GEI
1	United States	83.6
2	Switzerland	80.4
3	Canada	79.2
4	United Kingdom	77.8
5	Australia	75.5
6	**Denmark**	74.3
7	Iceland	74.2
8	**Ireland**	73.7
9	**Sweden**	73.1
10	**France**	68.5
11	**Netherlands**	68.1
12	**Finland**	67.9
14	**Austria**	66.0
15	**Germany**	65.9
17	**Belgium**	63.7
20	**Luxembourg**	58.2

(...)Rank	Country	GEI
23	**Estonia**	54.8
25	**Slovenia**	53.8
29	**Lithuania**	51.1
30	**Poland**	50.4
31	**Portugal**	48.8
32	**Cyprus**	48.0
34	**Spain**	45.3
36	**Slovakia**	44.9
38	**Czechia**	43.4
42	**Italy**	41.4
44	**Latvia**	40.5
46	**Romania**	38.2
48	**Greece**	37.1
50	**Hungary**	36.4
54	**Croatia**	34.0
69	**Bulgaria**	27.8

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Source: Global Entrepreneurship Development Institute - Global Entrepreneurship Development Institute- 2018 Global Entrepreneurship Index

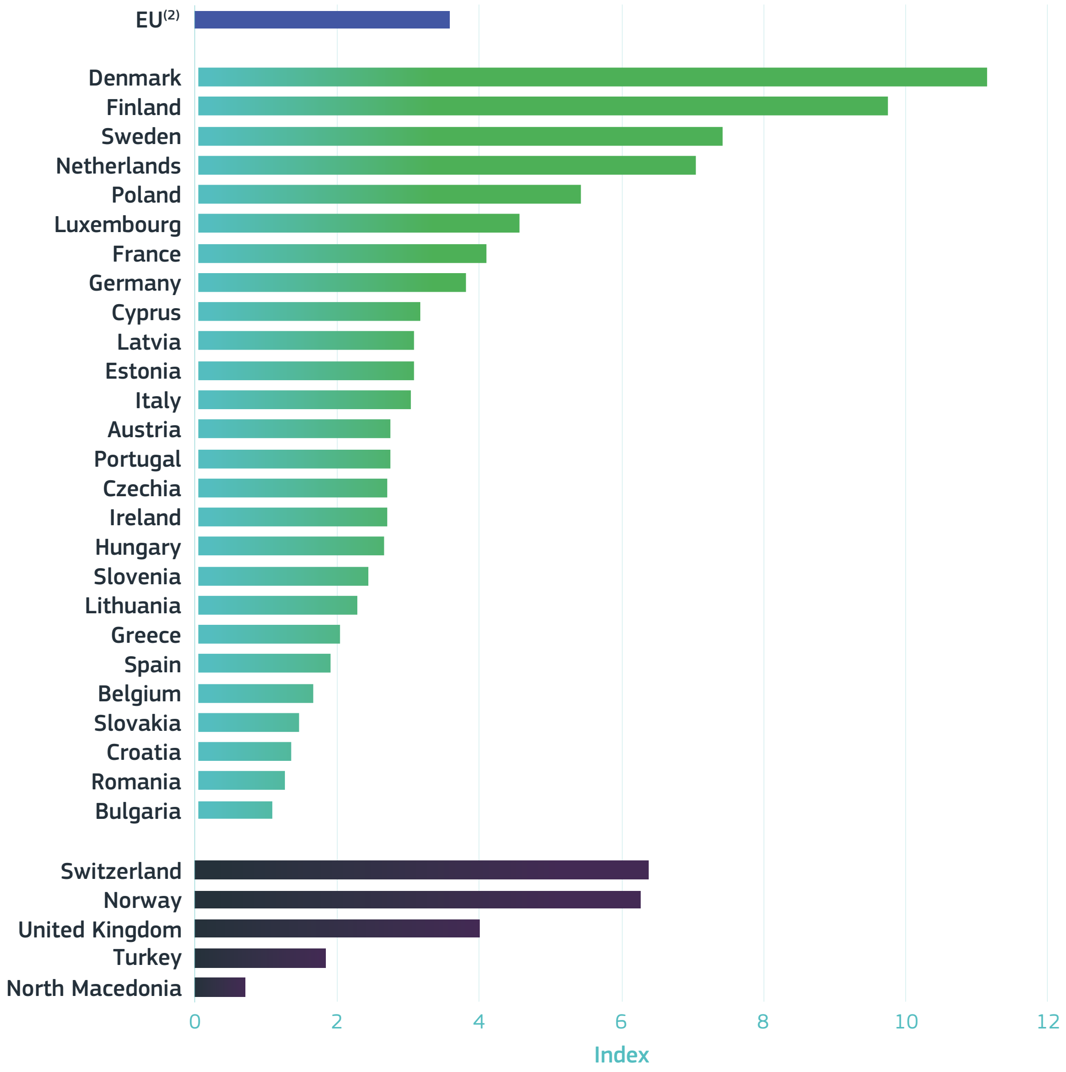
Note: [1]The Global Entrepreneurship Index is an annual index that measures the 'health of the entrepreneurship ecosystems' in each of 137 countries. It then ranks the performance of these against each other. The GEDI methodology collects data on the entrepreneurial attitudes, abilities and aspirations of the local population and then weights these against the prevailing social and economic 'infrastructure' – this includes aspects such as broadband connectivity and the transport links to external markets. This process creates 14 'pillars' which GEDI uses to measure the health of the regional ecosystem.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter33/figure-33-28.xlsx

In the EU, 'innovation leader' entrepreneurs are more attracted by an opportunity in the market, while in southern and eastern European countries necessity remains an important factor driving the decision to become an entrepreneur. The Global Entrepreneurship Monitor distinguishes between entrepreneurs who *are pulled to entrepreneurship by opportunity and because they desire independence or to increase their income*, and those who are pushed to entrepreneurship out of necessity or those who sought only to maintain their income. The results are depicted in Figure 3.3-29. Building a tolerant and learning culture from 'failure', which is widespread in the EU, is also paramount when it comes to innovation.

Overall, innovation leader countries (Denmark, Finland, Sweden) exhibit a higher prevalence of opportunity-driven entrepreneurship due, in principle, to more opportunities and choices provided by the market to make a living. On the other hand, where the ratios are lowest (in countries such as Bulgaria, Romania and Croatia), it seems that necessity is still an important driver to become an entrepreneur.

Figure 3.3-29 Opportunity-driven entrepreneurship[(1)] by country, 2018



Source: European Innovation Scoreboard 2019

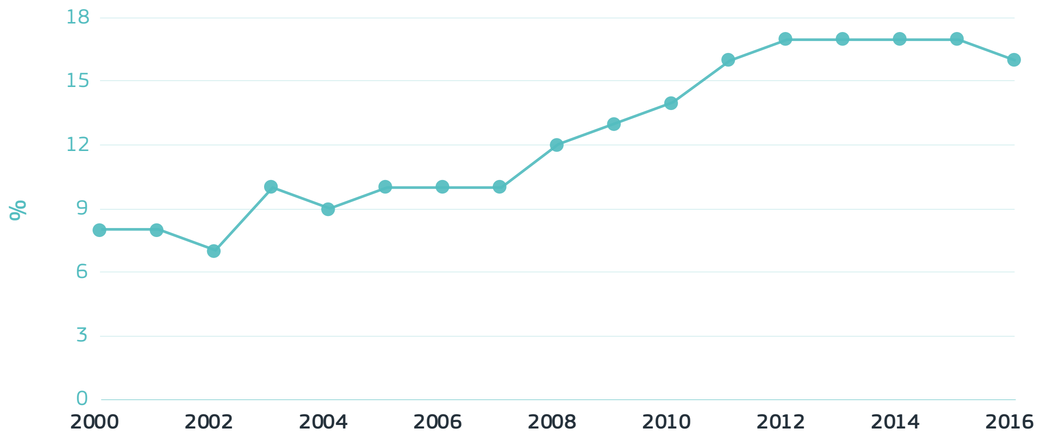
Notes: (1)The opportunity-driven entrepreneurship index is calculated as the ratio between the share of people involved in improvement-driven entrepreneurship and the share of people involved in necessity-driven entrepreneurship; three-year averages were used (EIS2019). (2)EU is the average value of Member States and does not include Malta.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter33/figure-33-29.xlsx

Despite some progress, a pronounced gender gap remains in the creation of innovative startups. There are also cross-country differences. Overall, female startup founders remain under-represented in the creation of startups despite having doubled their representation from 8% in 2000 to 16% in 2016 (Figure 3.3-30). Lassébie et al. (2019) show that *the gender gap in innovative high-potential startups is thus much larger than the gender gap in entrepreneurship in general*.

Moreover, a study by the Global Entrepreneurship Monitor indicated that Europe has the lowest female involvement, only 6 %, in the early stages of entrepreneurial activities. Rossetti et al. (2018) also found a gender imbalance in the Startup Europe initiative, where 90 % of digital startups supported by the Startup Europe Initiative had a male founder. This figure was found to increase with the age and the development stage of the firms.

Figure 3.3-30 Evolution of the share of innovative startups with at least one female founder, 2000-2016



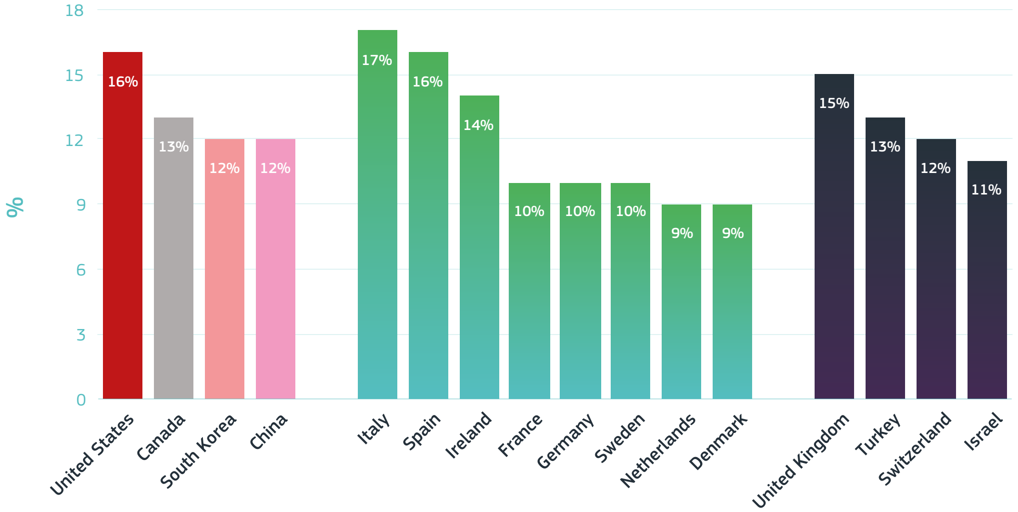
Source: Adapted from OECD estimates on Lassébie et al. (2019) and computed from Crunchbase data

Note: The sample is restricted to companies located in OECD, Colombia, and BRICS countries, founded between 2000 and 2017, and for which the gender of at least one founder can be identified.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter33/figure-33-30.xlsx

Figure 3.3-31 shows the **gender gap in startup creation across countries**. Taking into account the countries with available data, the share of innovative startups with at least one female founder is highest in the United States, Italy, Spain and the United Kingdom, and lowest in Ireland, France, Germany, Sweden, the Netherlands and Denmark.

Figure 3.3-31 Share of innovative startups founded between 2000 and 2017 with at least one female founder per country



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Source: OECD estimates based on Lassébie et al. (2019), computed from Crunchbase data

Note: The sample is restricted to companies located in OECD, Colombia, and BRICS countries, founded between 2000 and 2017, and for which the gender of at least one founder can be identified. Figures reported only for the top 20 countries in terms of number of startups.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter33/figure-33-31.xlsx

Female-founded unicorns are still rare, despite recent improvements. Figure 3.3-32 depicts the evolution of private unicorns with at least one female founder between 2013 and 2019 (until May) based on Crunchbase. It shows that the rate of new female-founded unicorns has increased at a greater speed in recent years although this remains a relatively rare phenomenon. In fact, in 2018, of the 127 new unicorns that joined the 'unicorn leaderboard'[11], only around 9% (12) had at least one female founder.

When considering the economic and social benefits of gender balance in economic activities, understanding the reasons for the gap in female-founded startups is an issue that deserves policymakers' attention. Verheul and Thurik (2006) showed that higher female engagement in entrepreneurial activities can improve the quality of entrepreneurship as it increases firms' creativity and ultimately their innovation activities. Moreover, it also offers the potential for greater diversity in consumer insights, leading to the introduction of new products and processes.

The economic and social benefits being clear, Lassebie et al. (2019) summarise some of the potential explanations for the gender gap in innovative entrepreneurship in the literature. Gender differences in STEM education may explain why male founders have been more present in STEM-related (and also more tech fields) than women (see Chapter 4.1 –

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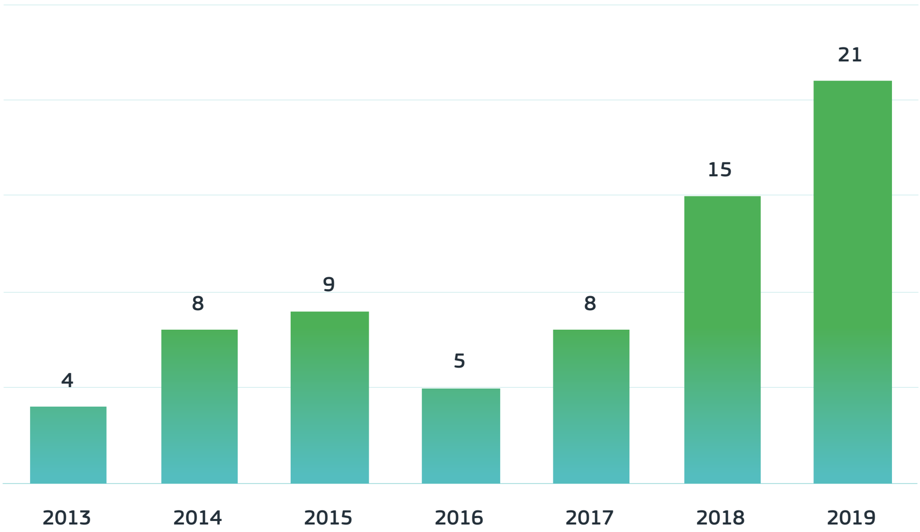
[11] According to CB Insights, accessed on 2 December 2019.

Figure 3.3-32 Number of unicorns[1] with at least one female founder, by year of first round of equity raised, 2013-2019



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Source: Crunchbase News - More Female-Founded Unicorns Were Born In 2019 Than Before, Data Shows, 18 December 2019

Note: [1]A private unicorn is a private company with a post-money (i.e. 'after funding') valuation of more than USD 1 billion.

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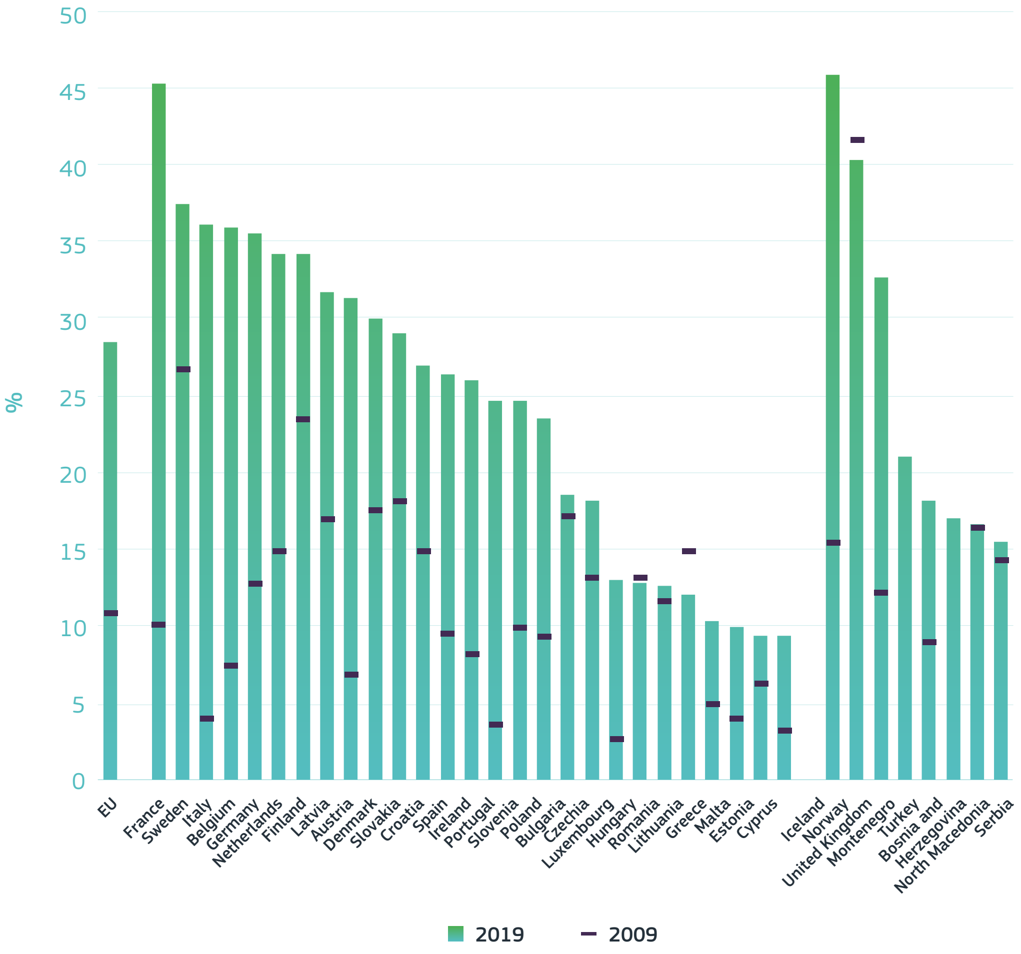
Innovation, the future of work and inequality). Furthermore, since venture capital tends to be more associated with STEM areas, this could also hint at the existing gender funding gap of innovative startups (see Chapter 8 - Framework conditions). Also, there may be factors of a sociological nature. For instance, some studies have documented differences in the personality traits ascribed to women and those attributed to the entrepreneur. This refers to, for instance, risk-taking behaviour and confidence in a negotiation. Increasing the number of female role models and mentors can raise the interest of women in the entrepreneurial path from an early age, and also balance out differences in aspirations.

A gender gap in management positions also remains in the EU and is even more evident at the top management level. However, there has been some progress over time, although substantial differences across the EU persist. According to the European Institute for Gender Equality (EIGE) and Eurostat, women accounted for 37 % of management positions in 2019, which compares with lower shares of 18 % for women as senior executives and 28.4% as board members in the largest publicly-listed companies. To note, however, that there has been progress over time. For instance, the share of women sitting on the board of the largest publicly listed companies in the EU has more than doubled in over a decade, from 10.9% in 2009 to 28.4% in 2019 (Figure 3.3-33). Nevertheless, progress at the EU aggregate level ´hides´ some differences across EU Member States. The share of women as board members is highest in France (45.2%), Sweden (37.5%) and Italy (36.1%), and lowest in Cyprus (9.4%), Estonia (9.4%) and Malta (10%).

Figure 3.3-33 Share of female board members in the largest publicly listed companies



Source: Eurostat (sdg_05_60), based on European Institute for Gender Equality (EIGE)

Note: The indicator measures the share of female board members in the largest publicly listed companies. Publicly listed means that the shares of the company are traded on the stock exchange. The largest companies are taken to be the members (max. 50) of the primary blue-chip index, which is an index maintained by the stock exchange and covers the largest companies by market capitalisation and/or market trades. Only companies which are registered in the country concerned are counted. Board members cover all members of the highest decision-making body in each company (i.e. chairperson, non-executive directors, senior executives and employee representatives, where present). The highest decision-making body is usually termed the supervisory board (in case of a two-tier governance system) or the board of directors (in a unitary system).

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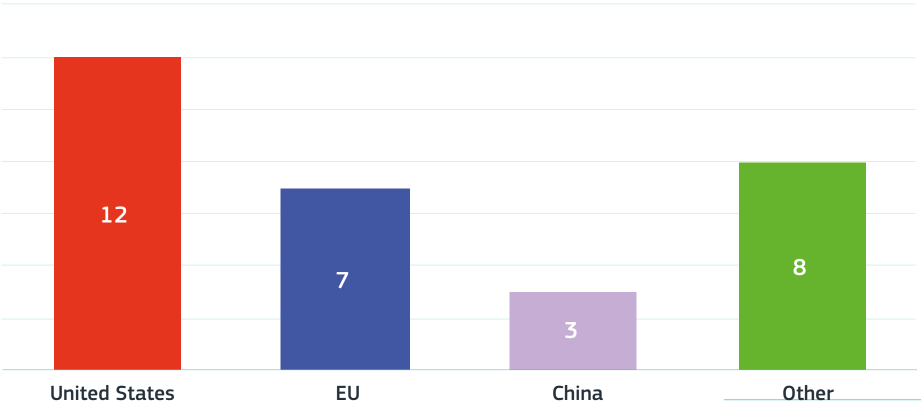
4. In the global technological race, Europe could benefit from developing its startup ecosystems further to reach a greater critical mass

The EU has seven ecosystems in the world top 30 startup ecosystems, compared to 12 in the United States and only three in China. Startup Genome (2019) uses data from over 1 million companies across 150 cities to rank startup ecosystems in terms of performance, funding, market reach, talent and startup experience[12]. Figure 3.3-34 shows that the United States leads in the number of quality startup ecosystems, with 12 in the top 30 world startup ecosystems. The EU comes next, with seven ecosystems, then China with three.

The EU's top ecosystems are Paris, Berlin, Stockholm, Amsterdam-StartupDelta, Barcelona, Dublin and Munich (Figure 3.3-35). Paris ranks high in terms of access to funding and quality, global connectedness, quality of the tech talent, and access to talent in life sciences. Berlin's relative strengths seem to be in global reach and in the quality of its tech talent. Stockholm also stands out for its global connectedness and quality of its talent. The quality of the tech talent and access to life sciences talent are key strengths found in Amsterdam-StartupDelta.

In the top 3 global startup ecosystems are two US ecosystems – Silicon Valley and New York – and London. As mentioned above, the high quality of these ecosystems across most dimensions assessed below justifies the move or relocation of unicorns originating in the EU to the United States and the United Kingdom for a greater market reach, access to funding and often to tech and life sciences talent.

Figure 3.3-34 Number of startup ecosystems in the top 30 by region, 2019



Science, research and innovation performance of the EU 2020

Source: STARTUP GENOME (2019), Global Startup Ecosystem Report 2019

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter33/figure-33-34.xlsx

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[12] Performance includes startup output, exits, valuations, early-stage success, growth-stage success, and overall ecosystem value. Funding concerns growth in early-stage investments and funding quality through the presence of experienced venture capital firms. Market reach is linked to global connectedness and global and local reach, based on the startups' proportion of foreign customers and the national GDP. Talent refers to the access, cost and quality of talent. Finally, startup experience refers to the team and ecosystem experience in terms of knowledge and networks available from which startups can develop.

Figure 3.3-35 2019 Global Startup Ecosystem Ranking, by category

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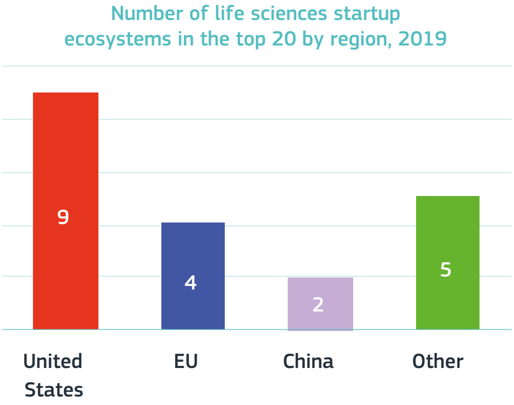
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter33/figure-33-35.xlsx

Four of the 20 most developed startup life sciences ecosystems can be found in the EU. The United States leads with nine ecosystems in the top 20. Figure 3.3-36 shows the ranking of the top life sciences ecosystems. The United States leads with nine ecosystems. The four EU ecosystems in the top 20 are Munich, Amsterdam-Startup Delta, Paris and Stockholm. China has only two ecosystems in the list.

Figure 3.3-36 Top 20 Life Sciences Ecosystems 2019, ranking and regional distribution

Ranking	Life sciences startup ecosystem
1	Silicon Valley
2	Boston
3	San Diego
4	New York City
5	London
6	Los Angeles
7	Lausanne-Bern-Geneva
8	Jerusalem-Tel Aviv
9	Shanghai
10	Washington DC
11	Beijing
12	Chicago
13	Seattle
14	Munich
15	Amsterdam-StartupDelta
16	Paris
17	Toronto-Waterloo
18	Stockholm
19	Singapore
20	Austin



Science, research and innovation performance of the EU 2020

Source: STARTUP GENOME (2019), Global Startup Ecosystem Report 2019
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter33/figure-33-36.xlsx

Even though the EU trails behind the United States in some aspects related to the quality of startup ecosystems, the EU is a leader in terms of fast-growing ecosystems across different maturity phases. Figure 3.3-37 depicts the top high-growth ecosystems in the world by phase of the ecosystem life cycle, namely activation, globalisation and attraction[13]. The EU leads with one fast-growing ecosystem – Western Denmark – in the activation phase, three in the globalisation phase – Paris, Antwerp and Copenhagen – and two in the attraction phase – Amsterdam-StartupDelta and Stockholm. The six EU high-growth ecosystems compare with none in the United States and three in Asia.

Figure 3.3-37 Fastest-growing ecosystems(1) by maturity phase of the ecosystem life cycle(2)

	Fastest-growing ecosystems by phase
Activation	1 Western Denmark
	2 Belgrade and Novi Sad
	3 Taipei City
	4 Atlantic Canada
	5 Manila
Globalisation	1 Paris
	2 Montreal
	3 Antwerp
	4 Sydney
	5 Copenhagen
Attraction	1 Amsterdam-StartupDelta
	2 Bangalore
	3 Stockholm

Science, research and innovation performance of the EU 2020

Source: STARTUP GENOME (2019), Global Startup Ecosystem Report 2019

Notes: (1)Based on growth in funding, exits and number of startups. (2)The Global Startup Ecosystem report defines four main phases in the life cycle of a startup ecosystem: activation, globalisation, attraction, integration.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter33/figure-33-37.xlsx

The top 'ecosystems to watch' in the EU are notably present in fintech, cleantech, agritech and advanced manufacturing and robotics. The EU lags behind in blockchain and artificial intelligence. Figure 3.3-38 displays the top 'ecosystems to watch' by technology field, according to Startup Genome. The EU stands out in fintech with seven ecosystems to watch – Berlin, Copenhagen, Estonia, Frankfurt, Lithuania,

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[13] According to Startup Genome, the activation phase is characterised by limited startup experience, low startup output of around 1 000 or fewer startups. The globalisation phase means that increased startup experience led to the production of a series of regionally impressive 'triggers', usually over USD 100 million, and with an output of 800 to 1 200 startups. Finally, in the attraction phase, there are usually more than 2 000 startups (depending on population), a series of globally impressive triggers that could be unicorns, and exits above USD 1 billion which generate global resource attraction. At this stage, very few success factor gaps remain.

Madrid and Paris. This compares with only three in the United States. As regards cleantech, the Amsterdam-StartupDelta and Stockholm stand out. In agritech and new food, the Amsterdam-StartupDelta also stands out, as does the Mid-East region of Ireland. Furthermore, three EU ecosystems – Paris, Rhineland and Western Denmark – emerge in the field of advanced manufacturing and robotics.

However, where the EU seems to lag behind is in the fields of blockchain and artificial intelligence (see Chapter 7 - R&I enabling artificial intelligence). In the case of AI, only Berlin and Greater Helsinki are mentioned.

Figure 3.3-38 Top 'ecosystems to watch'(1) in selected technology fields, by region

Technology field	Region	'Ecosystems to watch'
Fintech	**European Union**	Berlin
		Copenhagen
		Estonia
		Frankfurt
		Lithuania
		Madrid
		Paris
	United States	Chicago
		New York City
		Silicon Valley
	Other	São Paulo
		Bahrain
		Tel Aviv
		London
		Nur-Sultan
		Bengaluru
		Beijing
		Jakarta
		Manila
		Singapore
		Sydney
		Tokyo
Cleantech	**European Union**	Amsterdam-StartupDelta
		Stockholm
	United States	Houston
		New York City
		Silicon Valley
		Austin
	Canada	Calgary
		Vancouver

Technology field	Region	'Ecosystems to watch'
Agritech & new food	**European Union**	Amsterdam-StartupDelta
		Mid-East Region, Ireland
	United States	Denver-Boulder
		New York City
		Silicon Valley
	Other	London
		New Zealand
Advanced manufacturing & robotics	**European Union**	Paris
		Rhineland
		Western Denmark
	United States	Boston
		New York City
		San Bernardino County
		Silicon Valley
	Other	Montreal
		Tel Aviv
		Shenzen
		Taipei City
		Tokyo
Blockchain	**United States**	Silicon Valley
		New York City
	Canada	Toronto-Waterloo
		Vancouver
	Other	London
		Belgrade and Novi Sad
		Singapore
Artificial Intelligence	**European Union**	Greater Helsinki
		Berlin
	United States	Silicon Valley
		Boston
		Chicago
		Houston
		New York City
		Seattle
	Other	Edmonton
		Montreal
		Québec City
		London
		Tel Aviv
		Jerusalem
		Beijing
		Taipei City

Source: STARTUP GENOME (2019), Global Startup Ecosystem Report 2019

Note: (1)According to STARTUP GENOME criteria based on startup output, exits, and funding.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter33/figure-33-38.xlsx

5. Presence of zombie firms is still problematic in some Member States, while others have undertaken a de-leveraging process

Rigidities in the market limiting their well-functioning may lead to capital and resources locked in so-called 'zombie firms'. This means that these resources could have improved economic performance had they been redirected towards higher-productivity firms. Overall, the shares of zombie firms have increased in the aftermath of the crisis and while there has been progress in some countries in recent years via, for example, a more effective deleveraging process, in others zombie firms continue to rise, especially in the services sector. Zombie firms are companies that survive in the market without being profitable in the long run because of external support that 'keeps them artificially alive' (European Commission, 2018). The consequence is the use of resources by non-productive firms that might otherwise have been used by more-productive companies, ultimately leading to productivity growth.

Figure 3.3-39 shows the **evolution of the average shares of zombie firms during three different periods, both in manufacturing and services**[14]. Right in the aftermath of the crisis (i.e. 2008-2010) the shares of zombies in the manufacturing sector were highest in Portugal, Italy and Spain, and zombie firms were mostly prevalent in the services sector in Portugal, Sweden and Spain. Looking at their evolution over time, overall shares have continued to rise, particularly in the services sector; exceptions include Portugal, for example. Even though the incidence of zombie firms is typically higher in manufacturing, the gap with services is limited apart from Finland.

The EU Member States with the highest incidence of zombie firms in the period 2011-2013, namely Spain, Italy and Portugal, have more recently experienced a decline in their share across sectors, the largest drop being reported by Portugal. This phenomenon was accompanied by an increase in the firms' profitability as well as the de-leveraging of zombie firms[15]. Since 2013, the weight of zombie firms has been on the decline in Spain, Italy and Portugal, for all the sectors covered by Figure 3.3-39. These EU Member States had the highest shares in 2008-2010.

Zombie firms were found mainly in the construction – real estate sector but were less common in the information and communication sector. Portugal, in particular, saw the largest drop in zombie firms after 2013.

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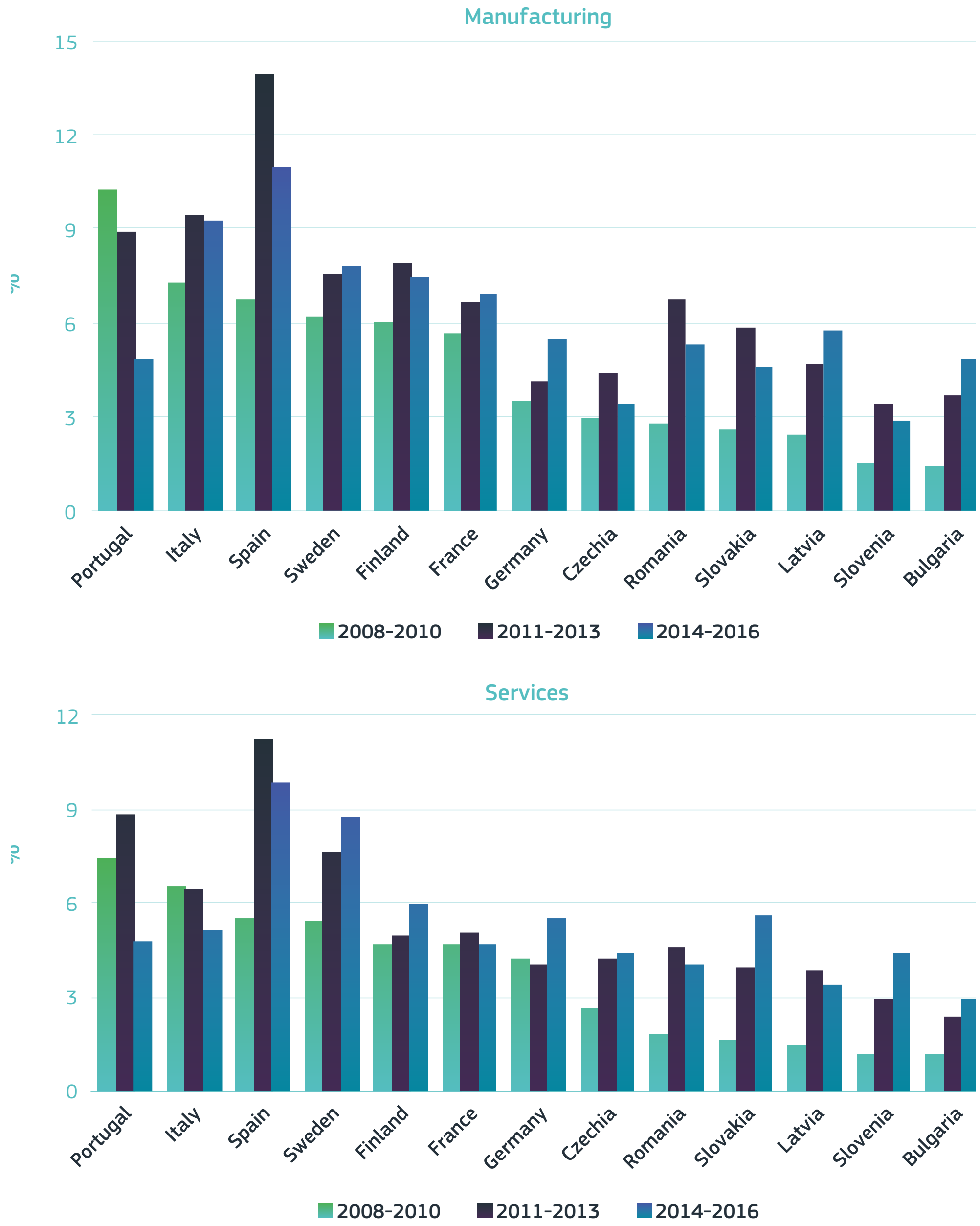
[14] See Bauer et al. (2020).

[15] Source: Hallak et al. (2018).

Figure 3.3-39 Evolution over time of the share of zombie firms[1] in total firms in the manufacturing and services sectors[2], 2008-2016



Source: JRC estimations based on Orbis data

Notes: [1]A zombie firm is a firm that is at least 10 years old and has an interest coverage ratio below 1. This latter term suggests that the firm does not make enough profit to pay debt obligations on bank loans. This is the OECD definition. [2]The figure reports the time variation of the share of zombies in each country in our sample. We report three-year averages in manufacturing and services in the periods: 2008-2010 (left), 2011-2013 (middle), 2014-2016 (right). Countries are sorted by the zombie shares in the figure according to the last period 2014-2016.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter33/figure-33-39.xlsx

Figure 3.3-40 Evolution over time of the share of zombie firms[1] in Spain, Italy and Portugal[2] by sector, 2008-2016

Source: JRC estimations based on Orbis data

Notes: [1]A zombie firm is a firm that is at least 10 years old and has an interest coverage ratio below 1. This latter term suggests that the firm does not make enough profit to pay debt obligations on bank loans. This is the OECD definition. [2]The figure reports the yearly share of zombies in Spain, Italy, and Portugal in the period 2008-2016, in six broad sectors. Italy, Spain and Portugal report the top three zombie shares in the sample in the period 2011-2013.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter33/figure-33-40.xlsx

6. A ‘tech-for-good’ approach to match the urgent challenges of our time

Technological progress is behind many scientific and technological breakthroughs that have, for instance, significantly increased life expectancy worldwide from just 34 years in 1913 to 60 in 1973 and 71 in 2019. Incomes have risen and technology has also ‘freed’ workers from certain routine and/or dangerous tasks, thereby providing more leisure time[16]. But living longer also means that there is a greater concern about living healthier lives and improved well-being. Economic growth has also benefitted strongly from technologies that have boosted resource efficiency and productivity across all sectors (see Chapter 3.1 - Productivity puzzle and innovation diffusion).

While innovation has resulted in greater choice from the growth in products and services, there is an ongoing debate as to whether all innovation has created value (and proven its relevance) for society. Kalff and Renda (2020) revised academic literature on the role of innovation and noted that ‘not all innovation is equally relevant for society’, arguing that entrepreneurship and innovation should be the means to address the most pressing challenges of our time (see Chapter 1 - Megatrends and sustainability).

Moreover, tech with a social purpose can also drive profit as consumers are now demanding a shift in the mission of businesses towards social good[17]. As highlighted in Chapter 2 - Changing innovation dynamics in the age of digital transformation, consumers increasingly want social impact to be integrated into companies’ missions so as to achieve ‘economic value that is inclusive and sustainable’[18]. Putting the emphasis on responsible and ethical tech does not mean that products and services will not be scalable. On the contrary, it provides a business model in which consumers will have more trust. As a result, it also creates new opportunities for profit that can maximise social value, too.

Activating a global mindset which directs innovation activities towards solutions that effectively address societal challenges is challenging but certainly necessary and collectively achievable. The World Economic Forum (2020) refers to a set of enablers which include: responsible technology governance, leadership to mobilise commitment and standards, partnerships for collaboration and collective action, public policy and regulation for the Fourth Industrial Revolution, finance mechanisms to stimulate market solutions, breakthrough innovation, including collaborative R&D agendas, managing data and tools, and capacity development and skills. The EU is well-positioned to lead in this ‘tech-with-a-purpose’ approach thanks to its new growth strategy – the EU Green Deal – the prominence of the partnership approach in its Framework Programmes, the support of market-creating innovation with the European Innovation Council (EIC), etc.

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[16] https://www.mckinsey.com/featured-insights/future-of-work/tech-for-good-using-technology-to-smooth-disruption-and-improve-well-being

[17] https://technation.io/insights/tech-for-social-good/

[18] https://www.weforum.org/agenda/2020/01/davos-2020-heres-what-you-need-to-know-about-tech-for-good/

7. Conclusions

Business dynamism plays an important role in promoting creative destruction in the economy, which may ultimately raise productivity growth. For this reason, **the decline of business dynamism (notably in terms of entry rates) in Europe and other parts of the globe may hamper current and future productivity growth**, although the reasons for such a decline can be multiple. Moreover, **most jobs created by new firms emerged in less-productive sectors of the economy and hence were, in principle, lower-paid jobs**. However, in some countries there has been progress towards new job creation in more-productive sectors.

Europe´s scaling-up performance needs to be revamped. While the share of high-growth enterprises has increased over time in most EU Member States, there is only a small share in high-tech, medium-high-tech manufacturing and high-tech knowledge-intensive services, although this has increased in recent years. Furthermore, our analysis shows that **when it comes to tech scaleups and unicorn companies, a pronounced scaling-up gap remains when compared to the United States and (sometimes) China**. In particular, 1.3 scaleups per 100 000 inhabitants in the EU compares with 7 scaleups in the United States. Moreover, for each private unicorn in the EU, there are seven in the United States and four in China. In other words, the EU only accounts for around 7 % of all private unicorns worldwide. The EIC in Horizon 2020 and Horizon Europe, the VentureEU programme, and the different financial instruments available via the European Investment Bank aim to tackle the scaling-up needs in terms of capital among EU startups. Europe should capitalise on its strong science and richness of ideas for innovation to play a role on the global scene **reflecting the EU's values and ambitions to lead in the fight against climate change, healthy societies, and in the digital age**, to name but a few. Indeed, **a tech-with-a-purpose approach could integrate social and environmental concerns in businesses' missions to ensure that new products and services bring** both economic and societal value.

The **New Industrial Strategy for Europe**[19] stresses that 'relevant players should work together to create lead markets in clean technologies and ensure our industry is a global frontrunner'. This includes regulation, public procurement, rules for fair competition and involving SMEs, too. In addition, the Strategy also encourages place-based innovation and experimentation so that regions can develop and test new solutions with the involvement of both SMEs and consumers, capitalising on their local strengths and specificities.

Our research also identifies a group of 'EU DNA' unicorns that have started or moved their operations to the United States and the United Kingdom because of the greater availability of capital, the intense network, market size and other benefits. However, EU DNA unicorns tend to keep strong connections 'back home'. Although this could be seen as a normal consequence of globalisation and the new phenomenon of 'dual companies', at the same time it reflects the lower availability of risk capital in the EU and barriers to scaling up related to the yet to be fully completed Single Market. In addition, in the digital age, digital infrastructure, notably 5G, will also be a determinant in shaping innovation and its speed in the future. Research and other physical infrastructure also play an important role.

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[19] https://ec.europa.eu/commission/presscorner/detail/en/ip_20_416

Although there are resilient, high-quality and interconnected ecosystems in the EU, the United States still appears to lead globally. The EU has fewer startup ecosystems in the top world ecosystems, including in the life sciences. However, Europe appears to score well in fintech, cleantech, agritech and advanced manufacturing and robotics. By incentivising science-business collaboration, creating and attracting talent, pooling public and private resources, promoting strategic public-private partnerships, etc. the EU can reach greater critical mass and lead the way.

There is substantial cross-country variation in entrepreneurial attitudes in the EU. This calls for a culture of more tolerance towards startup failure, widespread entrepreneurship education, and improving the business environment in aspects including the ease of starting a business, availability of capital, innovation-friendly regulations, etc. The European Institute of Technology and the different Knowledge and Innovation Communities have also played an important role in this respect.

A pronounced startup gender gap remains in the creation of innovative enterprises worldwide, including in Europe. The share of female (co)-founders is still low, despite some progress over time. This calls for policies promoting the wider involvement of women in entrepreneurial activities, starting at an early age at school, the promotion of 'female role-models', a better work-life balance, greater female participation in STEM activities, and tackling the documented gender bias in the attribution of private funding, among other aspects.

Zombie firms remain prevalent in some Member States, especially in services. Although there has been a delivering process in some countries since the crisis, in others the presence of zombies has been aggravated. This requires careful consideration of the economic and financial conditions in each country.

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CHAPTER
4.1

INNOVATION, THE FUTURE OF WORK AND INEQUALITY

KEY FIGURES

11.1 % adult participation in learning	**73 %** of platform workers are men
1 in 5 jobs created in 2017 were part-time	**133 million** new work roles may emerge worldwide until 2022

What can we learn?

- Digitalisation, automation, and robotisation risk creating **job displacement and further shrinking the labour share of income**, which could have consequences for inequality, particularly income inequality and inequality in opportunities.

- **Changing skills demand may lead to high job polarisation** in the labour market and is hollowing out the middle-skilled jobs.

- Even if technologies and business models may produce a sufficient number of new jobs to keep unemployment low, **they may contribute to a decline in overall job quality and employment standards**.

- While there is a lack of evidence on **massive disruption across sectors**, technological transformation will not be friction free and individuals or whole sectors need to **capitalise on the benefits** of new technologies in the workplace.

- The emergence of digital technologies **does not help to close the gender gap**, as observed by the lower participation of women in ICT-related fields and platform work.

What does it mean for policy?

- With very limited growth in the share of adults participating in education and training, it is important to increase **adult participation in learning**, in particular for those in most need of access to learning.

- Improved **skills intelligence, labour-market relevant skills provision, transparency and recognition** of all types of skills remain a challenge. Increased synergies among programmes such as Horizon Europe, the European Social Fund (ESF) and Erasmus+ could address these challenges at different stages. Furthermore, policymakers need better **intelligence to act** (shorter forecasts, scenario planning and simulations in forecasting models) and **policy design that allows for a quick response**.

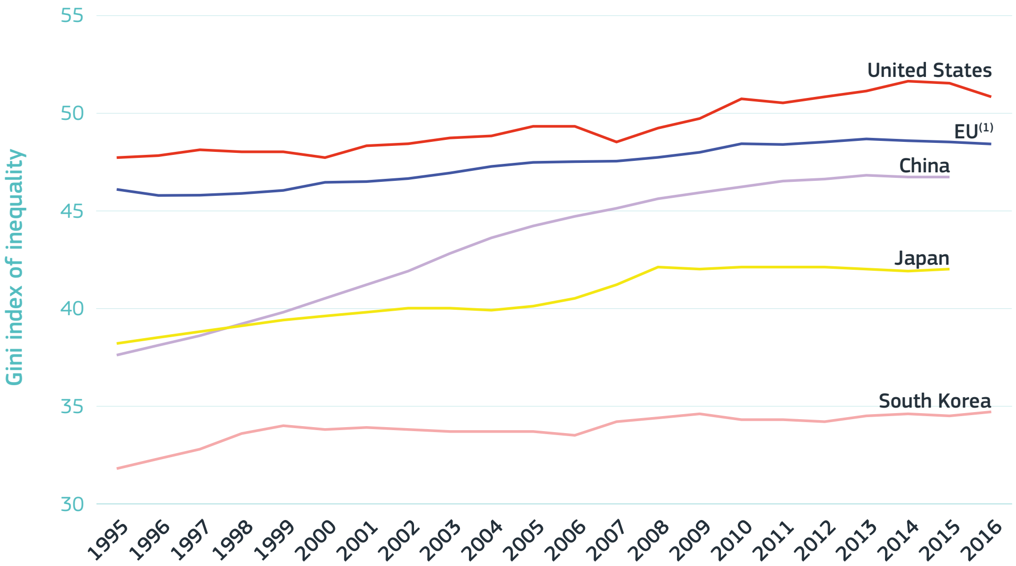
- Uptake of new technologies and industries has not helped reduce gender gaps; policies to **support the participation of women in specialised ICT-related positions** should be maintained and where possible reinforced to make further progress.

1. Rise in inequality and its perception related to technological developments

Inequality has been growing in most advanced economies in recent years, as indicated by the Gini coefficient of market income inequality (Figure 4.1-1). The index shows that inequality in market income has grown with the EU currently facing similar levels of market income inequality as in the United States. Nevertheless, Europe remains a more equal place to live compared to other countries because the national tax and welfare systems reduce the relatively high market income inequality. Although a substantial mitigation of a general rise in income inequality can be observed in Europe, there are certain age groups or places of residence that face increased income inequality (OECD, 2019). Furthermore, phenomena such as youth unemployment and inequality of opportunity can have long-lasting effects on young people in many European regions.

While fiscal policy has a direct impact on disposable income (i.e. after taxes and social benefits), **other policies enhancing productivity and real wages, or upgrading skills and providing equal opportunities can be equally important. Technological change ranks among the most important factors**[1] **affecting income distribution** as an increase in the demand for high-skilled employees leads to increases in their wage premiums and amplifies wage dispersion (EC, 2017).

Figure 4.1-1 Gini index of inequality - household market income (pre-tax, pre-transfer), 1995-2016



Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on Eurostat data

Note: (1)EU is the weighted average of the values for the EU Member States.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter41/figure-41-1.xlsx

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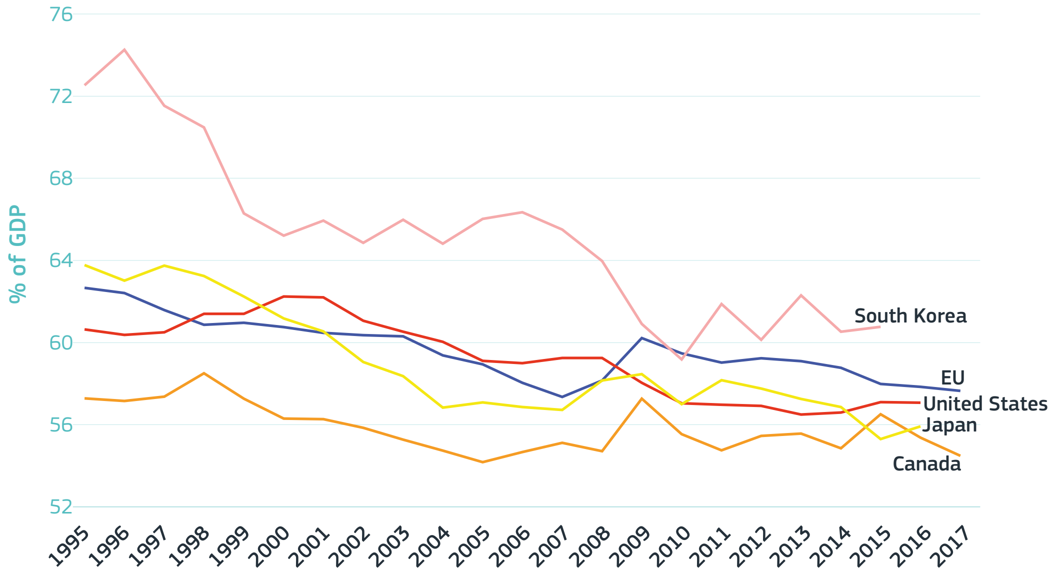
[1] Globalisation, demographic developments and household composition rank among other factors.

This growing inequality is closely related to technological change that has affected the distribution of production factors towards higher shares of capital and technology (Figure 4.1-2). With the increasing ability of machines – potentially reinforced with contributions from artificial intelligence – to automate a greater number of job tasks performed by humans, the distributional implications increase inequality. As automation increases productivity and decreases the cost of production, it can lead to deeper automation – i.e. further improvements to existing machinery in tasks that have already been automated.

Although both effects further increase demand for labour, automation contributes to a higher increase in outputs per worker than their wages and therefore the labour share in national income could shrink. This would mean that the rise in real incomes[2] resulting from automation is skewed towards a narrow segment of the population with much lower marginal propensity to consume than those losing incomes and possibly their jobs (Acemoglu and Restrepo, 2018). Such a technologically accelerated substitution of labour with capital could introduce productivity gains while also reducing the labour share of income and contributing to future inequalities affecting mostly lower-skilled workers. Companies are

Figure 4.1-2 **Evolution of labour income(1) share (as % of GDP), 1995-2017**



Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on Eurostat, OECD and DG Economic and Financial Affairs (AMECO database)

Note: (1)Labour income is calculated by multiplying compensation of employees by hours worked by all those employed (total employment domestic concept) and divided by the hours worked by employees.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter41/figure-41-2.xlsx

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[2] Evolution of the labour income share in the EU28 reveals a declining trend from 72 % in 1995 to around 60 % in 2015.

increasingly relying on a variety of intangible assets such as, for example, goodwill or patents, and it is increasingly the low-skilled workers who suffer the negative consequences brought about by technological change and new types of capital assets. A closer look at the intangibles within the distribution of income is crucial to understand the decline in labour shares over past decades.

More unequal distributions of income and wealth have increased attention to tax shifts towards capital. As there is a gap between capital income and labour income taxation, higher labour taxation could dampen employment levels and contribute to higher capital accumulation. Therefore, the suggestion is that shifting taxes away from labour towards capital could increase the labour share and lead to stronger overall productivity growth (JRC, 2019a). Important policy questions relate to how and where to tax capital income and what might be the broader economic effects of such taxation (Mathé et. al., 2015).

2. Broad technological uptake would have repercussions for the quantity and quality of jobs

While employment rates are at record high numbers since the crisis in many European countries and in the United States[3], polarisation has appeared in the job market with a significant shrinking of medium-skilled routine jobs and an increase in high- and low-skilled jobs. With almost 236 million people in employment in 2017, EU employment is at an all-time high and means an increase of 19.5 million since 2002 (EC, 2018). This is mainly due to a strong increase in female employment as well as a higher employment rate among older workers. As labour market conditions have continued to improve, many countries have reached values above their pre-crisis level (Figure 4.1-3). The same applies to unemployment rates which have continued to fall across the EU. In April 2019, the unemployment rate had dropped to 6.8 % in the EU, which is the lowest level since 2008[4].

Available evidence concerning the impact of new technological development on the labour market is inconclusive[5]. A high level of uncertainty accompanies different estimates, as they are highly sensitive to the choice of data sources and the methods used to categorise tasks. Implications for the net displacement of jobs will depend on the new models of work organisation and management of workplaces, including platform work and new unconventional working arrangements. Figure 4.1-4 shows various assessments of automatable job shares, but also more balanced employment effects when job-creation effects are included (Wolter et al. 2015; Arntz et al. 2018).

While estimates identified a broad range of job shares with routine tasks, it seems that automation and digitalisation are less likely to destroy large numbers of jobs in the short term. A greater

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[3] Employment rate (age range 15-64) in OECD countries rose from 66 % in 2010 to 69.5 % in 2017; in the EU from 64.1 % to 67.7 % and the United States from 66.7 % to 70.1 %.

[4] EU (from 2019) value; Eurostat. Unemployment – monthly average.

[5] See European Commission (2018) Chapter 2, World Bank (2016), Frey and Osborne (2013; 2017), Nedelkoska and Quintini (2018).

Figure 4.1-3 Labour force participation rate, 15-64 year-olds, as % in same age group, 2006 and 2018

Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on Eurostat (online data code: lfsi_emp_a) and OECD data

Note: Employment by activity - total active population as percentage of total population. The economically active population is the sum of employed and unemployed people. Inactive people are those who, during the reference week, were neither employed nor unemployed. [(1)]EU estimated by DG Research and Innovation.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter41/figure-41-3.xlsx

degree of automation and data exchange in manufacturing technologies will inevitably affect firms' strategic approaches and organisational models in their production and innovation systems. Low-qualified and low-skilled workers are likely to bear the burden of the adjustment costs as trends in the labour market seem to work against them. Therefore, the likely challenge for the future lies in coping with rising inequality and ensuring sufficient training, especially for low-qualified workers. To understand the magnitude of the challenge, various attempts have been made to assess the share of automatable jobs (Figure 4.1-4). A full understanding of broader impacts and reskilling needs demands factoring in issues such as adjustments in learning systems, individual motivation, and financing schemes, which represent additional layers of complexity.

While many of the current jobs will become obsolete through technology, many others will change the set of performed tasks and new jobs will be created. The changing task content of occupations introduced by technological innovations ranges from generally reducing the importance of physical tasks to higher safety standards and better-quality jobs (see Box 4.1-1).

Figure 4.1-4 Share of highly automatable jobs and net effects on employment

Source	Share of automatable jobs	Time horizon	Remarks
Frey and Osborne (2013)	47 %	10–20 years	USA, all sectors
Bowles (2014)	47 % to 60 %	10–20 years	EU Member States, following the approach of Frey and Osborne (2013)
Bonin et al. (2015)	12 %		DE, all sectors
Arntz et al. (2016)	9 %		21 OECD countries, following the approach of Bonin et al. 2015
World Bank (2016)	50 % to 60 %	coming decades	USA and Europe, real effects moderated by lower wages and slower technology adoption
Nedelkoska and Quintini (2018)	14 %	10–20 years	32 developed, mostly OECD countries, following the approach of Arntz et al. (2016)
Source	**Automatable jobs and job creation**	**Time horizon**	**Remarks**
Wolter et al. (2015)	- 1 %	25 years	DE, manufacturing, incl. economy-wide compensation effects
Arntz et al. (2018)	+1.8 %	5 years	DE, incl. job-creation effects, baseline

Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation

Note: See the references for full citations. Conclusions simplifed for presentation purposes.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter41/figure-41-4.xlsx

BOX 4.1-1 Current jobs with new tasks

Innovations in **production techno-logies and work organisation** reduce **workplace risks** and increase the **overall quality of jobs**. In recent decades, automation technologies have helped to significantly improve health and safety across industries. The quality of jobs can be broadly understood as a measure of the richness of work and creative human activity. It is improved by more intellectual tasks which increase the variety and stimulation. a shift to more work in teams along assembly lines helps to boost social interaction in the workplace (Eurofound, 2019).

New jobs are not centred on the automation process with humans plainly assisting machines or algorithms in the production process. Although many new occupations will be enabled through technology, they will not be technology- or machine-specific. New jobs will respond to human needs and societal challenges, such as global warming or food production[6]. The downside of this is that educators are often tasked with tackling the problems of preparing people during education for jobs that do not yet exist, eventually using technologies that have not yet been invented and solving problems that we have yet to define clearly (Penaluna and Rae, 2018). Any forecasts about the number of newly created jobs or predictions on the net destruction of jobs must be taken with caution (Chapter 11 - The consequences of AI-based technologies for jobs). Replacing labour with technology is accompanied by countervailing mechanisms that are difficult to quantify. Dedicated studies, such as that by Bruegel on the impact of industrial robots on employment conclude with displacement effects, particularly significant for medium-skilled workers, for example[7]. A later study by Autor and Salomons (2018) shows that although automation leads to job displacement in industries, it facilitates indirect employment gains in customer industries and contributes increasing aggregate demand, ultimately leading to net employment growth. Given the human imagination and ingenuity, other estimations are oriented towards more qualitative approaches categorising new roles and jobs according to their technological proximity, time horizon or emerging sectors of the economy (Figure 4.1-5).

The effects of an increasingly digital economy, including many jobs created through the platform economy and new unconventional working arrangements, start to emerge for a growing number of workers. Permanent full-time employment constitutes the largest share of employment by far, although a growing incidence of less standard forms of employment may bring structural change. Contractual stability and employment quality still greatly depend on industrial relations and coverage by collective agreements. The evidence shows that one in ten adults have some experience of supplying goods or services on internet platforms (Figure 4.1-6). The majority of platform workers provide professional services (such as software development, translation services, or writing) which demand high skill levels (Gonzalez Vazquez et al., 2019).

New technologies could provide workers with greater job satisfaction, but they can also demand more flexibility, creating new jobs that are less stable. New ways of working emerge on digital platforms and in the collaborative economy, with more part-time and freelance work and self-employment. The new features, such as higher degree of flexibility, a better work-life balance, and supplementary income inevitably bring the traditional employer-employee relationship into question. Online platforms acting as intermediaries between service users and providers revoke the temporary work agency model. Service providers working for the platforms are considered self-employed by the platform, even though the relationship between them often has features of an employment relationship based largely on subordination[8].

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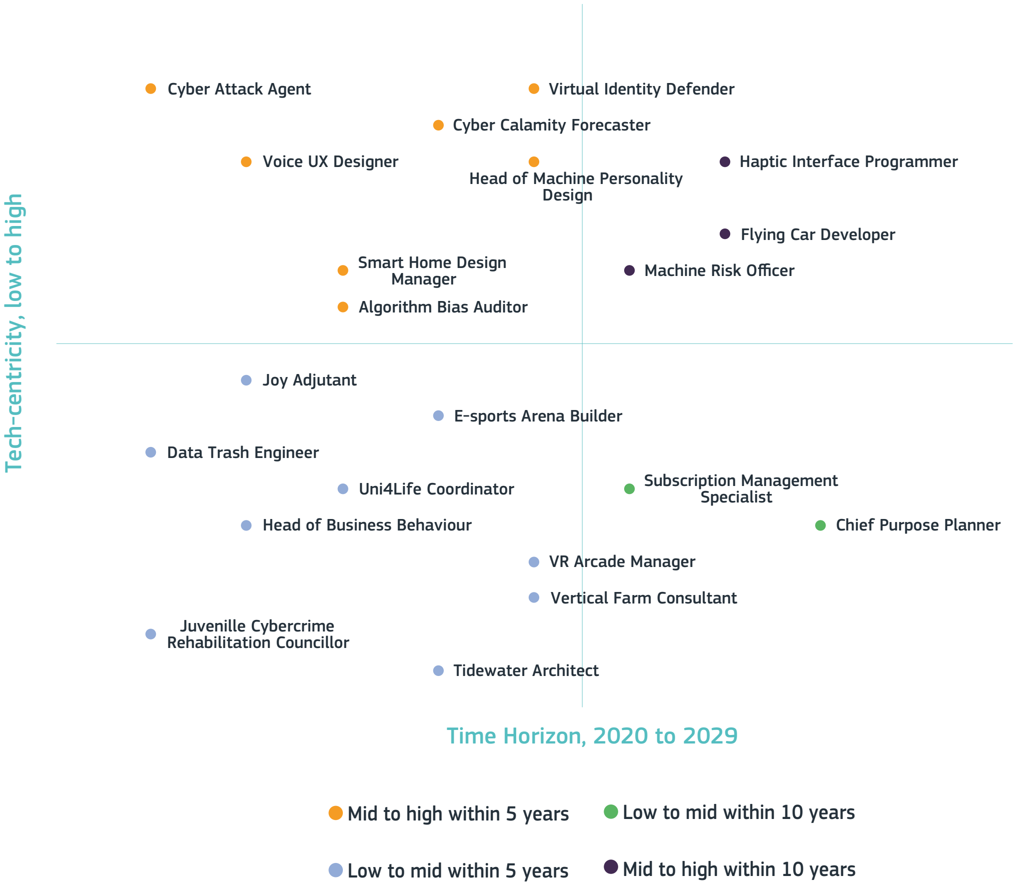
[6] Experts list jobs such as 'vertical farm consultant' or 'tidewater architect'; Cognizant (2018). 42 Jobs: The Road to 2028-2029.

[7] The study examined the impact of industrial robots on employment and wages in six EU countries that account for 85.5 % of the EU market for industrial robots. The assessment was that one additional robot per thousand workers would reduce the employment rate by 0.16-0.20 percentage points. The study also found a particularly strong displacement effect for medium-skilled workers and for young cohorts. Chiacchio, F., Petropoulos, G. and Pichler, D. (2018), The Impact of Industrial Robots on EU Employment and Wages: a Local Labour Market Approach, Bruegel Working Papers, Issue 2.

[8] More details in the Commission report 'The Future of Work? Work of the Future!', a report by Michel Servoz.

Figure 4.1-5 Jobs of the future along expected time horizon and tech-centricity



Science, research and innovation performance of the EU 2020

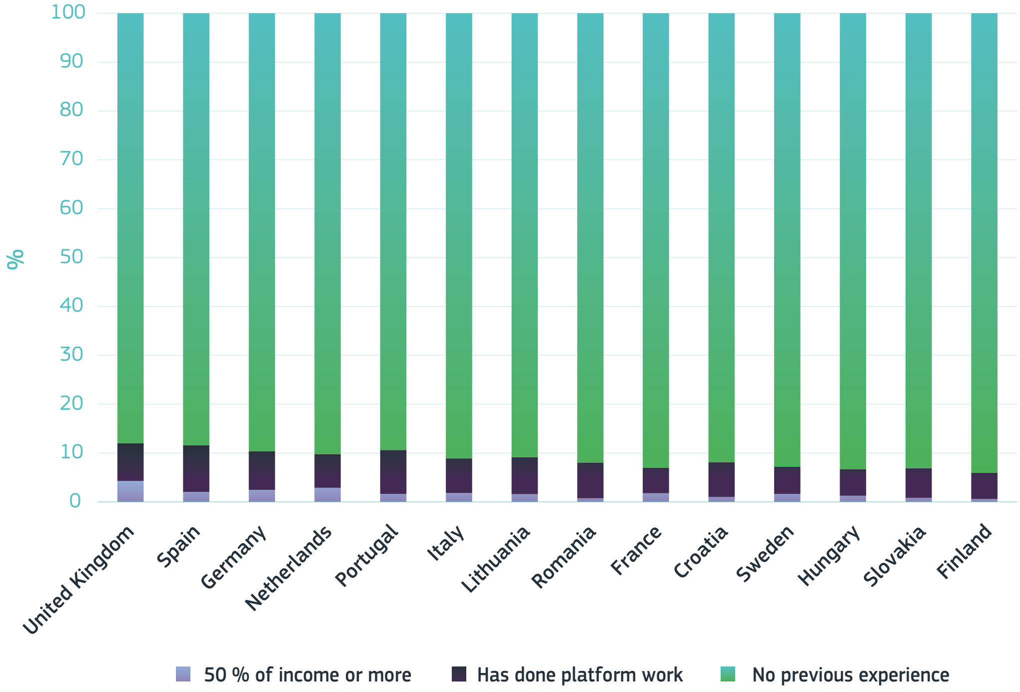
Source: Cognizant forecast based on the report 21 More Jobs of the Future (2018)

Note: Cognizant presented 21 jobs of the future in the order they expect them to appear. A more detailed description of each job is available in the report.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter41/figure-41-5.xlsx

While embracing the benefits of flexibility enabled by technologies, the future employee-employer relationship will have to deal with challenges such as rules on working time, equal access to training, and other benefits. Due to the slowly evolving nature of these challenges and a lack of robust evidence sometimes, many national governments are responding via policy experimentation. The Dutch government proposed to regulate self-employment with a minimum hourly rate for self-employed people, while French independent workers enjoy full rights to set up or participate in trade unions (JRC, 2019a; SZW, 2019).

Figure 4.1-6 Adult population involved in platform work (%), 2017



Science, research and innovation performance of the EU 2020

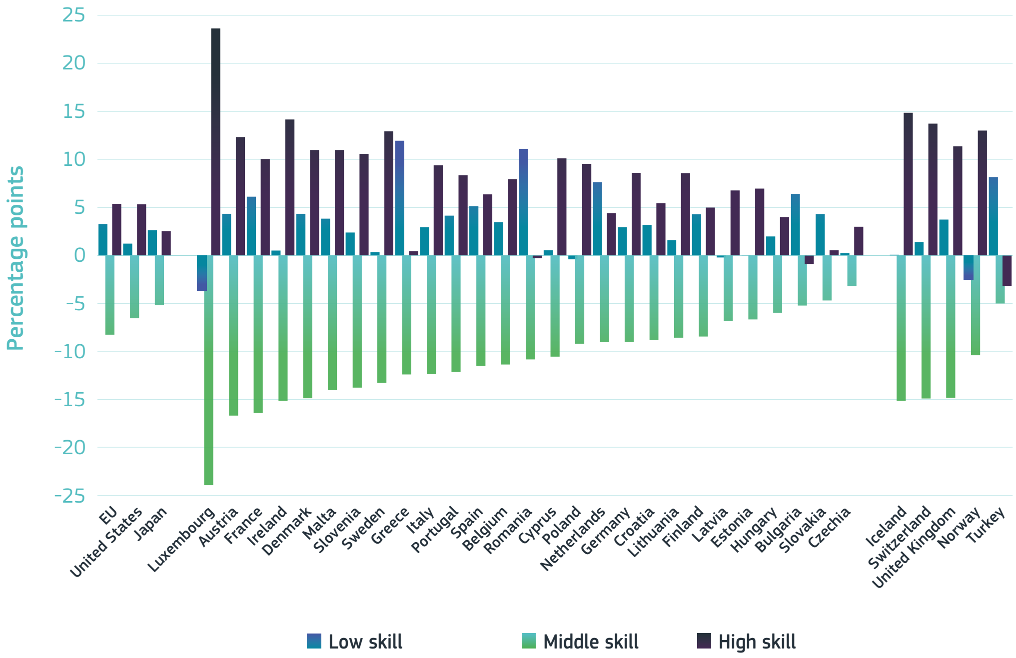
Source: European Commision, DG Employment, Social Affairs & Inclusion calculations based on COLLEEM survey 2017

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter41/figure-41-6.xlsx

3. Changes in the labour market require new skills

Although we observe only mild symptoms of unemployment, further progress in ground-breaking digital transformation that has brought more efficient production and business processes can have a disruptive impact on workers. In particular, the rise of automation and digital technologies is already affecting labour markets, with **high rates of job polarisation and a hollowing of medium-routine tasks jobs**. This trend is expected to accelerate as digital technologies become more pervasive. At the same time, the quality of jobs done by the least skilled is likely to decline, as is their income share. This trend appears less pronounced in many of the new Member States where labour costs are relatively low and the incentives for automation are supposedly lower (OECD, 2017).

Figure 4.1-7 Percentage point change among shares of occupational groups[1], 1995-2018[2]



Science, research and innovation performance of the EU 2020

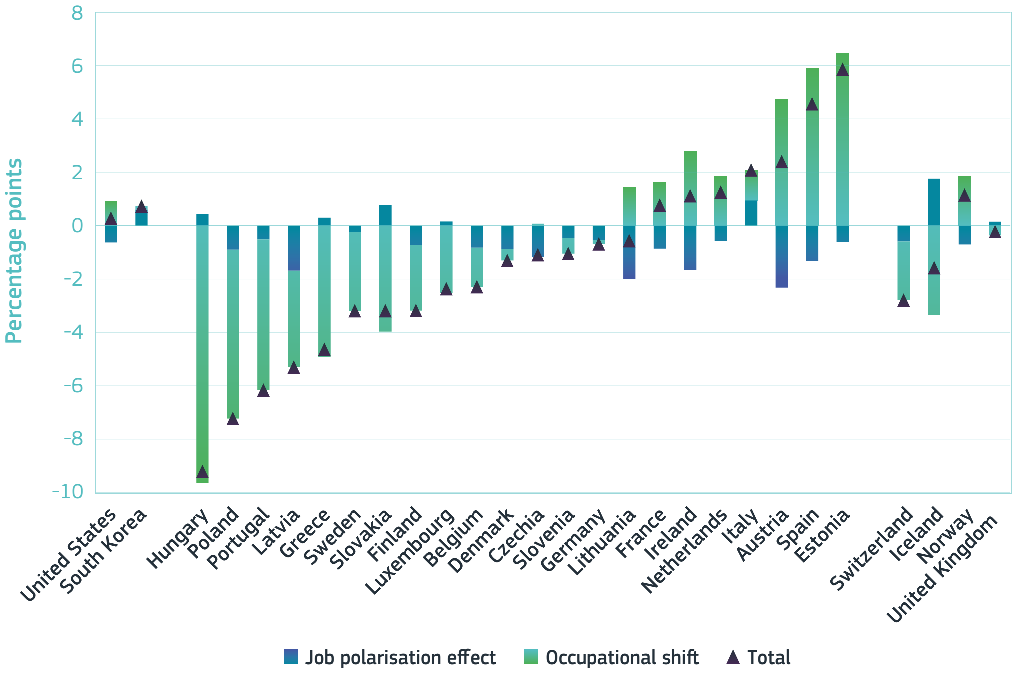
Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on Eurostat (online data code: lfsa_egised) and OECD data

Note: [1]High-skilled occupations include jobs classified under the ISCO-88 major groups 1, 2, and 3. Middle-skilled occupations include jobs classified under the major groups 4, 7, 8, and low-skilled occupations include jobs classified under the groups 5 and 9. [2]US: 1995-2015; JP: 1995-2010; SI, NO, CH: 1996-2018; CZ, EE, HU, PL, RO, FI, SE: 1997-2018; LV, LT, SK: 1998-2018; CY: 1999-2018; BG, MT: 2000-2018; EU, HR: 2002-2018; TR: 2006-2018.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter41/figure-41-7.xlsx

The borders between different skills and earning levels become fluid as some jobs demanding a high level of skills tend to no longer provide high incomes. This development seems to be primarily driven by very low wage growth among workers in high-skilled occupations in last decade or so (OECD, 2019). The overall effect on income distribution is still uncertain a priori since the emergence of new tasks and jobs may reward workers differently across the skills spectrum. Further evidence suggests that workers with less than tertiary education have shifted towards low-skill occupations, including mid-skilled workers, and face a higher risk of unemployment. The share of low-paid jobs is declining due to job polarisation and occupational shift. Job polarisation explains why the number of highly skilled occupations grew faster than other occupations, while the rest of the shift is explained by occupational shift whereby several occupations tend to pay lower wages. The overall trend in rising skill needs at lower levels creates further questions about changing mid-level occupations and future skills defining these occupations (Chatzichristou, 2018).

Figure 4.1-8 Percentage point changes in the share of low-paid[(1)] jobs by type of effect, 2006-2016[(2)]



Science, research and innovation performance of the EU 2020

Source: OECD Employment Outlook 2019

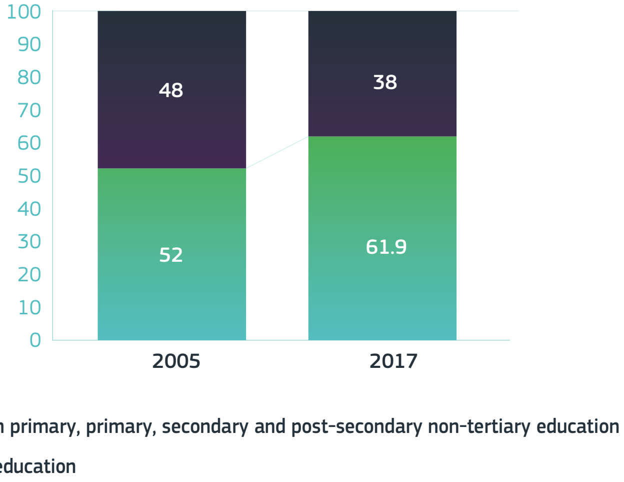
Notes: (1)Low-paid jobs are those paying less than two thirds of the median wage, while high-paid jobs are those paying more than 1.5 times the median wage. (2)Different time periods coverage for KR (2006-14), EL, LV, PT (2007-16), IT (2007-15), CH (2008-15), IE and LU (2006-15), and IS (2006-13).

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter41/figure-41-8.xlsx

At the level of labour-market entrants, education is the solution to equip people with better skills which will increase both their employability outlook and earnings. Tertiary education is often associated with a considerable increase in the level of skills, especially in high-quality systems. Until recently, and despite massive expansion, in many countries the returns for university graduates remained high. Education belongs at the core of the inequality debate as differences in educational attainment and status are important markers of inequalities. In turn, unequal educational opportunities have repercussions on social cohesion and mobility (EC, 2017a).

While ICT skills seem to be slowly improving among the EU population, there is a growing need for highly skilled IT professionals. The best-known skills gap is perhaps the digital one where the lack of IT specialists is growing (according to IDC and Empirica, the shortage is expected to reach over 749000 by 2020). Most jobs in the EU already require at least basic digital skills (Cedefop, 2018) and there is growing share of individuals with tertiary education working as ICT specialists in the EU labour market (Figure 4.1-9). On the other hand, 35% within the overall EU labour force do not have at least basic digital skills (Eurostat, 2019).

Figure 4.1-9 Share of employed ICT specialists by educational attainment level (%), EU



Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on Eurostat (online data code: isoc_sks_itspe)

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter41/figure-41-9.xlsx

The changing content and nature of jobs require new knowledge, skills and mindsets. Soft skills[9] are increasingly important for all types of jobs, including those in the digital sector. While job- and sector-specific skills remain essential to support competitiveness and innovation, transversal skills[10], including digital skills, are increasingly determining our ability to adapt, progress and succeed in a fast-moving labour market. The latest evidence suggests a broader set of skills being demanded for the digital age, including not just digital skills but softer ones such as adaptability, entrepreneurship and multidisciplinarity (EPSC, 2019). This points to a solid base of social skills facilitating interaction and communication with others as a favourable complementary asset for employees in the future.

Moreover, the EU labour market is already demanding more soft and digital skills, and specifically a combination of both. The JRC report (Gonzalez Vazquez et al., 2019) showed that the vast majority of occupations which have expanded in recent years are in the groups of professionals or service and commercial managers who require a combination of ICT use and soft skills, e.g. to deal with customers and teams.

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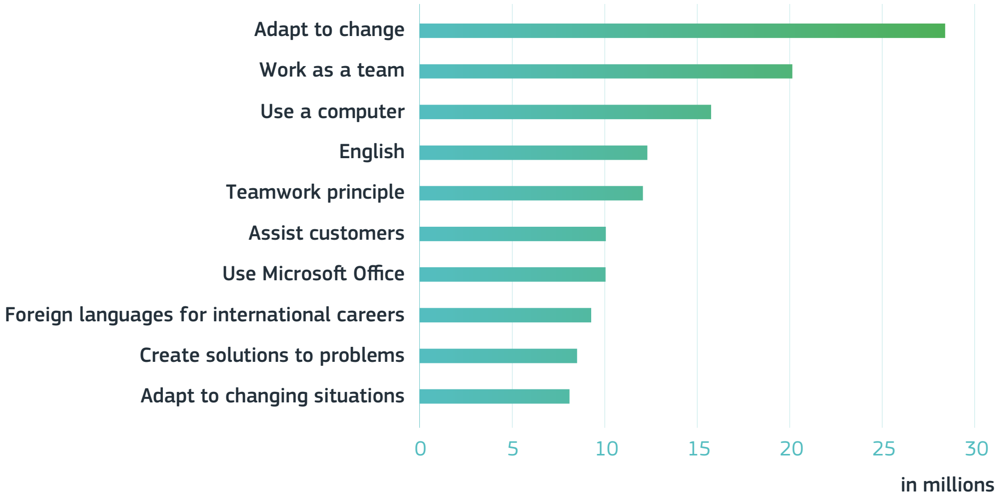
[9] Personal skills not thought to be measured by IQ or achievement tests. Their attributes receive various labels in the literature, including non-cognitive, personality traits, non-cognitive abilities, etc.

[10] In general, skills which have been learned in one context or to master a special situation/problem and can be transferred to another context are relevant to jobs and occupations other than those they currently have or have recently had (as broadly defined by Cedefop).

Figure 4.1-10 Most-sought-after skills 2018-2019



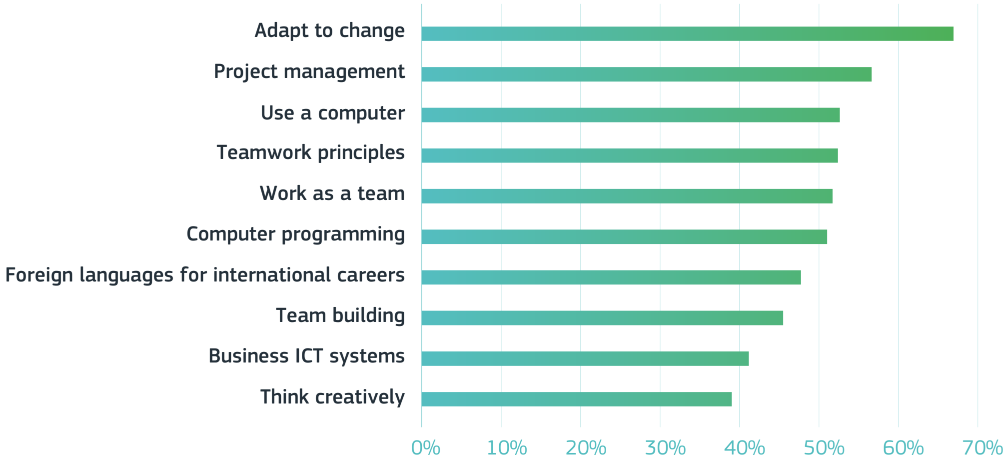
Science, research and innovation performance of the EU 2020

Source: Cedefop's Skills-OVATE 2019

Note: Based on analysis of online job-vacancy data in 18 EU Member States.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter41/figure-41-10-11.xlsx

Figure 4.1-11 Share of most-sought-after skills, 2018-2019, for ICT professionals[1]



Science, research and innovation performance of the EU 2020

Source: Cedefop's Skills-OVATE 2019

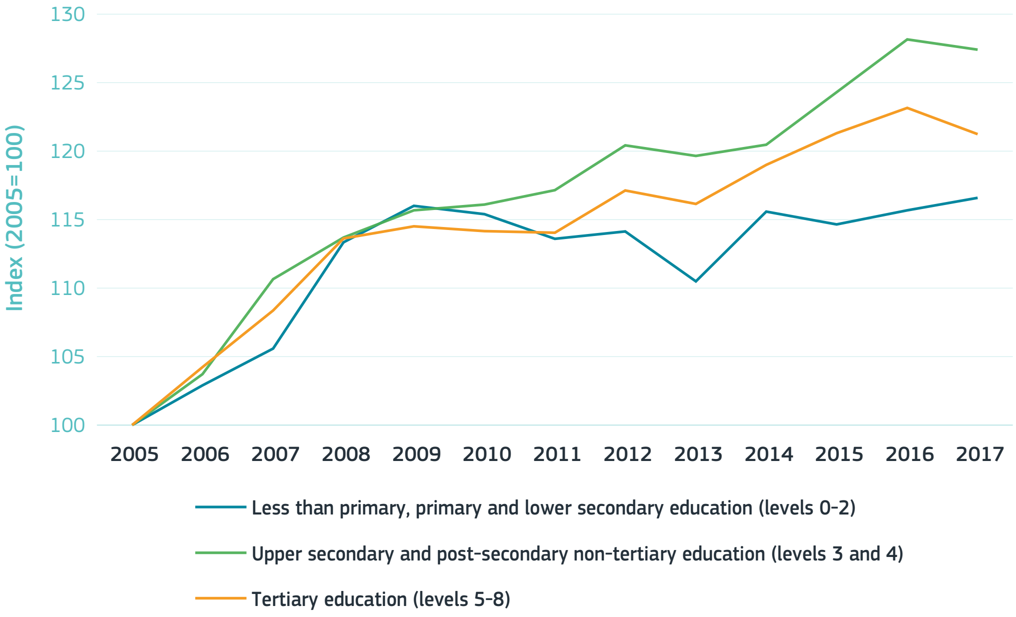
Note: (1)Shares for skills when mentioned in vacancies at the 2 digit ISCO occupation for ICT professionals.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter41/figure-41-10-11.xlsx

4. Skill-relevant policies need to be inclusive

Returns on investment in education have not always met expectations in countries that have expanded access to tertiary education without ensuring high quality since, in such cases, tertiary education does not lead to a substantial improvement in skills. Furthermore, the latest data suggests that tertiary wage premium is starting to decline, driven primarily by very low wage growth among workers in high-skilled occupations (Figure 4.1-12)[11]. If the expansion in the share of adults with high-level qualifications continues to exceed the speed of expansion in jobs requiring such qualifications, tertiary graduates' prospects may deteriorate. In some countries, it is already evident that tertiary graduates are more frequently undertaking jobs that do not require a high level of education, which also implies income and career prospects that fall below the expectations for someone holding a tertiary qualification and, on an aggregated level, leads to skill mismatch. In that context, the high numbers of highly educated people among platform workers (more than 50% of European platform workers have tertiary education) are remarkable given that the tasks performed by platform workers often do not require a high level of education (EC, 2018).

Figure 4.1-12 Evolution of median equivalised net income by educational attainment, EU(1)(2), 2005-2017



Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on Eurostat (online data code: ilc_di08)

Notes: (1)The calculation is based on the EU 2007-2013 composition with the UK before accession of Croatia. (2)The calculation includes incomes of workers from 18 to 64 years.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter41/figure-41-12.xlsx

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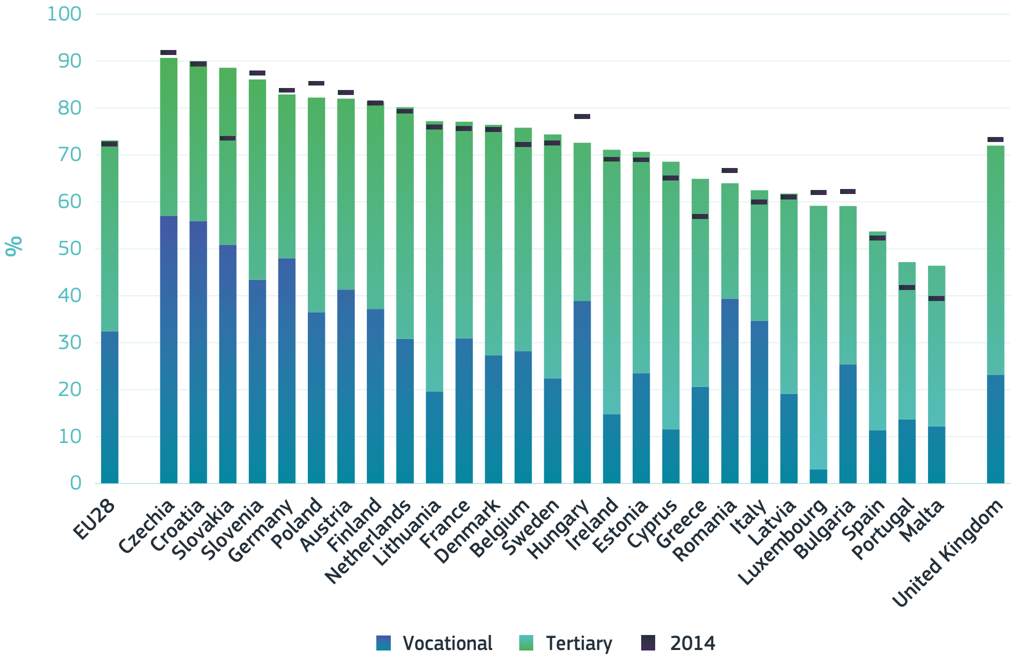
[11] Additional evidence at: OECD (2019) The future of work. OECD Employment outlook 2019.

When properly designed, vocational education and training systems can offer high levels of employability and access to high-quality jobs, including in emerging sectors such as the digital economy. After compulsory education, around half the young people in Europe enrol in vocational education and training (VET) programmes. Traditionally, VET systems were concentrated in the initial education systems and targeted low-performing students to help them acquire the skills required to work in sectors with a predominance of manual or low-skilled tasks. Nowadays, to a large extent, economies do not rely on these sectors where a high proportion of the population could be employed with a lower level of skills. **Therefore, developing a high-quality vocational learning experience is necessary to equip young people with strong foundation skills and job-specific skills which are in high demand in the labour market**. This would provide access to jobs requiring middle and high levels of skills, as well as creating a sustainable base for lifelong learning. As shown in Figure 4.1-13, both types of educational path allow young adults to enter the labour market. The challenge is to preserve such a balance through a well-developed VET system that leads to high levels of employment and has the capacity to respond swiftly to changing trends in the demand for skills.

Figure 4.1-13 Share of young adults holding a vocational or tertiary education qualification[1] (%), 2014 and 2018



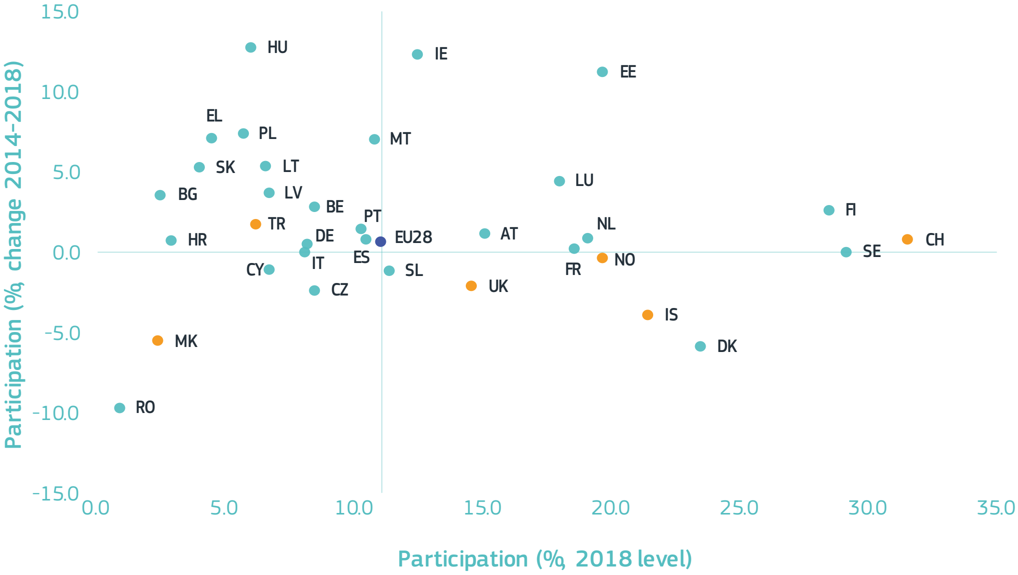
Source: Eurostat (online data code: edat_lfs_9914)

Note: [1]Shares of young adults aged 30-34. Vocational education attainment includes qualifications at ISCED levels 3-4 with a vocational orientation; tertiary educational attainment includes qualifications at ISCED levels 5-8.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter41/figure-41-13.xlsx

The importance of learning during adulthood is also increasing for all workers. A paradigm shift is taking place that requires the transformation of traditionally more front-loaded education systems delivering general and specialised skills at an early age into effective lifelong-learning models. Adult learning is perhaps the stage that requires the development of new models in most countries in order to learn and train workers during their lifetime, combining formal, non-formal and informal ways of gaining new knowledge. Broad participation in training remains a challenge for all EU Member States as currently only 10.9% of European adults are participating in training and the participation rates are not improving with time (Figure 4.1-14).

Figure 4.1-14 Participation rate in adult training (%)



Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on Eurostat (online data code: trng_lfse_01)

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter41/figure-41-14.xlsx

Those individuals likely to be the most affected by changes in the world of work are under-represented in training. There are large participation gaps between adults with low skills and their more-skilled peers, between those earning low wages compared to those on medium-high wages, and between different sectors of economy. Overall, there are broad opportunities for improving the general coverage of adult-learning systems to engage the adult population in learning (OECD, 2019a). The latest data reveal that 61 million adults aged 25-64, many of them in employment, are still low qualified[12]. Furthermore, the employment rates among the low qualified are already much lower than for medium and

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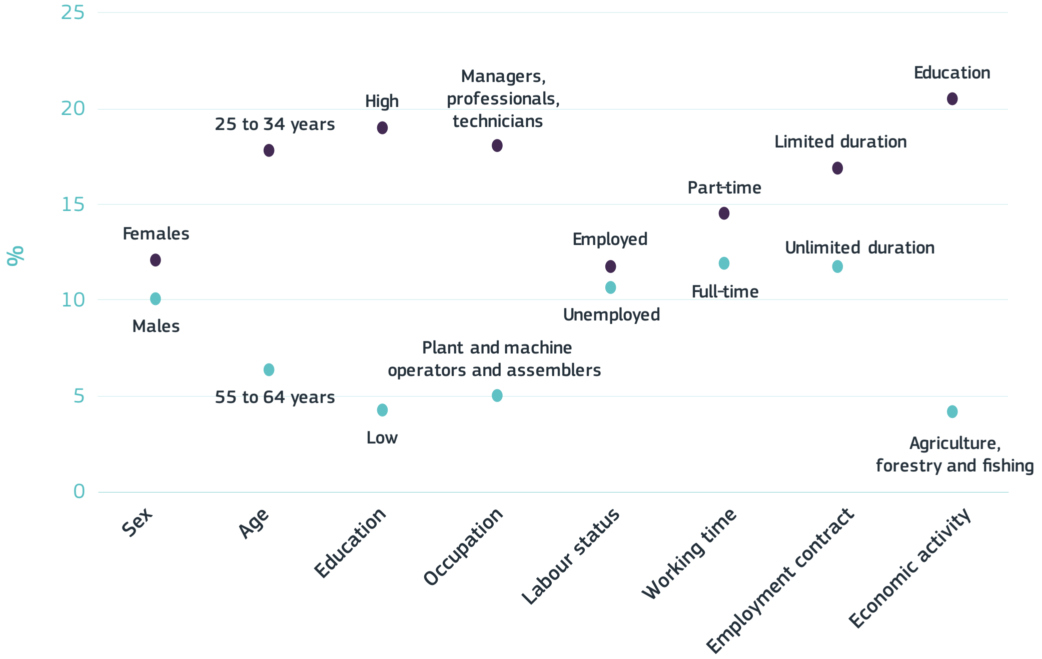
[12] Low-qualified people include lower secondary education at most. Among the 61 million low-qualified adults, aged 25 to 64, more than 34 million are in employment, over 21 million are inactive and less than 6 million are unemployed (EU, LFS, 2017).

higher qualified – around 55 % for low qualified compared to 75 % for medium qualified and 85 % for high-qualified people. **It is important that adult-learning systems are inclusive and aligned with skills needs in order to reach out to workers at most risk of job loss or displacement**. More can be done in this area as workers with jobs at significant risk of automation show lower participation rates in training (especially non-formal training) compared to workers at low risk of automation (Figure 4.1-15). These gaps in training participation and demands of the future labour market demand coordinated policy actions.

Figure 4.1-15 Highest and lowest shares of job-related adult learners by groups (%) in EU28, 2018



Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on Eurostat (data from Labour Force Survey)

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter41/figure-41-15.xlsx

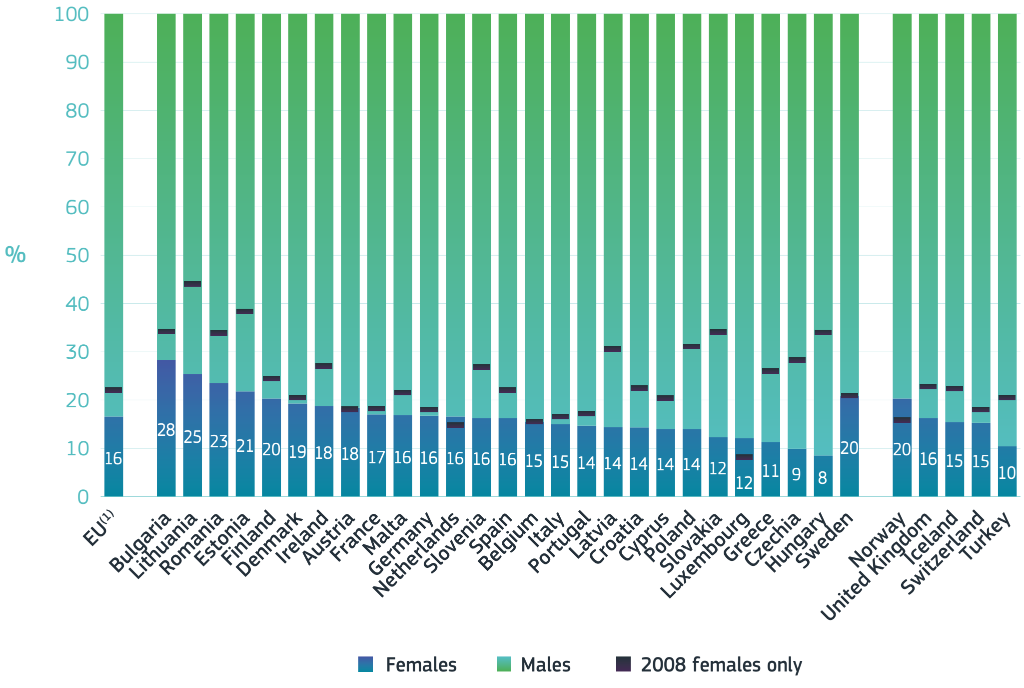
5. Gender gap in employment and entrepreneurship has new drivers

Although the EU has witnessed a significant increase in female employment over the last two decades, women's participation in the digital field is lagging behind in several areas, with varying participation rates across the Member States. Those Member States leading in digital competitiveness are also leaders in female participation in the digital sector. The gender gap is largest in the area of ICT specialist skills and employment:

82 % for ICT specialists and 65 % for science, technology, engineering, mathematics and ICT graduates (Figure 4.1-16).

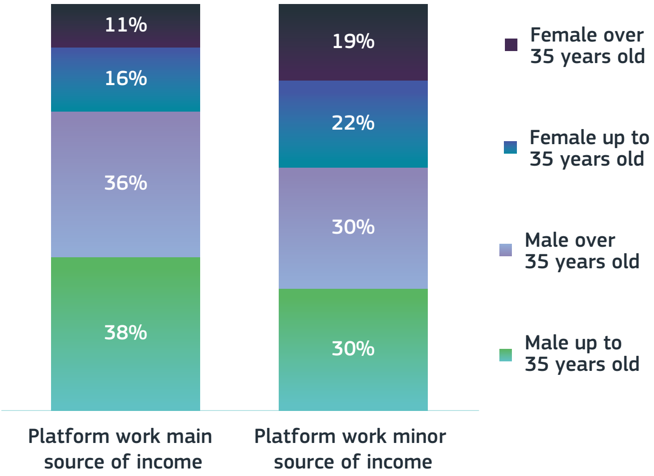
Women account for 52 % of the European population but only around 17 % of women work in ICT-related jobs. Women's participation in the development and deployment of AI technology, such as machine-learning researchers, and in platform work is unbalanced. a review of participants attending AI academic conferences reveals an under-representation of women in academia (19 % of conference authors) as well as industry researchers (16 % of conference authors; Mantha and Kiser, 2019). OECD came to the same conclusion that software development is male dominated, especially in companies (OECD, 2018a). As regards platform work in Europe, these jobs are mainly dominated by men and the gender gap widens with the importance of platform work relative to total income (Figure 4.1-17). Irrespective of the concerns about job quality, more work flexibility can boost employment and help parents combine work with family life. The flexibility to choose where and when to work is one of the major advantages of digital platforms and offers women the possibility to better combine motherhood with pursuing a career (OECD, 2018a). These initially positive expectations of technological developments on female employment seem not to have materialised.

Figure 4.1-16 Share of ICT specialists by sex (%), 2008 and 2018



Source: Eurostat (online data code: isoc_sks_itsps)
Note: (1)EU average estimated by DG Research and Innovation.
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter41/figure-41-16.xlsx

Figure 4.1-17 Share of platform workers by age and sex (%)



Science, research and innovation performance of the EU 2020

Source: European Commission, Joint Research Centre based on COLLEEM Survey 2017

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter41/figure-41-17.xlsx

Female entrepreneurship and funding opportunities for high-potential startups are characterised by a significant gender gap. For example, in the EU, the proportion of women in self-employment is under 10 % compared to 17 % for men[13]. Recent studies of high-growth start-up activity find that only a marginal share of start-ups are founded by women while start-ups with at least one woman in the founding team are often less likely to receive funding than start-ups founded by men only[14]. (For more information, see Start-up gender gap section in Chapter 3.3 - Business Dynamics and its contribution to structural change and productivity growth and in Chapter 8 - Framework conditions). There seems to be a division between 'STEM-related' industries that are more dominated by male-founded companies and female-led start-ups, meaning that at least one founder is a woman (Figure 4.1-18). These tend to be in areas generally perceived as less high-tech, such as lifestyle, education, and fashion rather than ICT technologies. Given the preference of venture capital providers to invest in sectors which typically generate big returns on small initial investments, such as information and communications technology or life sciences, women's starting position could improve by expanding into these areas. **Thus, a substantial part of the gender gap can be attributed to the origins of gender gap in education and later career paths (e.g. gap in STEM education)**. Policies to close the participation gap of women would need to address upstream factors related to education and training. Policy interventions focused on education policy, women's participation in STEM entrepreneurship and various accompanying business supporting schemes could potentially reduce these divisions.

To find out more, see Chapter 11 - The consequences of AI-based technologies for jobs.

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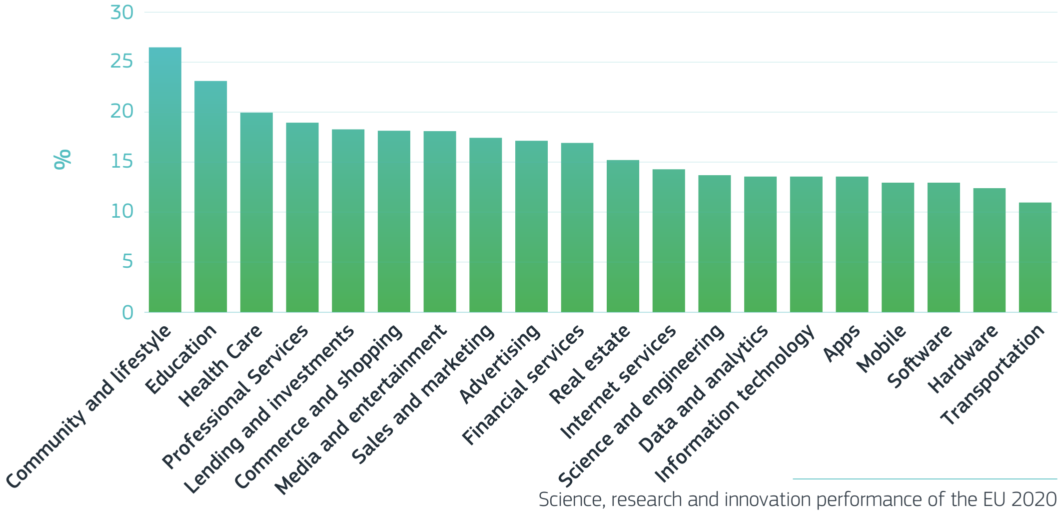
[13] Eurostat. Employment and Self-employment by sex, 2018: 20.5 million self-employed men compared to 9.9 million self-employed women in the EU28.

[14] Only 10-15 % of startups have been founded by women in the United States (Brush et al., 2014). Start-ups with at least one woman in the team of founders are 10 % less likely to receive funding compared to start-ups founded by men only. OECD (2019): Levelling the Playing Field: Dissecting the Gender Gap in the Funding of Innovative Start-Ups Using Crunchbase.

Figure 4.1-18 Female-founded startups across different sectors - share of companies with at least one female founder (%)



Science, research and innovation performance of the EU 2020

Source: OECD estimates based on Lassébie et al. (2019) and computed from Crunchbase data

Note: Sample limited to firms created between 2000 and 2017, located in OECD, Colombia, and BRICS countries. Graph restricted to the top 20 technological fields in terms of number of firms in the sector.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter41/figure-41-18.xlsx

Summary of Peter Cappelli - The consequences of AI-based technologies for jobs

This contribution follows the recent public debate on the changes across industrial countries that stem from information technology, including notions of artificial intelligence and its implications for how work is performed. While acknowledging the size and pervasiveness of these discussions, **the article discusses the core argument related to the impact of information technology on the way businesses and organisations operate, how these changes could translate to the labour market**, and other potential outcomes such as lower wages or unemployment.

The argument begins with an introduction to the two ways in which people tend to anticipate future developments. This either happens through estimates based on prior experience (commonly known as forecasting) or through a belief in a real uncertainty of future developments and reliance on other kinds of evidence besides traditional forecasts. The article maps the projected impact of technological uptake on the labour markets and reviews the empirical evidence. It touches upon many of the above-discussed trends, such as skill-biased technological change or routine-biased technological change and their implications for skills demand. With an historic perspective, the article argues that predictions based on the past may be less relevant in the current context. Although new equipment and practices could eliminate certain jobs, on balance they do not necessarily destroy jobs because their overall effects on improving productivity and overall wealth create jobs elsewhere.

To understand why assumptions claiming that the future is like the past are not correct and extrapolations from prior experiences are unlikely to be accurate predictors of the future, read Chapter 11 - The consequences of AI-based technologies for jobs.

6. Conclusions

Technological developments accompanied by growing computing power and the greater availability of big data are shifting the boundaries of what can be automated by machines and could further reduce the costs of automation, in particular of so-called routine tasks. Although employment levels have not declined, other trends, such as the **polarisation of labour markets with a declining share of medium-skilled occupations**, have emerged across advanced economies. This suggests that the technological potential should not be equated with the actual impact on employment as this depends on specific circumstances. For example, a wider diffusion of technology is a necessary precondition for any broader occurrence of technology-driven employment effects. Furthermore, the evolving set of tasks within occupations can reshuffle the existing pool of jobs and the expected job-creation effects are currently difficult to quantify. In general, many of the developments in employment between occupations or whole industries introduced by cutting-edge technologies **are related to structural change within economies towards more productive and innovative activities**.

The various challenges in the field of education and training require actions from multiple stakeholders. **Better labour market intelligence that helps anticipate change and promotes innovation, new angles to lifelong learning and adult education that emphasise inclusiveness, or contributions by technologies to the training process** rank among the priorities. More focused training and qualification measures may help workers to target expanding occupations in a technology-rich environment and reduce the potential losses of those working in shrinking occupations, although this will depend on the accuracy and level (sectoral or company specific) of forecasts.

Exploring how to better align innovation and skills policy is increasingly relevant and some initial efforts have taken place, for example through the Skills Agenda, Sectoral Skills Alliances projects and, more recently, through the Vocational Excellence initiative. The **definition and diffusion of skills, along with new high-quality knowledge and technologies**, could support structural change and provide solutions to global challenges. However, this would require that policies supporting innovation and skills, both at the EU and national level, become increasingly more synergetic.

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CHAPTER
4.2

REGIONAL R&I IN EUROPE

KEY FIGURES

40%
of jobs are in risk of automation in the West Slovakia region

10 out of 29
European unicorns are located outside of capital regions

27 out of 266
regions account for half of the EU's annual R&D spend on patent applications

3%
in Hovedstaden (DK) is the highest share of researchers in the number of employed people

What can we learn?

- The **high concentration of R&D activities and agglomeration** effects imply that there are regions with more incentives for R&D investments.

- **Scientific production has become more dispersed** and higher investment in R&D has led to more scientific output from the central and eastern European countries and regions.

- Increasing concentration of economic and innovative activities in capitals and metropolitan areas, on the one hand, and declining industrial or peripheral areas on the other lead to **negative developments in regions with low capacity to exploit innovation**.

- **Upward convergence of economic growth at the regional level is stalling**. While many of the capital regions witnessed fast convergence, other regions have shown little progress and their labour productivity is slowing down. This suggests the **importance of R&I as a new growth engine for innovation-driven productivity growth in less-developed and transition regions**.

- Negative economic developments paired with the impact of globalisation and technological change on disadvantaged groups, i.e. the older and less educated, living in industrial or decaying areas, have led to a set of local economic conditions known as the **geography of discontent**.

What does it mean for policy?

- European innovation policy must place a **greater emphasis on promoting innovation in less-developed and transition regions to trigger economic dynamism** that would increase the competitiveness of the EU as a whole and close the innovation divide.

- Policymakers need to align policies targeted at improving R&I capacities and territorial inequalities with **greater coordination at all levels**. These include aligned R&I policies and Cohesion Policy, together with education and training.

- With substantial variation across EU regions in terms of institutional quality, **improvements in institutional quality and integration of smart specialisation strategies into regional development strategies** would improve the efficiency of R&I programmes, combat corruption and promote innovation.

1. Regional research and innovation systems show signs of convergence

R&D-intensive regions

In general, R&D intensity is high in western and northern Europe with some well-performing regions in other parts of Europe, too. A closer look at the type of expenditure and the spending dynamism reveals specific patterns. As economies become more knowledge-based and dependent on intangible assets, economies and firms achieve large returns on R&D investments which also help to create new and better jobs. However, the latest literature concludes that R&D investment does not trigger the same returns everywhere. The reasons for this include the distance to the technological frontier and the related creation and distribution of new knowledge. The following maps show to what degree the core R&D-performing areas attract and concentrate resources.

R&D investment shows a high concentration of spending in regions with high R&D intensity. Within countries, there is strong concentration (in absolute terms) of R&D expenditure in a few regions, typically capital regions or those with large urban agglomerations. The R&D-to-GDP ratio provides an insight into contributions from public budgets[1] and private actors during the economic cycle. While business R&D trends traditionally depend on business expectations, public R&D is expected to be more counter-cyclical, buffering the effects of economic downturns (OECD, 2014). Currently, the intensity of R&D spending across EU regions varies considerably with highly intensive regions in the west and north of Europe, often as a result of being endowed with headquarters of large tech companies (Figure 4.2-1). As these indicators are related to GDP, eastern European countries showed strong economic growth and many regions also experienced growth in R&D intensity. The absolute amount of R&D expenditure (as well as the number of patents in the region) in eastern Europe as a whole and in many of its regions has clearly increased (Figure 4.2-2). On the other hand, some of the regions with high R&D intensity have continued to expand their R&D expenditure which means the distance to the top-performing regions has not decreased significantly. There are some noticeable exceptions of regions with high absolute amounts of R&D and lower R&D intensity, representing relatively large regions, including, for example Catalunya (ES51), Lazio (ITI4), Lombardia (ITC4), or mid-sized regions with a high GDP per capita (e.g. Southern and Eastern Ireland (IE02). On the other hand, there are (smaller) regions with small absolute amounts of R&D expenditure that are actually very R&D intensive, e.g. Övre Norrland (SE33) and Kärnten (AT21).

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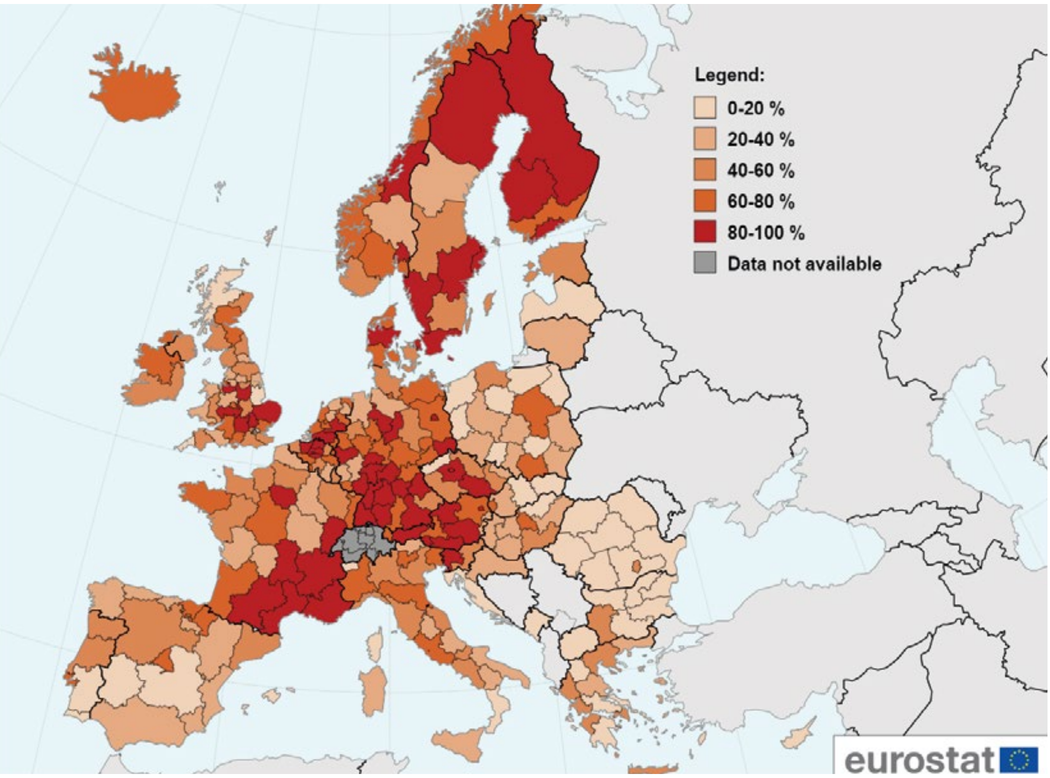
[1] Data on sectoral R&D expenditure based on sector of performance, hence business spending also includes money coming from public budgets and vice versa.

Figure 4.2-1 R&D intensity (2017 or latest available)[2]



Source: Eurostat (online data code: rd_e_gerdreg)
Note: R&D intensity of UK, IS, NO:2016; BE, IE, LT: 2015; FR: 2013. The maps use NUTS2013 and, where necessary, regional data were matched with NUTS2016 (HU, LT, PL).
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter42/figure-42-1.xlsx

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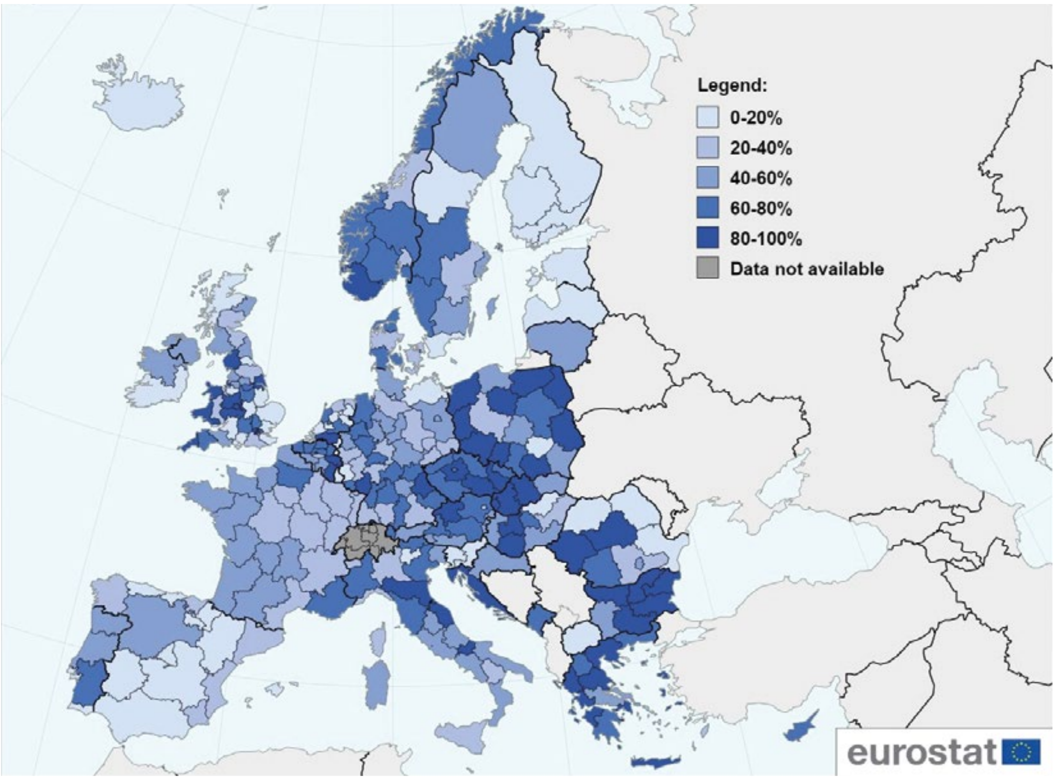
[2] The maps across this chapter divide regional values of selected indicator into five quintiles according to their performance (0-20% the lowest quintile).

Figure 4.2-2 R&D growth (2010-2017 or latest available)



Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on Eurostat (online data code: rd_e_gerdreg)

Note: Compound annual growth rates calculated NL: 2015-2017; DE, EL, AT, ME: 2011-2017; BE, IE: 2010-2015; UK, NO: 2010-2016; FR:2010-2013; MK: 2015-2017. The maps use NUTS2013 and, where necessary, regional data were matched with NUTS2016 (HU, LT, PL).

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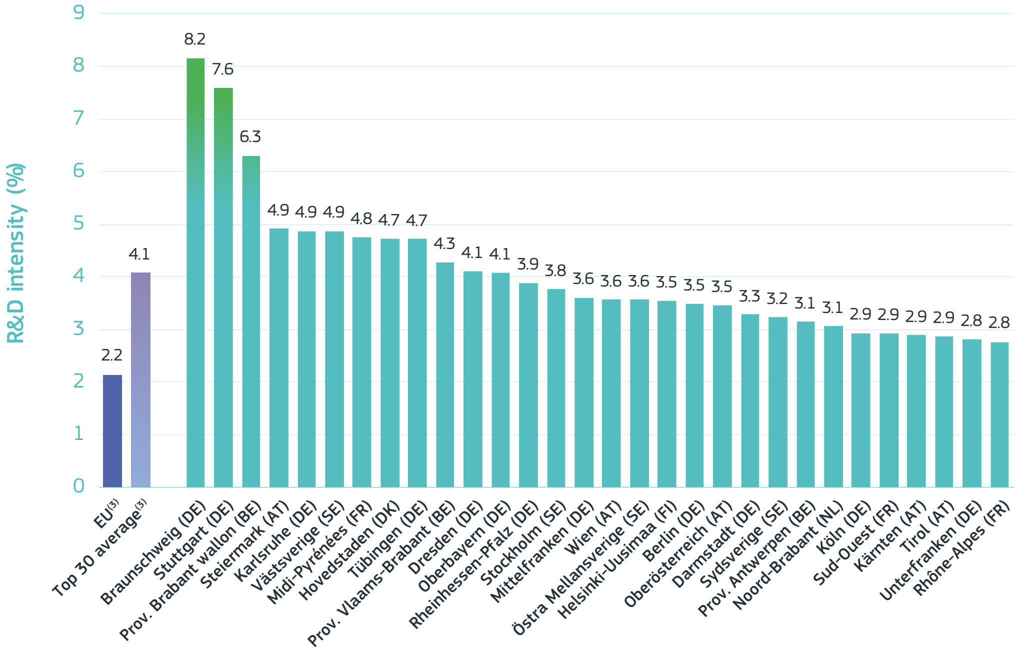
The EU's most R&D-intensive regions are all located in western and northern Europe and the degree of concentration confirms the described trends. The average intensity of the top 30 EU regions is more than twice the average intensity of the EU as a whole (Figure 4.2-3). In some cases, the regional R&D intensity is heavily influenced by presence of a single large tech company. An example is Braunschweig, the EU NUTS2 region with the highest R&D intensity, where the biggest European R&D spender Volkswagen has its headquarters.

Figure 4.2-3 The 30 most-R&D-intensive regions[(1)] in the EU - R&D intensity, 2017[(2)]



Science, research and innovation performance of the EU 2020

Source: Eurostat (online data code: rd_e_gerdreg)

Notes: [(1)]NUTS Level 2 regions. [(2)]BE: 2015; FR: 2013. [(3)]EU and top 30 regions' average calculated by DG Research and Innovation.

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Business and public R&D spending

While business R&D expenditure contributes to an increase in R&D intensity in some less-developed and transition regions, overall business R&D expenditure remains heavily concentrated. Business-driven R&D expenditure is expected to play an important role in higher EU competitiveness and job creation (EC, 2014) and to reduce the EU's innovation gap (EC, 2017). Furthermore, the ultimate objective is to accompany the transition of those regions and workers most affected by globalisation and industrial developments and to facilitate their transition to a low-carbon and circular economy (JRC, 2018). Despite certain convergence trends in regions' business R&D intensity, the latest data **suggest a persisting concentration of R&D expenditure in more-developed central locations**. Business R&D expenditure is even more concentrated in more-developed regions with a strong concentration in relatively few internationally active technology companies. Germany, the UK and France contribute to two thirds of total EU business R&D with a strong contribution from the automotive sector in Germany, pharmaceuticals in the UK, whilst France has a relatively balanced sector composition (JRC, 2018)[3]. Currently, more-developed regions represent about 85% of R&D expenditure in the EU, transition regions about 10% and less-developed regions about 5%. One example is Baden-Württemberg, which has about 2% of the EU population but an 8% concentration of the EU's business R&D[4].

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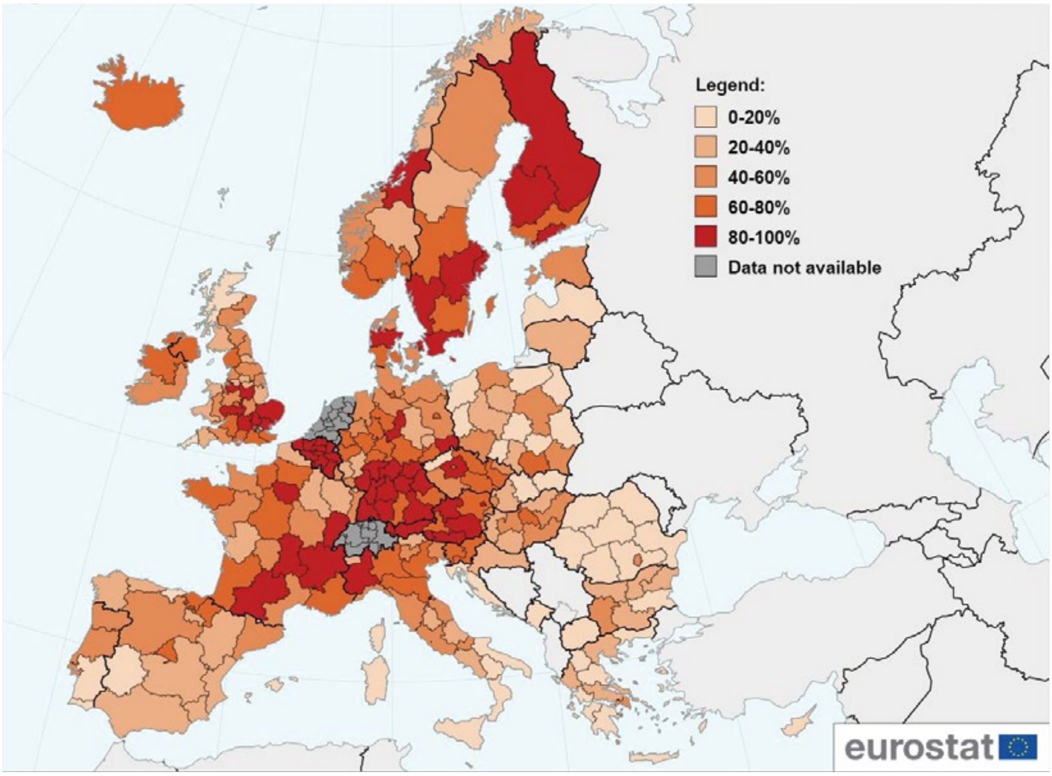
[3] Among the sample of 1 000 EU top spenders, 899 companies are based in the top 10 Member States, accounting for 97.1% of total R&D. Moreover, the overall performance of the EU 1 000 group is largely driven by the results of companies based in Germany, France and the UK, accounting for 61% of companies, 68% of the total R&D, and 68% of total net sales.

[4] The main NUTS2 reference region is Stuttgart DE11 (share of the EU, 2017).

Some upward convergence in R&D expenditure can be observed in many regions in central, eastern and south-eastern European countries (CESEE). Notably, regions such in Czechia, Hungary and Slovakia show an increase in business R&D intensity which seems to be driven by business R&D spending in the automotive and ICT sectors[5] (Figure 4.2-4.). Business R&D intensity in several regions in Greece – where recovery from the severe crisis has set in – is also increasing. In many regions of eastern and southern Europe, R&D expenditure has risen steadily in recent years, linked to a structural shift to more knowledge-intensive activities and expected returns on R&D investment. Although many less-developed regions began to grow from (and were facilitated by) low starting levels, high growth rates brought several regions closer to the performance of frontier regions. Střední Čechy (CZ02), Budapest (HU11) and Warszawski stoleczny (PL91), ranked in the top 20% of business R&D-intensive regions in 2017.

Figure 4.2-4 Business R&D intensity in 2017 or latest available



Source: Eurostat (online data code: rd_e_gerdreg)

Note: Business R&D intensity of UK, NO: 2016; BE, IE, LT: 2015; FR: 2013. The maps use NUTS2013 level 2 and, where necessary, regional data were matched with NUTS2016 (HU, LT, PL). BE on NUTS1 level, NL data confidential.

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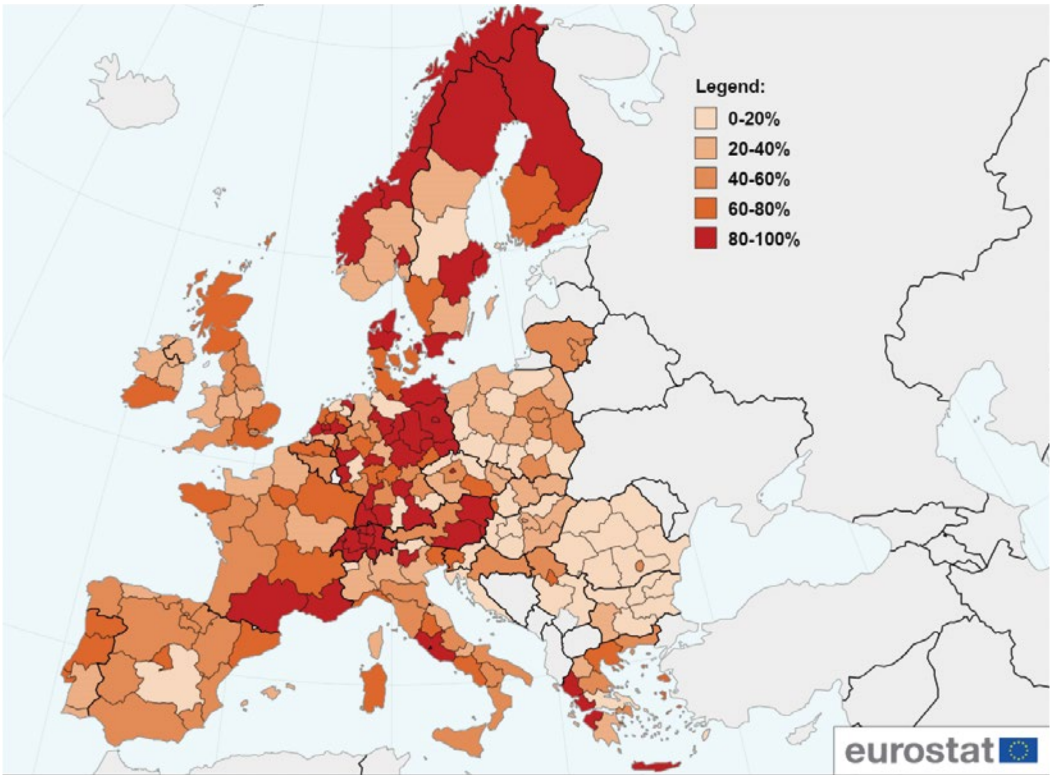
[5] Expenditure in the areas of manufacturing motor vehicles and information technologies represents 36 % of overall business R&D expenditure in Czechia and 33 % in Slovakia.

Public R&D expenditure show similar levels of concentration, with higher rates in regions of Nordic countries. This pattern of innovation-lagging regions that invest less in R&D and of innovation-leaders forging ahead with public R&D spending resembles the earlier observed patterns at the national level (Veugelers, 2014). In particular, Sweden, Germany and Denmark increased their public expenditure on R&D during the financial crisis by a higher degree than in the case of other public expenditures, and this trend seems to persist since then (Figure 4.2-5). In regions that are seemingly too far from the technological frontier and that may have a weak industrial fabric, increasing the R&D effort alone does not always yield greater economic growth. An earlier work identified regions, which failed to achieve economic growth that would be at all proportional to the regions' increases in public R&D investment (Rodríguez-Pose, 2014).

Figure 4.2-5 Public R&D intensity in 2016 or latest available



Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on Regional Innovation Scoreboard 2019

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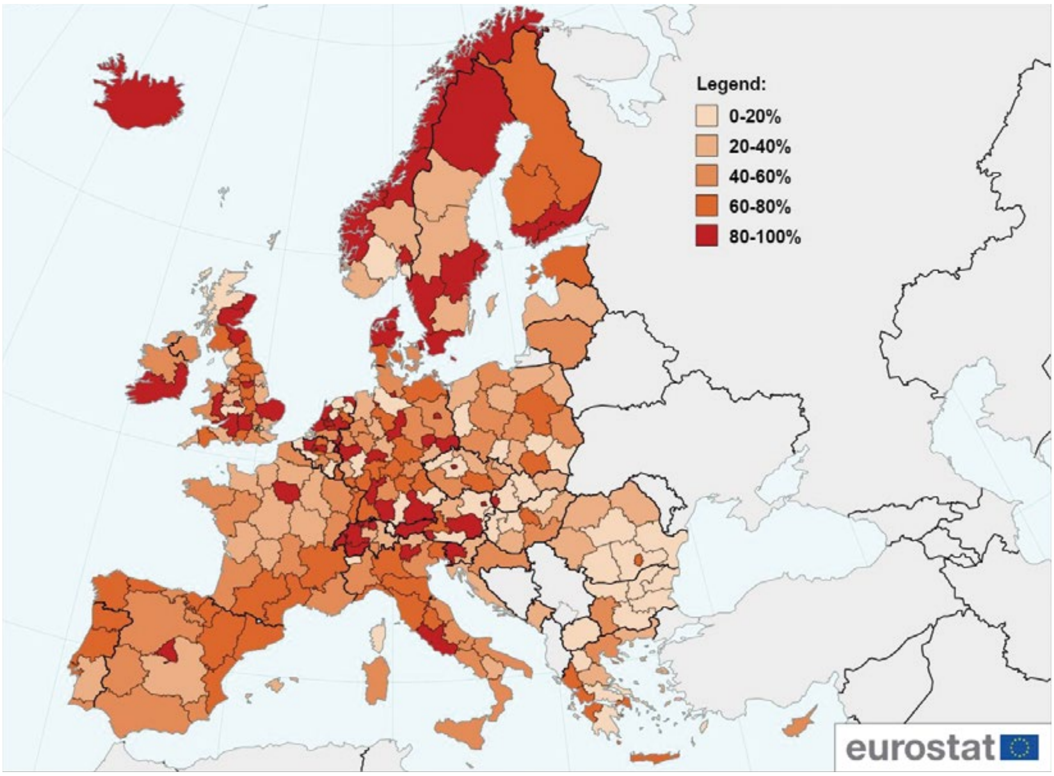
Scientific publications

Many of the lagging regions, mostly in eastern and southern Europe, have observed an improvement of their performance in scientific output, which indicates improved returns on R&D investment. The map of regional performance in scientific publications per capita shows a relatively dispersed pattern of scientific production across the EU (Figure 4.2-6). However, the picture becomes more concentrated when looking at the regional distribution of 10% top-cited publications per 1 000 inhabitants. This indicator shows poor performance particularly in regions in eastern Europe[6]. The quality indicator will potentially catch up in the future, as observed in the overall numbers of scientific publications, but the catching-up process may take longer. Currently, the production of high-quality publications is still very concentrated in western Europe with high shares of British and Dutch regions.

Figure 4.2-6 Share of scientific publications per 1 000 inhabitants



Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on CWTS using data from Web of Science database and Eurostat data

Note: Based on articles and reviews published in the period 2013-2017, covered by the Web of Science.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter42/figure-42-6.xlsx

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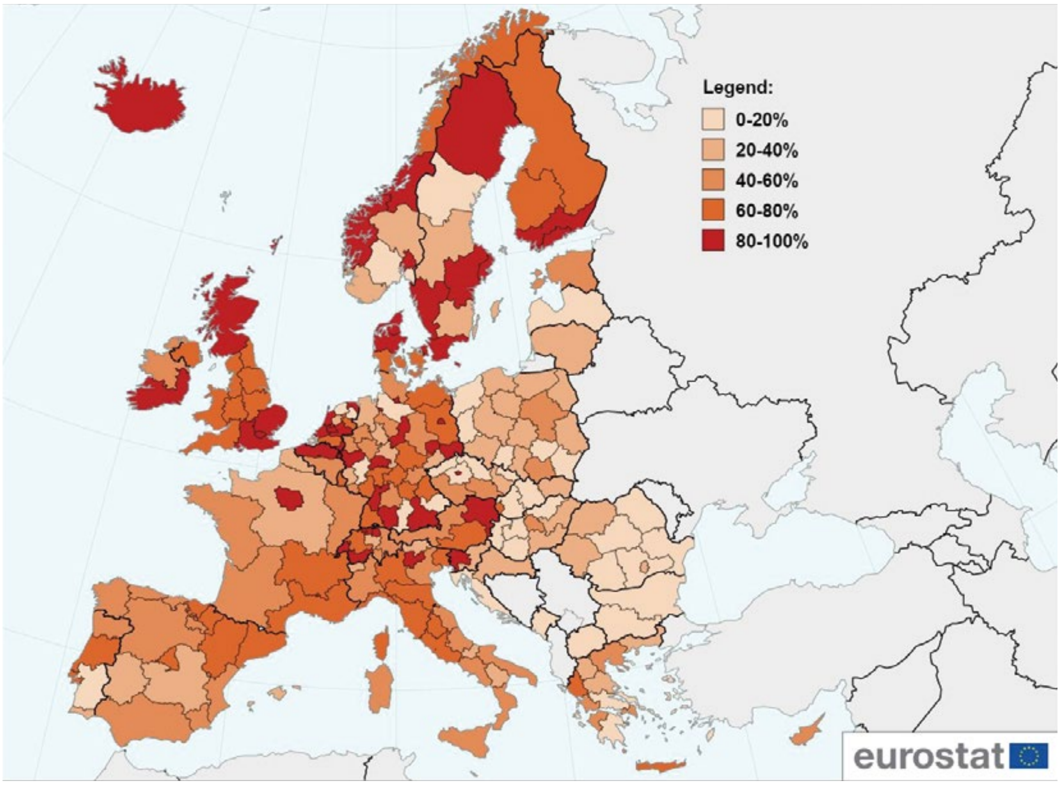
[6] Without adjustment per 1 000 inhabitants, the projected concentration of top-10% publications would increase further.

Figure 4.2-7 Share of top-10% most cited publications per 1000 inhabitants(1)(2)



Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on CWTS using data from Web of Science database and Eurostat data

Notes: (1)Based on articles and reviews published in 2015, covered by the Web of Science. (2)BE, FR, AT at NUTS1 level.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter42/figure-42-7.xlsx

The increasing level of knowledge complexity[7] **suggests that even the metropolitan areas and well-connected regions concentrate specific knowledge**. Figure 4.2-8 is a matrix table of specialisation showing how the regions concentrate specific knowledge relative to other regions and depicts relative patterns of specialisation. The listed regions are ranked by the overall number of their high-quality publications. The matrix columns assess shares of top scientific publications among these regions in the fields of societal challenges compared to the overall European shares[8]. Very few regions, such as Berlin or Madrid, do not show a specific pattern of scientific specialisation. Other regions have their specific focus, such as, for example, Vienna and the Dutch region of Veluwe which perform well on topics related to climate change and environment.

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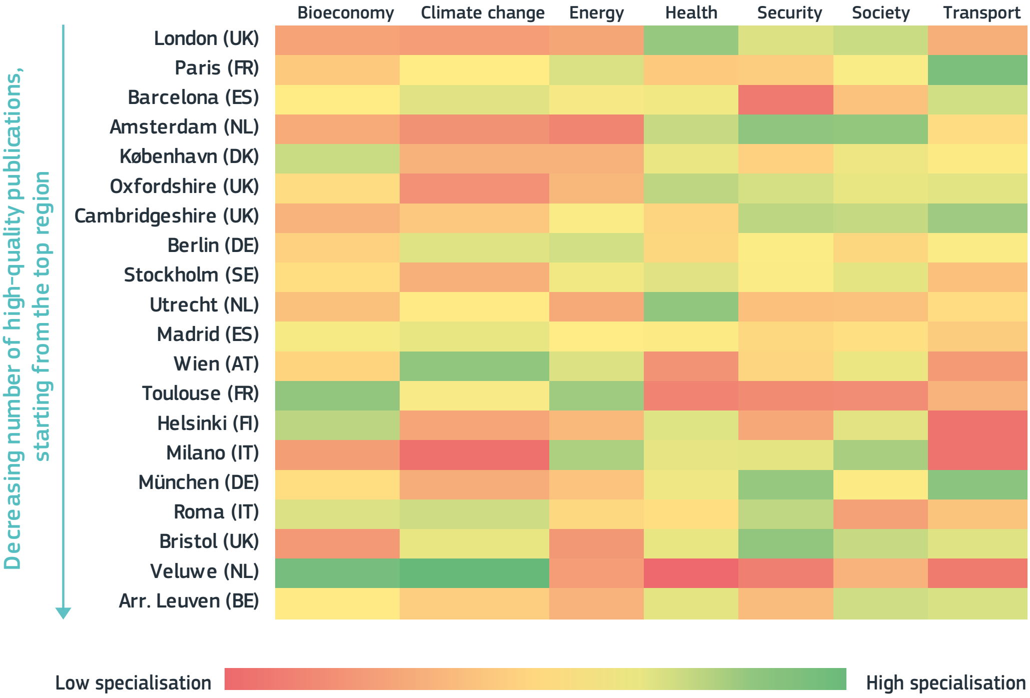
[7] Refers to assets for innovation activities in the knowledge economy. See Chapter 2 - Changing innovation dynamics in the age of digital transformation, or earlier publications, such as Westlund, 2006.

[8] Societal challenges as defined in the Horizon 2020 Framework Programme.

Figure 4.2-8 Relative specialisation of top regions by societal challenges(1)(2)(3)(4)



Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on CWTS using data from Web of Science database and Knowmak project

Notes: (1)Green indicates high specialisation and red indicates low specialisation (share of publications related to the challenge among the publications of the region divided by the share of publications related to the challenge among European publications). (2)Data refers to number of publications that are in the most-cited 10% of publications in 2016. (3)The selected regions present the 20 regions with the highest numbers of scientific publications in the top 10% cited. The regions are ranked by the number of publications (top-down). (4)The ontology for Societal Grand Challenges publications and definitions were developed by the Knowmak project (Horizon 2020 project number 726992).

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter42/figure-42-8.xlsx

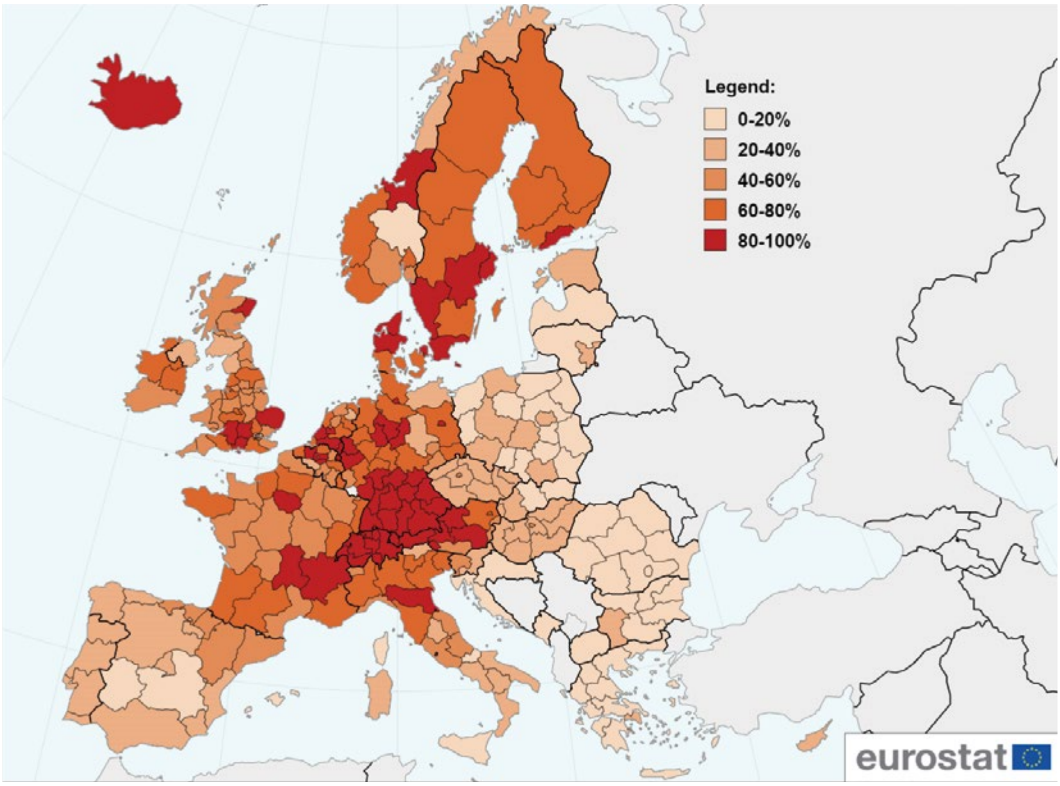
Technological production

The technological output, as measured by patents, is concentrated in regions with a high share of manufacturing and with tech companies' headquarters, such as southern Germany, Austria, Denmark and the Rhône-Alpes region. Furthermore, patenting is concentrated in capital cities (Figure 4.2-9). A high patent output per capita is observed in the Dutch NUTS2 Noord-Brabant (NL41) and Austrian Vorarlberg (AT34).

A look at trends in patent applications across European regions reveals a convergence pattern in the eastern European regions and growth in some southern European regions, too (Figure 4.2-10). Notably, growth in the south concerns regions that belong to the group of laggards. These findings do not confirm an increasing patenting divide but show a dynamic patenting activity instead. Another trend already observed at the national level is the concentration of innovation activities among large companies.

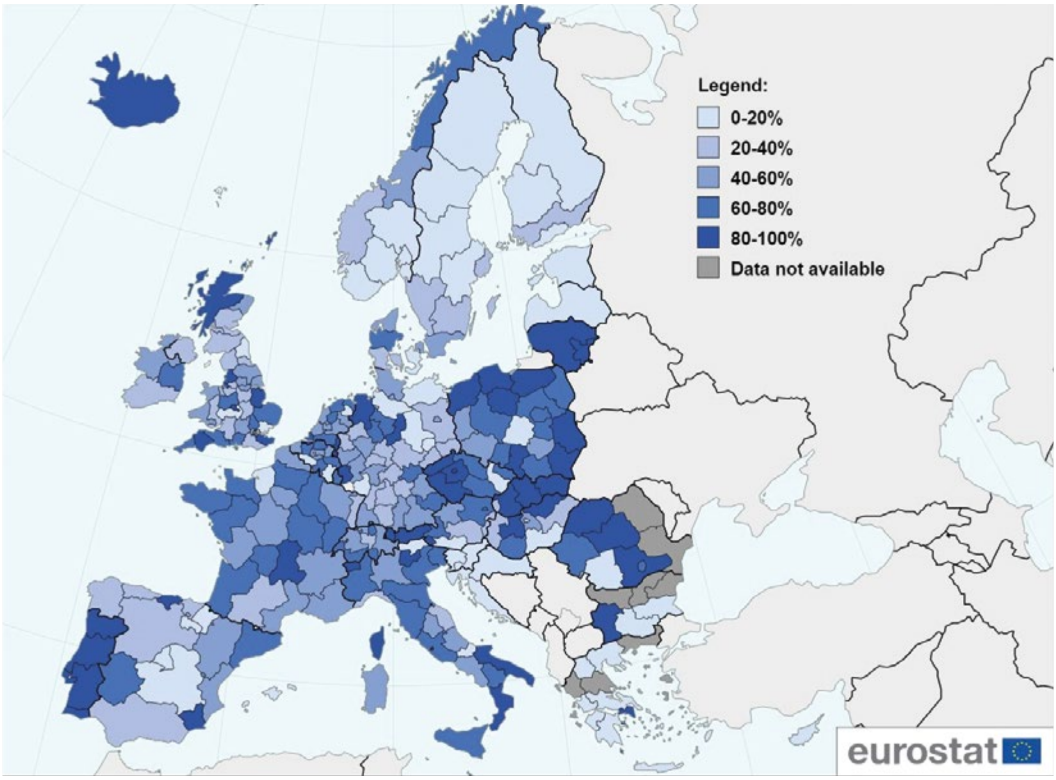
Innovation activity at the regional level, as measured by patent applications, is highly correlated to business expenditure on R&D and shows a similar spatial pattern. Large international technology companies have shifted manufacturing to eastern Europe, which is supposedly also boosting R&D expenditure and IP production in the corresponding regions. Therefore, innovation activities linked to technological production show a broad convergence trend (see more on the patenting divide in Chapter 12 - The research and innovation divide in the EU and its economic consequences).

Figure 4.2-9 **Share of PCT patent applications per 1 000 inhabitants, 2016**



Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit
Note: Data produced by Science-Metrix using data from the REGPAT database.
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter42/figure-42-9.xlsx

Figure 4.2-10 Growth in PCT patent applications between 2010 and 2016



Science, research and innovation performance of the EU 2020

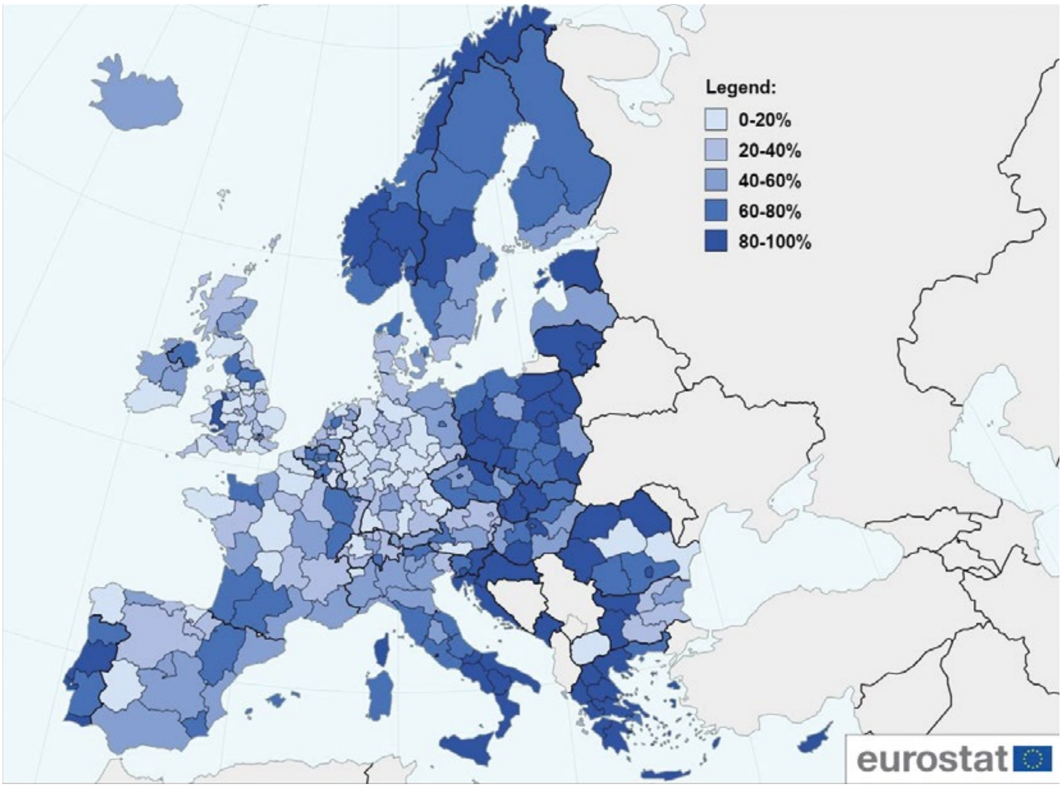
Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit.

Note: Data produced by Science-Metrix using data from the REGPAT database. The highest quintile shows regions with the highest increase from 2010 to 2016.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter42/figure-42-10.xlsx

Greater activity in design and trademark applications across Europe reveal emerging convergence trends and examples of local specialisation. A broader perspective on innovation output protected as intellectual property confirms that there is a high concentration and an overlap in the use of patents, designs and trademarks in some regions, but there are also more specialised regions. The emergence of specialisation in less technologically intensive fields covered by designs and trademarks could point to growth in service innovation or design-based innovation in lagging regions. Better performance in designs can be found, for example, in the Polish regions of Małopolskie (PL21) and Wielkopolskie (PL41), while trademarks play a prominent role in Andalucia (ES61) and in many Bulgarian regions (Figures 4.2-11 and 4.2-12). Bulgaria already outperforms the EU average as regards trademarks and design applications per unit of GDP. The changes in design and trademark applications over time show high growth rates in many regions of eastern and southern Europe and imply a catching-up process by some regions.

Figure 4.2-11 Growth in trademark applications between 2010 and 2018

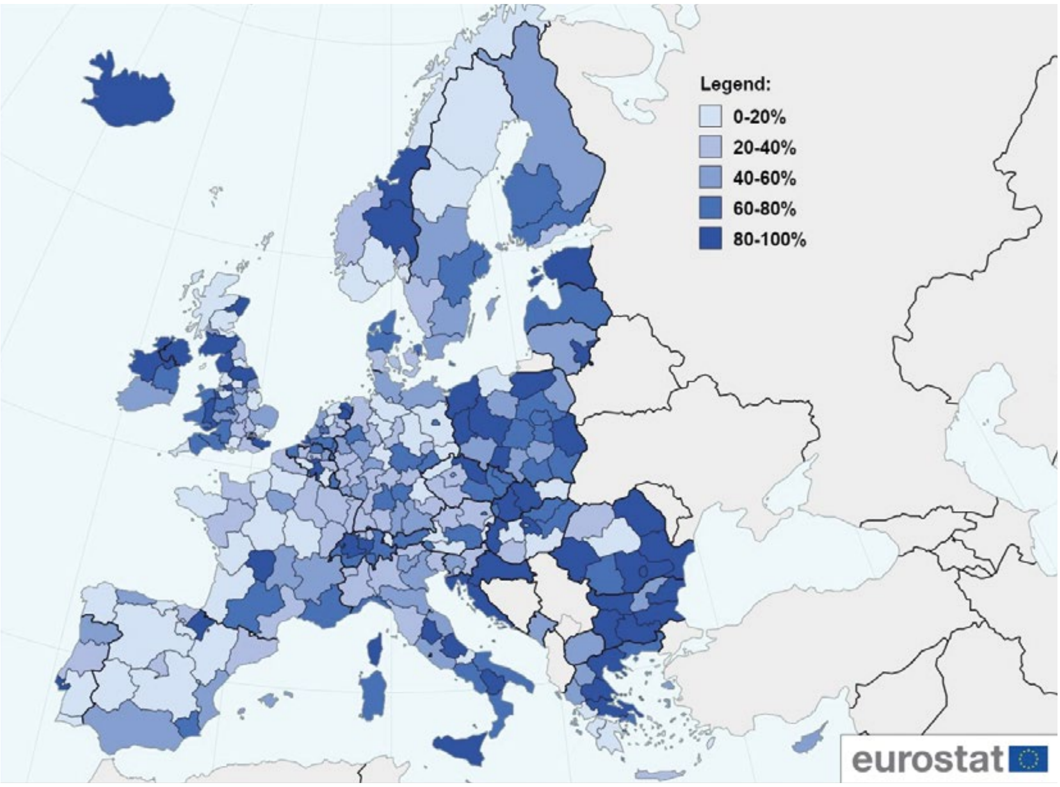


Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit

Note: Data produced by Science-Metrix using data from the EUIPO database. The highest quintile shows regions with the highest increase from 2010 to 2018.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter42/figure-42-11.xlsx

Figure 4.2-12 Growth in design applications between 2010 and 2018



Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit

Note: Data produced by Science-Metrix using data from the EUIPO database. The highest quintile shows regions with the highest increase from 2010 to 2018.

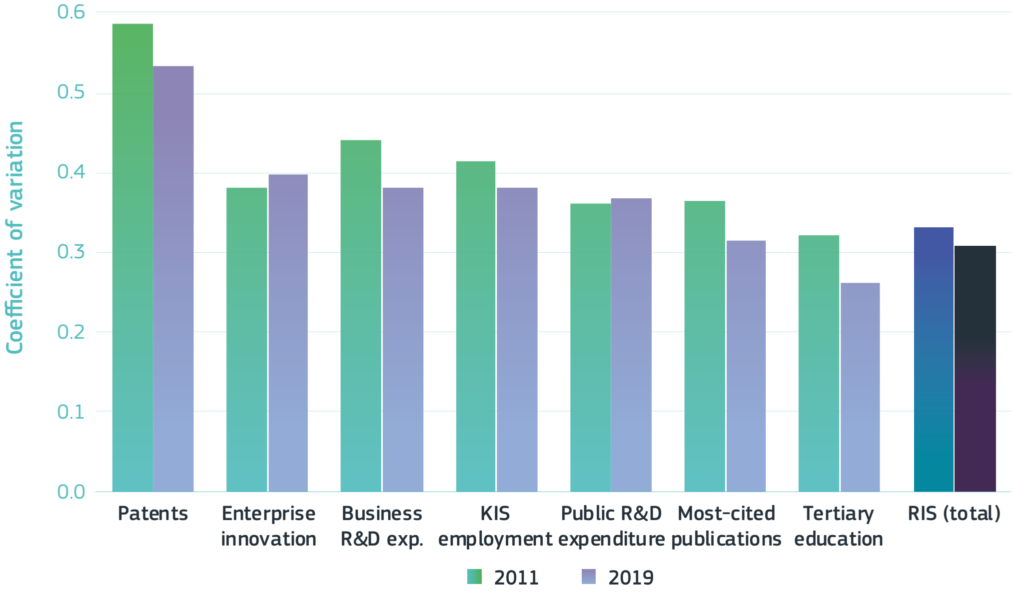
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter42/figure-42-12.xlsx

2. Technological output remains concentrated

The Regional Innovation Scoreboard (RIS) results show a convergence in R&I performance across the EU for the period 2011-2019. Nevertheless, a group of low-performing regions has barely improved and has slowed down the convergence process. The dispersion of regions in terms of innovation performance declined between 2011 and 2019[9]. Performance increased in two thirds of the regions (159 out of 238) but decreased in one third (79 regions). The share of regions that improved was 55 % in the innovation-leader category, 64 % in the strong-innovator category and 80 %, the highest share, in the moderate-innovator category. However, only 45 % of regions within the modest-innovator category improved and several regions in this category showed significant negative growth rates.

The RIS convergence trends confirm that R&I output linked to business shows significant gaps (e.g. patents) or lack of convergence (e.g. enterprise innovation). Figure 4.2-13 depicts in nutshell some of the trends described earlier. Tertiary attainment and top scientific publications are at the frontier of the convergence process, although some other indicators show persistent differences. a more detailed look at Regional Innovation Scoreboards would enable a better understanding of these indicators and regional developments.

Figure 4.2-13 Regional convergence of key R&I components in the EU (coefficient of variation), 2011 and 2019



Source: DG Regional and Urban Policy based on Regional Innovation Scoreboard

Note: The coefficient of variation (CV) is the ratio of the standard deviation to the mean, which shows the extent of variability of data in a sample in relation to the average value. The higher the coefficient of variation, the greater the level of dispersion around the mean.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter42/figure-42-13.xlsx

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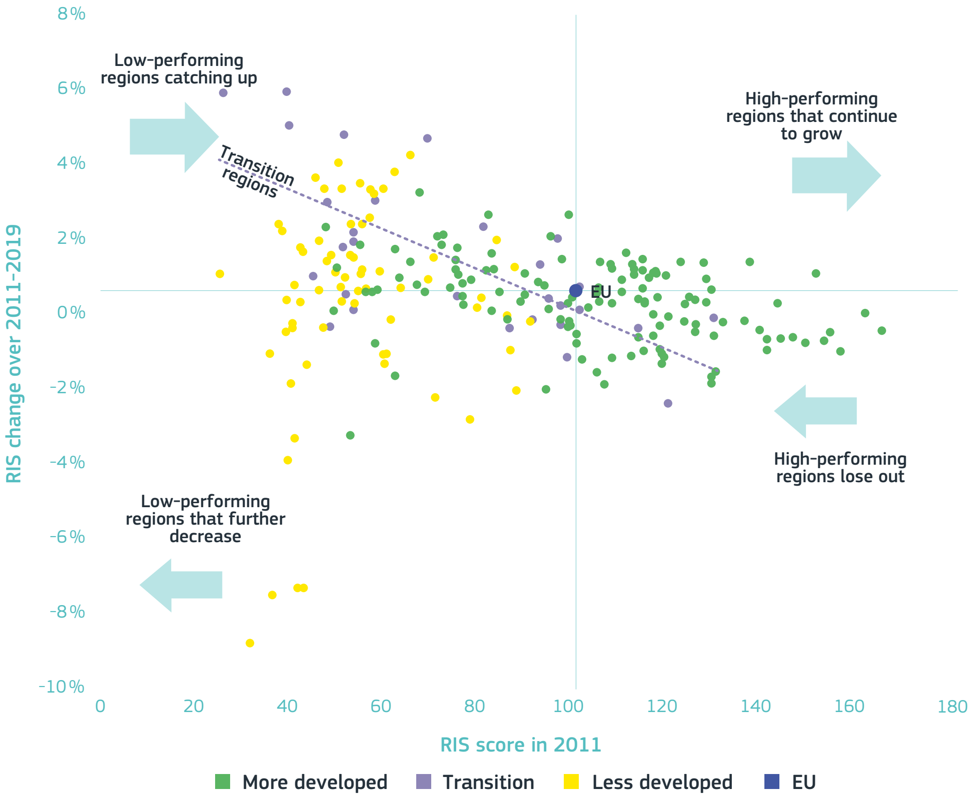
[9] The coefficient of variation of the regional scores was 0.314 in 2011 and 0.300 in 2019.

The overall R&I performance and convergence pattern differ according to the level of economic development, with a stronger convergence pattern in transition regions. The so-called transition regions, reaching 75-90% of the EU's average GDP, showed a convergence trend with a higher catch-up of low performers in this group and a declining rate of growth with higher levels of R&I performance. The performance of less-developed regions is influenced by a group of low-performing regions where performance has deteriorated significantly over the last decade (Figure 4.2-14). The majority of low-developed regions are in the CESEE countries and are considered to be moderate or modest innovators. Their poor digital capacities together with certain other bottlenecks, such as low R&D investment, could hinder higher absorption of current and future innovations. This issue, coupled with some skills gaps and underdeveloped innovation systems, could perpetuate their poor ability to transform R&D investment into scientific and technological capacity and might further restrict the region's potential to boost its economic growth from an improved innovation performance.

Figure 4.2-14 Regional convergence as measured by the European Regional Innovation Scoreboard, regions by level of economic development



Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on Regional Innovation Scoreboard 2019 and 2011

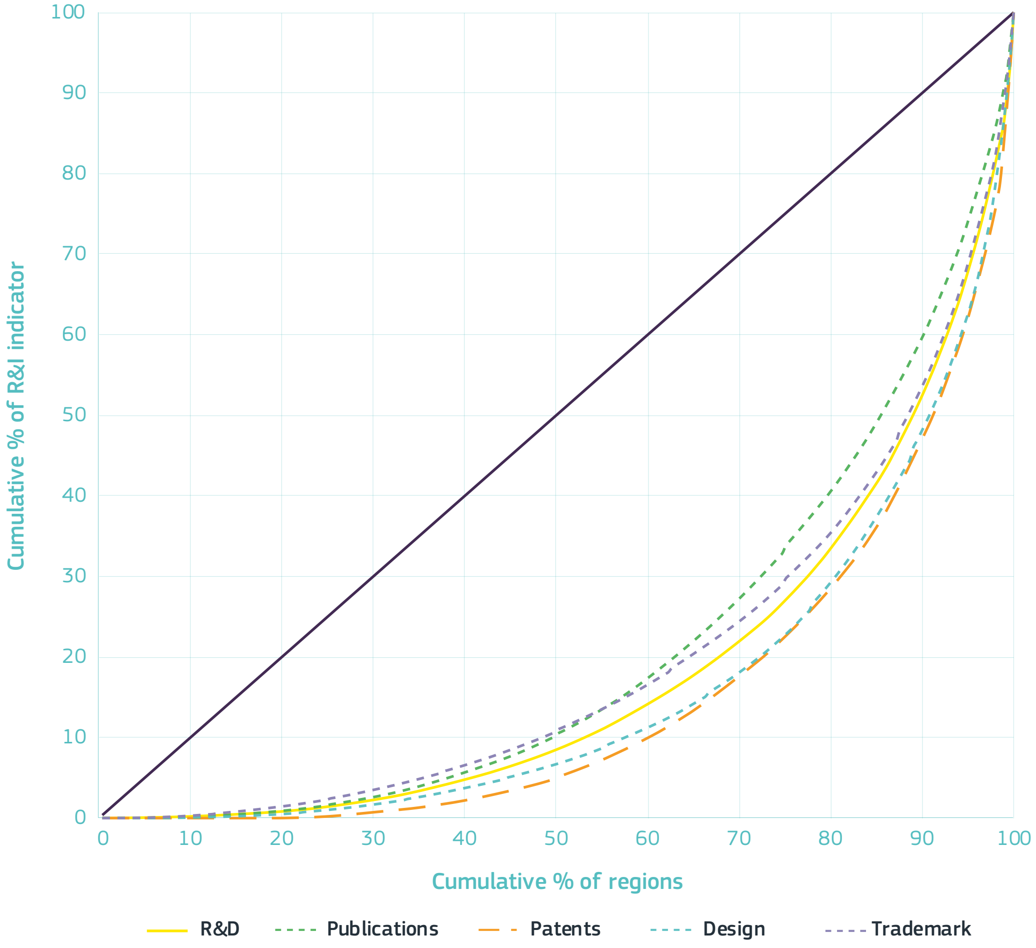
Note: The level of regional development refers to the GDP per capita of each region, measured in purchasing power parities (PPS) and calculated on the basis of EU figures for the period 2007-2009, and relates to the average GDP of the EU for the same reference period.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter42/figure-42-14.xlsx

Regional performance is affected by the capacity of regions to ride the undergoing innovation wave by producing, diffusing and adopting technologies which change the way we produce and compete globally. The high concentration of R&I activities and agglomeration effects imply that regions where these investments are located have an initial advantage, while those regions at the periphery need to rethink their economic growth model in order to position themselves better in global value chains. As long as these developments prevail over the benefits of knowledge spillovers, tailored R&I policy is needed to promote territorial cohesion and inclusive growth (see more on policy design in Chapter 12 – The research and innovation divide in the EU and its economic consequences), as well to manage the related social, economic and political consequences of widespread discontent (Dijkstra et al., 2018).

Despite overall convergence trends among European regional R&I systems, there is still a strong concentration in technological output. Patenting activity together with design applications show higher regional concentration than the numbers of scientific publications and less technologically demanding trademarks (Figure 4.2-15). The graph below shows that 70 % of regions hold a share of around 28 % of publications compared to only 18 % of patent applications. An increase in scientific output has narrowed the gap in scientific publications relative to the scientific leaders in Europe. In order to boost the overall performance of the R&I system, European regions have to increase the production of knowledge at the frontier while their business partners must reach high adoption rates. a weak technological innovation characterised by a focus on innovation in the service sector, along with an innovation activity in the low-tech and medium-tech manufacturing sector would not equip countries and regions well for the digital transformation. It is the complexity of technological developments and the novelty of business models that often restrict firms from becoming more innovative and thus hinder their competitiveness. The increasingly digital economy, characterised by 'winner-takes-all' dynamics, hampers the stronger uptake of innovations across companies, sectors and regions.

Figure 4.2-15 Regional concentration of R&I components[1]



Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on Eurostat, Science-Metrix based on EIPO database, Patstat, Web of Science

Notes: (1)Cumulative percentage shares within European NUTS2 regions. (2)Data refers to R&D investment in 2015, scientific publications in period 2013-2017, patent applications in 2014 and design and trademark applications in 2018.

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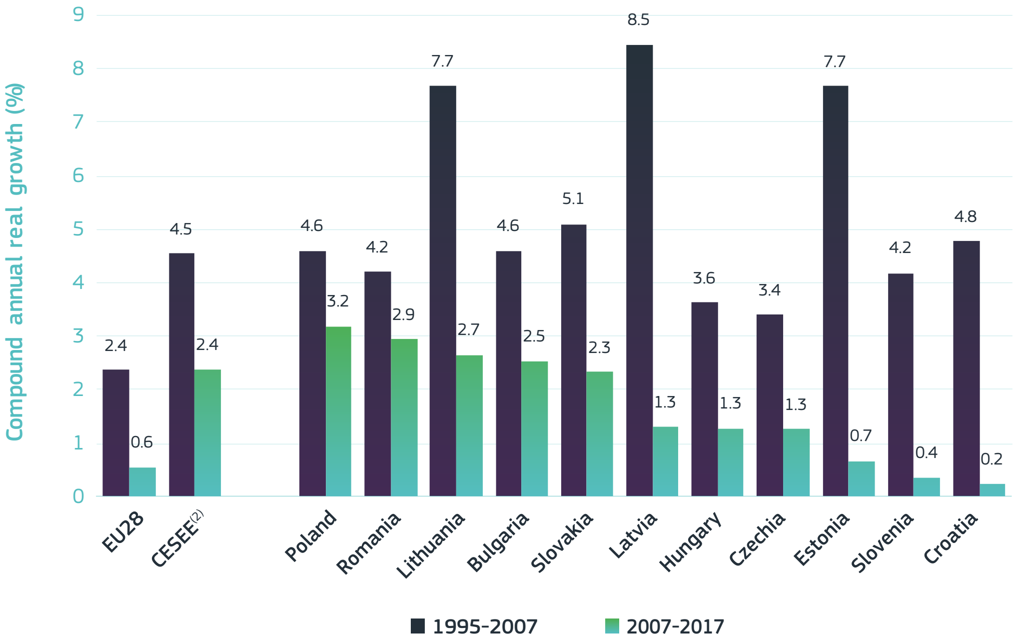
3. Stronger innovation could boost regional productivity and economic growth

Over the last two decades, the EU has shown convergence in economic output with many poorer countries catching up. However, the trajectory of economic convergence is changing as central and eastern European countries continue to converge more slowly and southern countries are falling behind. New Member States with a lower initial GDP per capita (in relative terms) have exhibited a higher speed of convergence towards the EU average. In the post-crisis decade, economic growth in CESEE countries slowed down and was mainly associated with slower TFP growth (Alcidi et al., 2018). On the contrary, the position of some southern Member States with an initially higher GDP per capita has deteriorated in relation to the EU. Four countries that were below the EU average in 2000 (Greece, Cyprus, Spain and Portugal) did not manage to keep pace with it and their relative position deteriorated (Figure 4.2-16).

Figure 4.2-16 GDP per capita[(1)] - compound annual real growth (%), 1995-2007 and 2007-2017



Science, research and innovation performance of the EU 2020

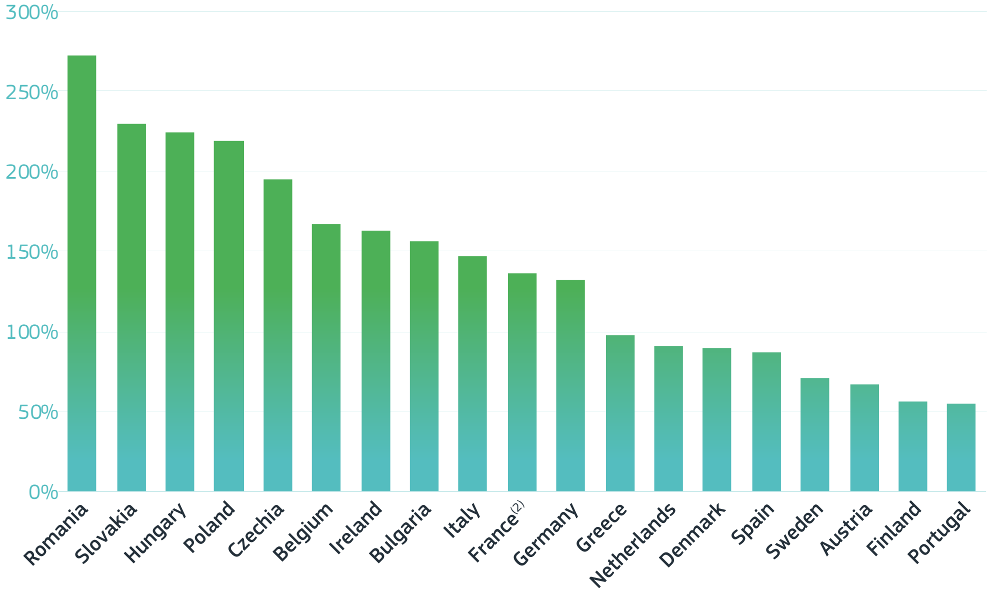
Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on Eurostat and DG Economic and Financial Affairs data

Notes: (1)GDP per head of population in PPS€ at 2005 prices and exchange rates. (2)CESEE: BG+CZ+EE+HR+LV+LT+HU+PL+RO+SI+SK.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter42/figure-42-16.xlsx

While trends at the national and regional level suggests that poorer Member States and regions have been converging towards a higher level of GDP per capita since 2000, there has been an increasing divergence within many countries. In terms of the growth rate of GDP per capita, convergence at the regional level has been particularly strong in Bucharest and Bratislava, enabling them to surpass the national growth rates. At the same time, these strong growth rates also contribute to inequalities within countries at the regional level (Figure 4.2-17). These exceptionally high regional growth rates reveal that country aggregates contain different patterns at regional level. This is the case in many central and eastern European countries, where capitals are accelerating the convergence process while the rest of the country lags behind. On the other hand, some regions have performed below their national average. Such regions are also among Greek, Italian and Spanish regions which suggests that that some of these underperforming regions either remained poor or became even poorer relative to the EU.

Figure 4.2-17 GDP per head of population(1) – the difference between the highest and the lowest NUTS2 regional values as% of the lowest value in 2017(3)



Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on Eurostat data

Notes: (1)GDP per head of population in current PPS€. (2)French NUTS2 regions Guadeloupe, Martinique, Guyane, La Réunion and Mayotte not included in the calculation. (3)HR, CY, LV, LT, LU, MT, SI excluded due to low number of NUTS2 regions.

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Labour productivity growth has been stronger in those regions that have traditionally lagged behind. Nevertheless, slower productivity growth over the last 10 years, notably in some less-developed and transition regions, explains the slowdown in the convergence process (Figure 4.2-18). Within the less-developed regions, there is a tendency for stronger growth rates in regions that started from lower levels, reflecting the convergence process. Nevertheless, despite their strong growth rates, all less-developed regions show levels of labour productivity that remain below the EU average (except Basilicata region in Italy)[10]. Over the last two decades, labour productivity growth rate has been higher in the low-developed regions (mainly CESEE) than in the EU. However, since the onset of the global financial and economic crises, several countries in the region have experienced low levels of labour productivity growth – in some cases, such as Slovenia and Hungary, labour productivity growth was even lower than the EU average. Regional productivity went through the same development and, after a convergence period, notably in the period 2000-2009, progress came to a halt after the crisis and there has only been a slight increase in divergence since 2013.

There is a mixed evidence on productivity growth in the European metropolitan and capital regions[11,12]. Capital regions in the east of the EU show the fastest productivity growth, while productivity has been shrinking in capital cities across the centre and south of the EU. Productivity growth in capital regions was notably slow in southern Europe (EL, PT, IT, ES) and in centrally located EU countries (AT, DE), where it fell between 2010 and 2017.

The potential of leading (superstar) cities and regions that benefit from agglomeration economies and have access to the intangible assets and human capital required by the increasing complexity of innovation is likely to gain in importance. The overall productivity growth in the United States has slowed considerably, accompanied by a stark gap between the high productivity of the relatively few metropolitan areas with very high shares of innovation industries and those without them (Atkinson et al., 2019). The European mapping of most specialised areas in innovation industries and the presence of large local innovation sectors that spur metro-wide productivity requires closer examination. From the initial observations, low and declining productivity growth in the service sector and a shift from industry to services contribute mainly to dampening down productivity growth in capital regions and other regions with large cities.

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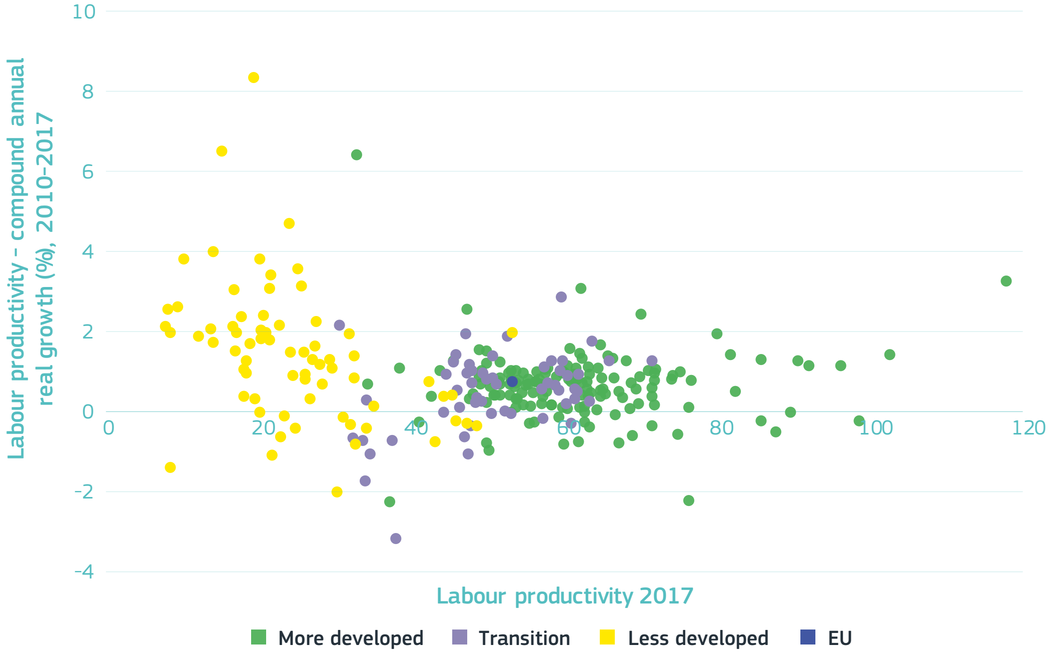
[10] The region of Basilicata has 0.57 million inhabitants but is home to a plant in Melfi where Fiat invested EUR 1 billion to boost production. This plant, with 8 000 employees, plays a big part in Basilicata's economy and is responsible for the recent boost in the region's economic output.

[11] Labour productivity calculations based on output-weighted average Eurostat data for capital regions and other regions with cities with over 0.5 million inhabitants, for the period 2010-2017.

[12] Metropolitan regions are NUTS3 regions or a combination of NUTS3 regions which represent all agglomerations of at least 250 000 inhabitants.

Figure 4.2-18 Labour productivity (GVA per person worked), 2017 and compound annual growth 2010-2017(1)(2)(3)



Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on DG for Regional and Urban Policy data

Notes: (1)EL+PL regions labour productivity value 2016 and growth 2010-2016. (2)French NUTS2 regions divided by level of development according to Eurostat 2017 calculations, not including Régions ultrapériphériques. (3)Data includes regions from United Kingdom.

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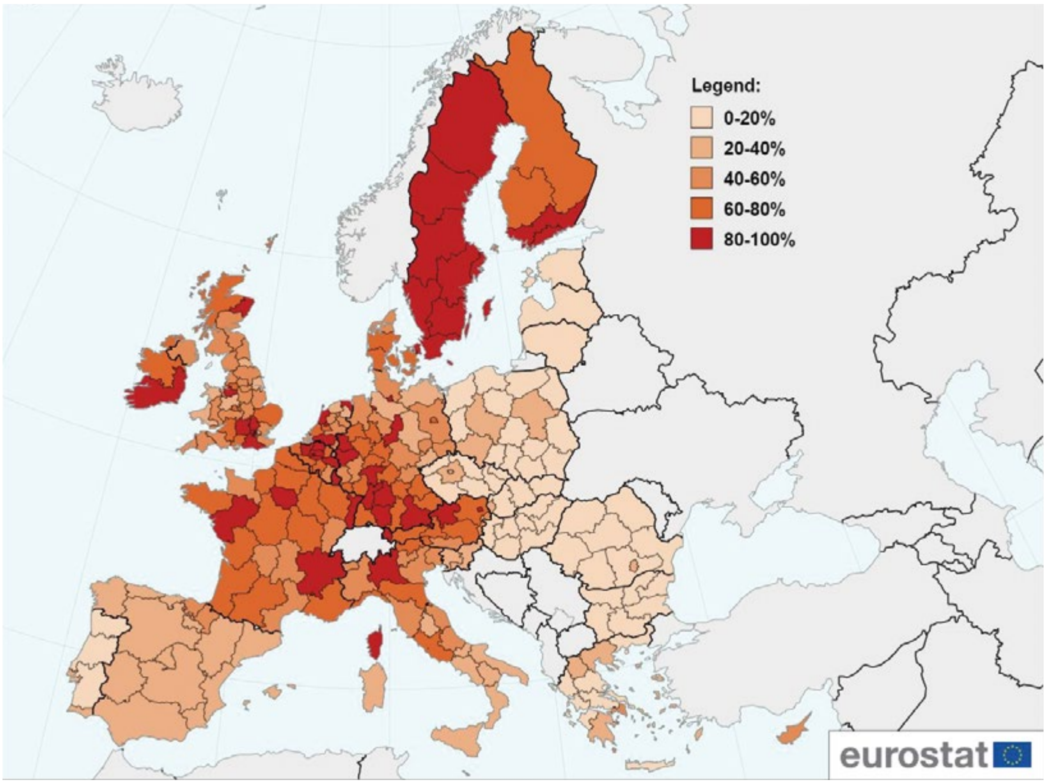
Lower labour productivity growth rates reflect the stagnation, or even the decline, in TFP growth over the last decade. Economic growth and social prosperity rely on the ability of an economy to mobilise all available resources while boosting productivity growth. TFP is arguably the best predictor for long-term economic growth and reflects an economy's overall efficiency and ability to work more smartly and produce higher value-added products and services. There is a clear divide in total factor productivity among regions in the eastern and southern part of the EU and the rest (Figure 4.2-19). Most of the regions in the eastern part of Europe have shown high growth rates during the last two decades. However, at the same time, many regions in the south of Europe, notably in southern Italy and Greece, have been falling behind in total factor productivity growth.

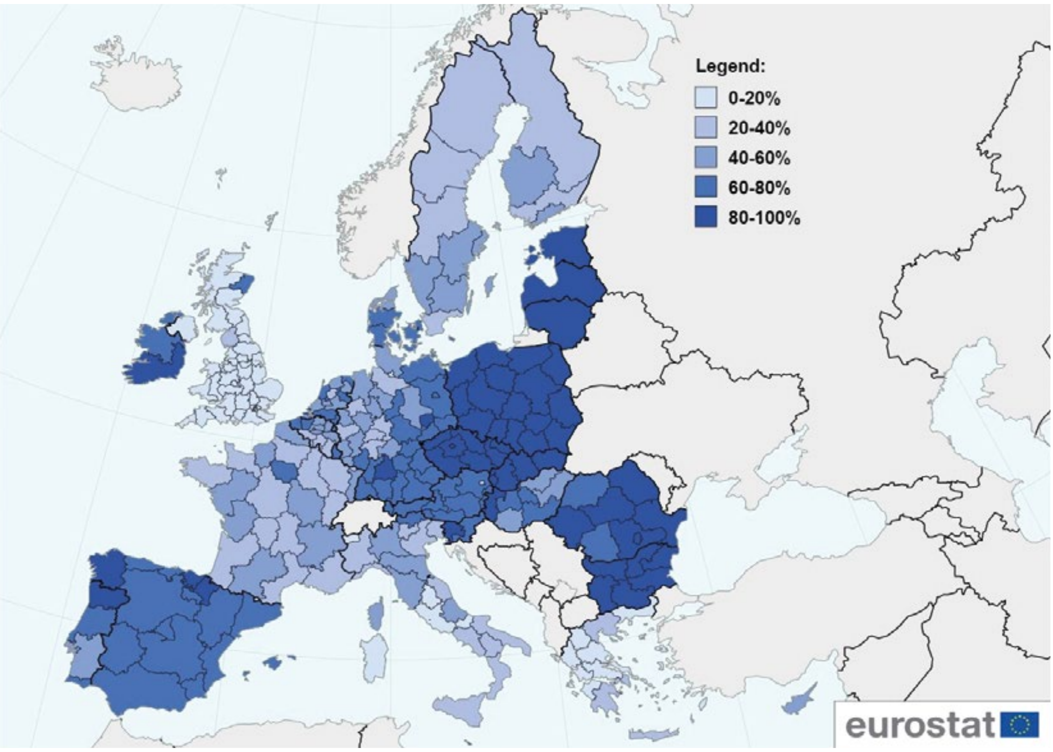
Figure 4.2-19 Total factor productivity in the EU28, 2015



Source: European Commission, DG Employment, Social Affairs and Inclusion

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter42/figure-42-19.xlsx

Figure 4.2-20 Total Factor productivity growth in the EU28 between 2005 and 2015



Source: European Commission, DG Employment, Social Affairs and Inclusion

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For more developed economies, boosting TFP growth is closely associated with the ability to foster innovation creation and diffusion. Although there are many factors explaining TFP growth, ranging from how institutions function and the rule of law (see more on institutional quality in Chapter 8 - Framework Conditions) to better infrastructure or high levels of education, TFP growth in high-income countries and regions is typically supported by a high level of technological advancement and innovation. Business enterprise R&D (BERD), as a proxy for innovation capacity, is highly correlated with TFP for high-income regions, whose prosperity rely on the ability to innovate (Figure 4.2-21).

More focus on R&I-driven growth and innovation diffusion would support productivity growth. As many less-developed (located predominantly in central and eastern European countries)[13] and transition regions approach higher levels of prosperity, avoiding a 'middle-

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[13] According to Regulation 1303/2013, the classification of regions into three categories shall be determined on the basis of how the GDP per capita of each region, measured in purchasing power parities (PPS) and calculated on the basis of EU figures for the period 2007-2009, relates to the average GDP of the EU for the same reference period.

income trap' will require a new growth model based on innovation. This growth model will need to be based on new innovation activities that move beyond the traditional drivers of economic growth in the regions. The emigration of skilled labour and insufficient home-produced innovation create risks for the sustainability of the convergence process in less-developed regions, making the case for building up innovation capacity. Without counteraction, the underdeveloped regional innovation systems, skills gap and poor institutional quality will undermine the growth potential of these lagging regions (EC, 2017b).

The group of some less-developed and mainly transition regions is immediately associated with the risk of falling into a 'middle-income trap'. With higher productivity and wages, they become less attractive for labour-intensive or low-skilled activities. These regions show the lowest GDP growth, mainly because they are neither very low cost nor particularly innovative or productive. This implies that the transition regions[14] are not innovative enough to compete with the most-productive and developed regions of Europe and the world, while their cost levels are too high to compete with low-cost, less-developed regions (EC, 2017a).

Figure 4.2-21 **Total factor productivity - compound annual growth, 2004-2014 business R&D intensity, 2005**(1)(2)

Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on DG EMPL and Eurostat

Notes: (1)Based on data for 243 European NUTS2 regions. (2)Data for Croatia not available.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter42/figure-42-21.xlsx

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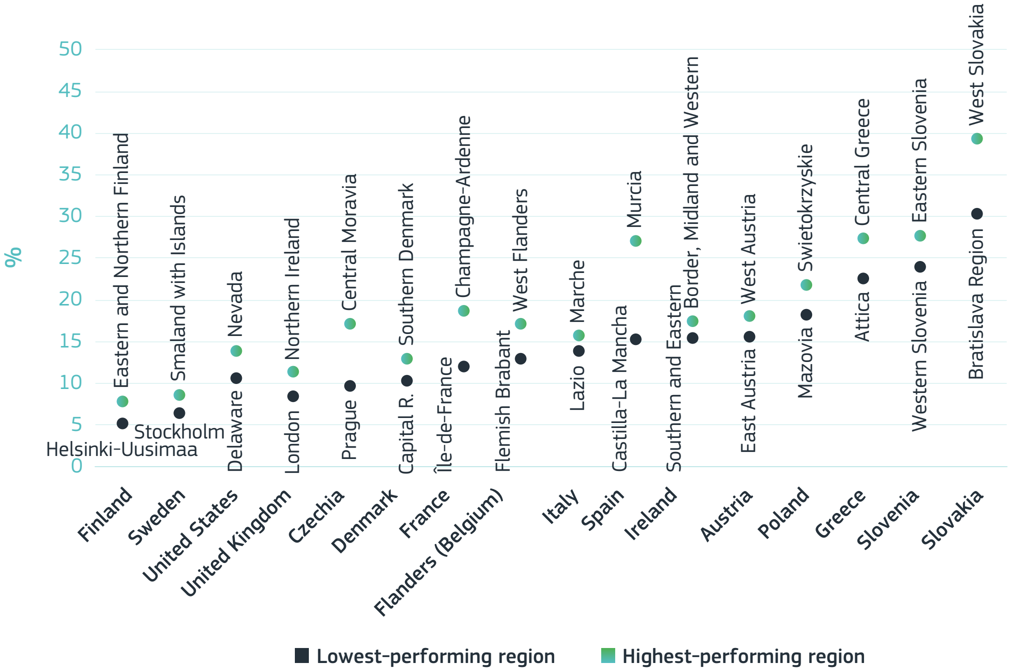
[14] As the classification of regional income groups differs, the 'Seventh report on economic, social and territorial cohesion' refers to the medium-income group of regions with a GDP per head of 75-120 % of the EU average.

Economic activity and innovation have become more concentrated in core cities and regions, which could potentially lead to a less economically and socially cohesive Europe. These internal divergences are most apparent in the growing gap between capitals and metropolitan areas where most economic and innovative activities are concentrated, on the one hand, and the declining industrial and peripheral areas, on the other hand, experiencing skilled emigration and less resilience to change. If left unmanaged, technological change is likely to widen these divergences, as shown by the most recent evidence (European Commission, 2017a; Iammarino et al., 2018).

As has been happening over the last decade, a 'geography of discontent' is emerging, with increasing distrust being shown towards political and democratic institutions. This is mainly driven by the dissatisfaction of those who are most affected by the negative impact of technological change, i.e. the older and less educated, living in industrial or decaying areas (Iammarino et al., 2018). The perceived risks are of concern as technological developments can contribute to the displacement of some current jobs, while many of the emerging and future jobs require a special set of conditions, as described above.

Figure 4.2-22 Share of jobs at high risk of automation across regions, 2016



Science, research and innovation performance of the EU 2020

Source: OECD - Job Creation and Local Economic Development 2018, based on Nedelkoska and Quintini (2018) and national Labour Force Surveys (2016)

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Jobs are increasingly becoming concentrated in a smaller number of capital or metropolitan regions. The large regional differences and concentration of new jobs in capital regions favour imbalances in employment developments. In Finland, Denmark and Ireland, more than 80% of net job creation between 2006 and 2016 took place in the capital region (OECD, 2018). Many of the new jobs were created in new industries, e.g. the number of jobs in the ICT sector for the period 2010-2017 increased by 72% in Bucharest, 31% in Berlin and 27% in Stockholm[15]. Although the 6% share of ICT employment across EU capital regions remains small compared to approximately 25% in retail and services[16], there are structural changes that will require targeted efforts to create an attractive environment for highly skilled jobs and growing industries across the regions. The transfer of skills and knowledge from mature industries often enables the emergence of new industries, but in cases of more radical technological change, the new industries draw directly from R&D (Storper et al., 2015).

To find out more, see Chapter 12 - The research and innovation divide in the EU and its economic consequences.

Summary of Andrés Rodríguez-Pose's Chapter 12 - The research and innovation divide in the EU and its economic consequences

This contribution looks at **the economic consequences of the R&I divide across EU regions** and highlights the policy challenge they represent. It reviews the theoretical factors behind current levels of territorial polarisation, maps the current state of this divide and presents an econometric approach to identifying the effects.

The core of the argument is that **R&D investment alone does not trigger the same returns on investment everywhere because of several factors**. These are linked to the cost of technology accessibility in different places, the distance to the technological frontier, positive externalities from larger and denser regions, the quality of local institutions, and hampered knowledge sharing.

Many of these factors disadvantage the less-developed regions in their efforts to broaden their innovation capacities with the aim of unleashing greater economic activity and growth. Nevertheless, most of the R&D growth in less-developed regions has been in the higher education sector, which has led to a substantial improvement in scientific output. The chapter discusses how to improve the efficiency of investment in R&I systems and strengthen innovation-driven economic growth.

In its conclusions, the chapter not only diagnoses the situation but also suggests elements of innovation policy for less-developed regions. These aim at **closing the innovation divide between more- and less-developed areas in the EU and increasing the EU's competitiveness** through a stronger role for innovation as a trigger of economic dynamism.

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[15] Employment by economic activity in NUTS2 regions. Estonia and Malta show even higher increases in ICT jobs.

[16] Wholesale and retail trade, transport, accommodation and food service activities.

4. Conclusions

Economic dynamism and productivity growth often depend on the implementation of structural policies, which do not take regional conditions into account. This implies an important role for further **place-based policies to boost underutilised regional potential and strengthen regional innovation systems**. To deliver on this ambitious innovation agenda, policymakers must align policies targeted at improving R&I capacities and territorial inequalities with **greater coordination at all levels**. These include R&I policies and Cohesion Policy, together with education and training implemented through a broad range of instruments.

European policies must put **greater emphasis on promoting innovation combined with more focus on the local context** to trigger economic dynamism in less-developed regions. An ambitious innovation agenda at the regional level should not focus solely on comparing performance with more-advanced regions but must embed local issues. Place-based approach in promoting innovation, especially the diffusion and commercialisation of existing innovation in lagging regions, is essential and should be supported in line with the specificities of each region and its current or possible comparative advantages as mapped in 'smart specialisation strategies'. Effective public support for innovation must understand the specificities of both the national and regional innovation systems and build on these. Furthermore, the substantial variation across EU regions in terms of institutional performance calls for **improvements in institutional quality**. The local authorities play a major role in well-tailored innovation strategies as well as in the efficiency of R&I programmes, combating corruption and tackling market failures such as the weak take-up of technology.

Policy in lagging regions can contribute to **improving economic competences**, especially managerial competences in firms, including internal processes and organisational structure, and **building technological capacities**, for example, by supporting technology transfer. The **reinforcement of local R&D capacities** and **pursuit of radical innovation** can be targeted by a mix of initiatives, such as **public procurement for innovation** on the demand side or dedicated supply-side measures.

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CHAPTER
5.1

INVESTMENT IN R&D

KEY FIGURES

17 %
of world R&D
expenditure
attributed
to the EU

1 %
annual increase
of EU R&D
intensity
since 2000

24
Member States
have increased
their R&D
intensity
since 2000

2/3
of EU R&D expenditure
performed by the
business sector

7 %
of EU public funding
comes from the
European Commission

What can we learn?

- With only 6% of the world population, the **EU accounts for almost 20% of global R&D expenditure**.
- **With 2.19% of its GDP invested in R&D, the EU is still far from its 3% target**. It underinvests compared to its main competitors, especially in terms of private investments.
- **EU R&D expenditure is largely dominated by a limited number of big countries** (61% in Germany, France and Italy together).
- **R&D intensity increased over the 2000-2018 period in 24 Member States**, with national R&D intensity ranging from 0.5% in Romania to 3.3% in Sweden.
- Member States are slowly steering their national budgets towards societal and environmental challenges.

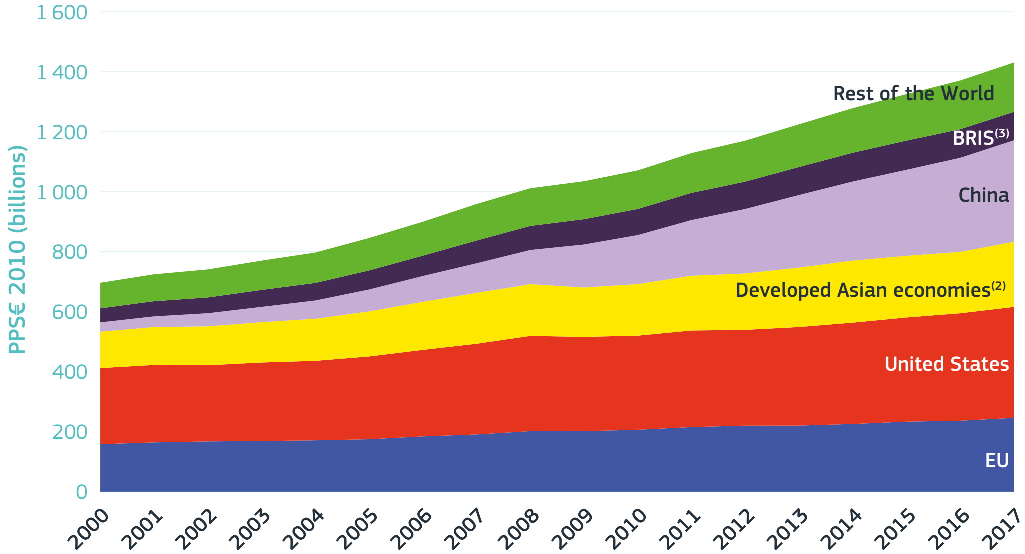
What does it mean for policy?

- R&I policy needs to **leverage further efforts in R&D investments**.
- Because of the scope, scale and urgency of the societal challenges facing Europe, policy is required to **pay more attention not just to the volume of R&D investments, but also to the overall direction of these investments**.
- Given the **significant increase in R&D tax incentives** over the last decade, there is a need to assess the use of this instrument in supporting transitions that require coordinated and strategic investment.

1. EU's share in world R&D expenditure is declining

World R&D expenditure is continuing to increase as all major regions have boosted their R&D spending. The EU's relative weight in this global R&D landscape is decreasing, although it still accounts for almost 20 % of global R&D expenditure. In 2017, the EU represented 17 % of total R&D expenditure in the world[1], down from 22 % in 2000 (Figure 5.1-1). The EU's continuously declining EU's share in world R&D expenditure is mainly due to the rapid rise of China whose share has increased almost fivefold from 5 % in 2000 to 24 % in 2017. The decline of the US share since 2000 has been even more pronounced than that of the EU, from 37 % in 2000 to 26 % in 2017. The share of the developed Asian economies shrank from 18 % in 2000 to 15 % in 2010, while the rest of the world's share has remained stable at around 12 %.

Figure 5.1-1 Evolution of world expenditure on R&D in real terms(1), 2000-2017



Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on Eurostat, OECD, UNESCO

Notes: (1)GERD in PPS€ at 2010 prices and exchange rates. (2)Japan+South Korea+Singapore+Chinese Taipei. (3)Brazil+Russian Federation+India+South Africa.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter51/figure-51-1.xlsx

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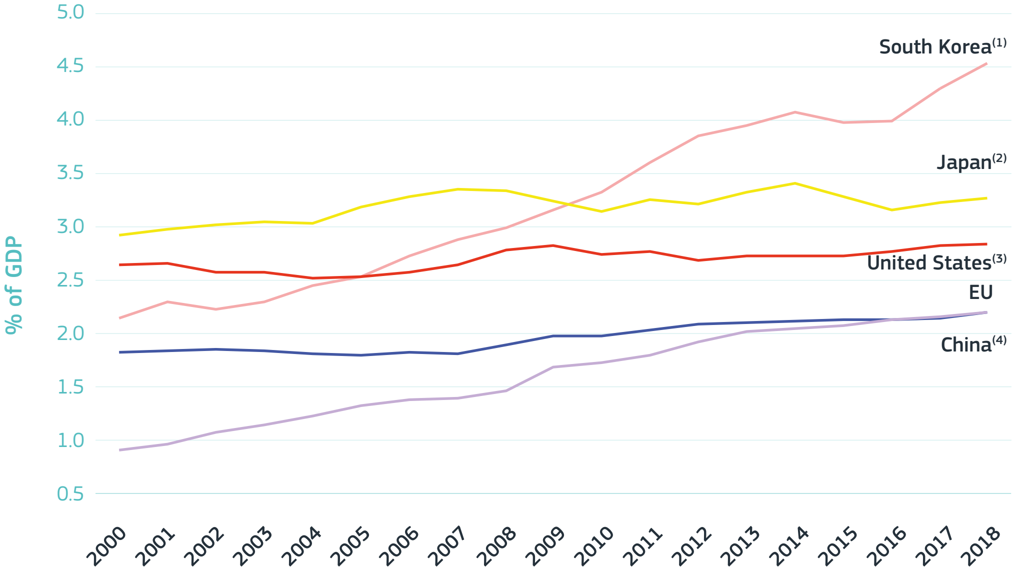
[1] R&D expenditure is measured in PPS€ at 2010 prices and exchange rates.

The EU's relatively strong position in the world R&D landscape is partly due to R&D investment[2] being one of the five Europe 2020 headline targets[3]. The EU's target of devoting 3 % of its GDP to R&D activities and further national targets have mobilised increasing resources for R&D in the last two decades. In addition, R&D intensity targets have led to the portfolio of R&I support instruments becoming more complex, experimentation with new policies, and greater attention to impact assessment and evaluation (Box 5.1-1).

Although R&D expenditure in the EU has been increasing annually by 1% since 2000, it remains lower than the 3% Europe 2020 target, and visibly below the performance of most of its main competitors. At the EU level, R&D intensity increased from 1.81% in 2000 to 2.19% in 2018. However, to meet the 3% target by 2020, its R&D intensity would have to increase by more than 10% per year. R&D as a share of GDP in the EU is smaller than in South Korea (4.53%), Japan (3.26%) and the United States (2.83%). China has more than doubled its R&D intensity since 2000 and in 2018 its R&D-to-GDP ratio was equal to the EU's (Figure 5.1-2).

Figure 5.1-2 Evolution of R&D intensity, 2000-2018



Source: Eurostat (online data code: rd_e_gerdtot), OECD (Research and Development Statistics)

Notes: (1)South Korea: There is a break in series between 2007 and the previous years. (2)Japan: There is a break in series between 2008 and the previous years and between 2013 and the previous years. (3)United States: (i) R&D expenditure does not include most or all capital expenditure; (ii) There is a break in series between 2003 and the previous years. (4)China: There is a break in series between 2009 and the previous years.

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[2] The R&D objective set at the EU level is expressed in terms of R&D intensity which measures the share of GDP invested in R&D.

[3] At the 2002 Barcelona Summit, the European Council agreed that the EU should set the objective of devoting 3% of its GDP to R&D activities by 2010. In 2010, this target became one of five headline targets in the Europe 2020 Strategy to be achieved by 2020 (European Commission, 2010).

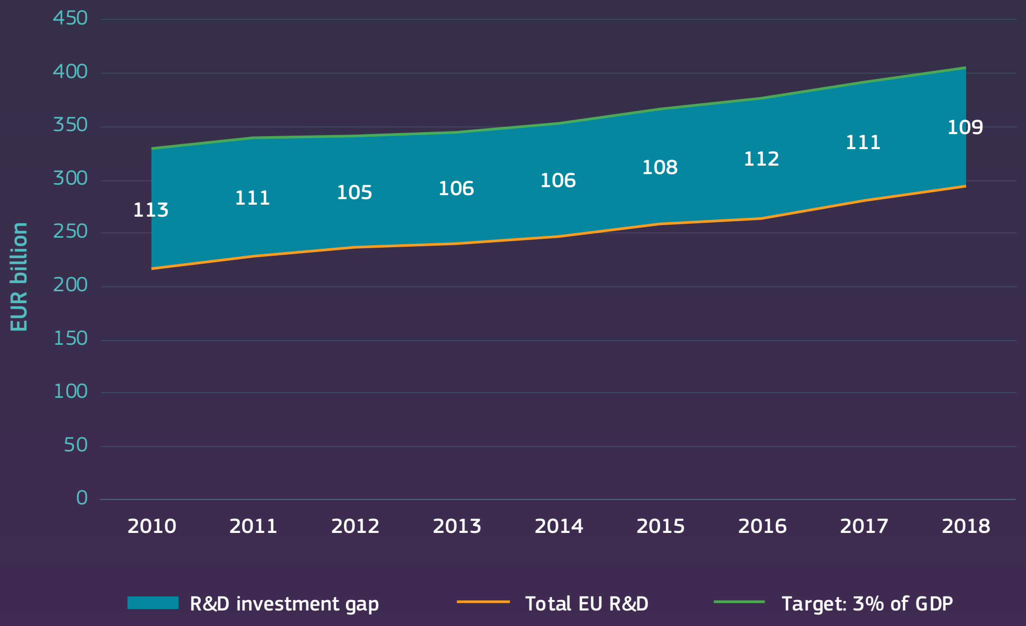
BOX 5.1-1 The 3 % target

As the Europe 2020 Strategy has come to an end, the 3 % investment target ceases to have a legal basis. The objective of investing 3 % of GDP in R&D was first set in the Lisbon Strategy with the aim of turning the EU into the most competitive and dynamic knowledge-based economy in the world by 2010. The ambition was reset in the Europe 2020 Strategy with a focus to 'increase combined public and private investment in R&D to 3 % of GDP' by 2020.

The Commission has monitored Member States' progress through the yearly European Semester cycle. At the beginning of 2020, the EU is still a long way from meeting its target. Although it has made progress over the past decade, the United States and key competitors in Asia invest in R&D at a higher rate than the EU. In order to reach an investment in R&D corresponding to 3 % of its GDP, the EU would need to invest an additional EUR 110 billion per year (Figure 5.1-3).

Although the EU has not fulfilled its R&D investment ambition, the 3 % target has proven to have had a clear mobilising effect as all Member States have set their own national targets. It has also stimulated reflections across Member States on their economic model and policy mix. It is a strong indicator within the European Semester that has provided a stimulus to the EU's R&I, growth and competitiveness policy. It is also an essential compass that can help accelerate the transition towards an environmentally, socially and economically sustainable Europe.

Figure 5.1-3 R&D investment gap in EU



Science, research and innovation performance of the EU 2020

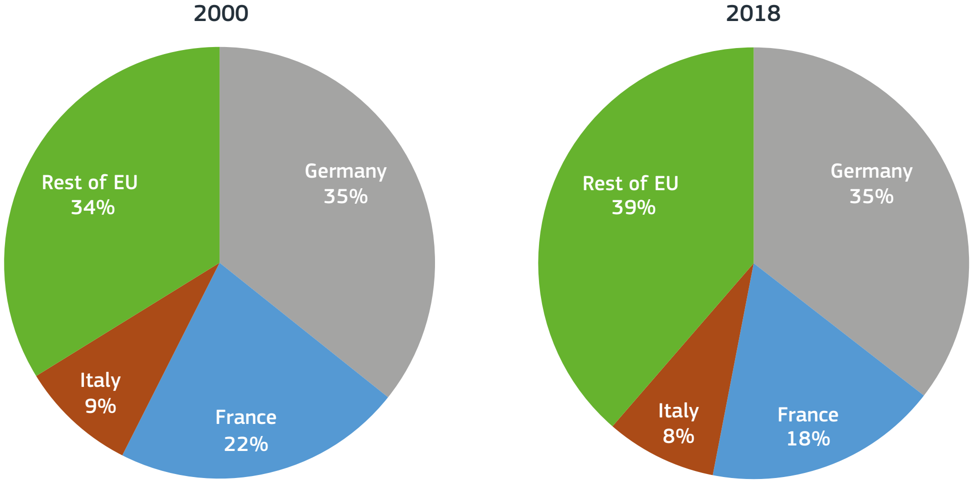
Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on Eurostat (online data code: rd_e_gerdtot)

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter51/figure-51-3.xlsx

EU R&D intensity is largely influenced by a limited number of big countries[4]: namely, 61 % of the EU's R&D expenditure in 2018 was performed in Germany, France and Italy. R&D expenditure in the other EU countries together has increased by 5 % since 2000 (Figure 5.1-4). However, Germany alone still accounts for almost the same amount of R&D spending as other 24 Member States combined. Hence, to a large extent, the overall EU R&D intensity is determined by its value in these three countries. If they do not set more ambitious targets and move forward, EU R&D intensity will not change drastically.

R&D intensity increased over the 2000-2018 period in 24 Member States. Despite this obvious progress, most Member States remained far from their national 2020 targets. The intensity of R&D spending across EU Member States varies considerably, with national R&D intensity ranging from 0.5 % in Romania to 3.3 % in Sweden. To a large extent, these big differences can be explained by their industrial specialisations, quality of academic research environment, and access to a large integrated technology market[5]. Three countries have already reached their 2020 target: Germany (3.13 %, with a target of 3 %), Denmark (3.03 %, with a target of 3 %) and Cyprus (0.55 %, with a target 0.5 %). Many of the countries with the lowest initial level of R&D intensity made the greatest progress. R&D intensity in Czechia, Cyprus, Greece, Estonia, Hungary and Poland[6] increased by more than 2.5 % annually from 2000 to 2018, while Sweden and Finland, with the highest initial R&D intensity[7], faced declining intensity growth.

Figure 5.1-4 Distribution of Gross Domestic Expenditure in R&D (GERD) within the EU, 2000 and 2018



Source: Eurostat (online data code: rd_e_gerdtot)

Note: (1)France: break in series between 2010 and the previous years.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter51/figure-51-4.xlsx

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[4] The levels of R&D expenditure in Germany, France and Italy play an important part in aggregate EU R&D intensity.

[5] van Pottelsberghe, 2008.

[6] In 2000, the R&D intensity in Cyprus was 0.23 %, Greece 0.56 %, Estonia 0.6 %, Hungary 0.79 % and Poland 0.64 %.

[7] In 2000, the R&D intensity in Sweden was 3.91 % and Finland 3.25 %.

Figure 5.1-5 Situation of each Member State with regard to its R&D intensity target[(6)(8)]

	R&D intensity 2018	R&D intensity target 2020	R&D intensity compound annual growth (%) 2000-2018[(1)]	R&D intensity compound annual growth (%) 2010-2018	R&D intensity compound annual growth (%) required to meet the 2020 target 2018-2020
Belgium	*2.76*	*3.00*	2.0	3.7	4.2
Bulgaria	*0.75*	*1.50*	2.4	3.6	41.0
Czechia[(7)]	*1.93*	*:[(2)]*	3.1	4.7	:
Denmark	*3.03*	*3.00*	1.7	*0.5*	*Target reached*
Germany[(7)]	*3.13*	*3.00*	1.5	*1.7*	*Target reached*
Estonia	*1.40*	*3.00*	4.8	-1.4	46.2
Ireland	*1.15*	*2.00[(3)]*	0.3	-4.0	32.1
Greece	*1.18*	*1.30*	4.6	8.8	5.1
Spain	*1.24*	*2.00*	1.9	-1.1	26.8
France	*2.20*	*3.00*	0.5	0.1	16.8
Croatia	*0.97*	*1.40*	0.1	3.4	20.0
Italy	*1.39*	*1.53*	1.8	1.6	4.8
Cyprus	*0.55*	*0.50*	5.0	*2.7*	*Target reached*
Latvia	*0.64*	*1.50*	2.1	0.6	53.2
Lithuania	*0.88*	*1.90*	2.3	1.4	47.2
Luxembourg	*1.21*	*2.30 - 2.60[(4)]*	-1.1	-1.1	42.2
Hungary	*1.53*	*1.80*	4.4	3.8	8.3
Malta	*0.55*	*2.00*	0.8	-1.2	90.6
Netherlands	*2.16*	*2.50*	0.5	2.0	7.5
Austria	*3.17*	*3.76*	2.9	1.9	8.8
Poland	*1.21*	*1.70*	3.6	6.7	18.4
Portugal	*1.35*	*2.70 - 3.30[(5)]*	2.2	-1.6	49.1
Romania	*0.51*	*2.00*	1.4	0.2	99.0
Slovenia	*1.95*	*3.00*	0.4	-3.0	24.0
Slovakia	*0.84*	*1.20*	1.5	4.0	19.7
Finland	*2.75*	*4.00*	-0.9	-3.7	20.7
Sweden	*3.31*	*4.00*	-0.6	0.5	9.9
EU	*2.19*	*3.00*	1.1	1.3	17.1

Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on Eurostat (online data code: rd_e_gerdtot and t2020_20)

Notes: [(1)]HR: 2002-2017; EL, LU, SE: 2003-2017; MT: 2004-2017. [(2)]CZ: A target (of 1.0%) is available only for the public sector. [(3)]IE: The national target of 2.5% of GNP has been estimated to equal 2.0% of GDP. [(4)]LU: A 2020 target of 2.45% was assumed. [(5)]PT: A 2020 target of 3.0% was assumed. [(6)]DK, EL, FR, IT, LU, HU, NL, PT, RO, SI, SE: Breaks in series occur between 2000 and 2018; when there is a break in series the growth calculation takes into account annual growth before the break in series and annual growth after the break in series. [(7)]DE: new 2025 target of 3.5%. CZ: new 2030 target of 3.0%. [(8)]Values in italics are estimated or provisional.

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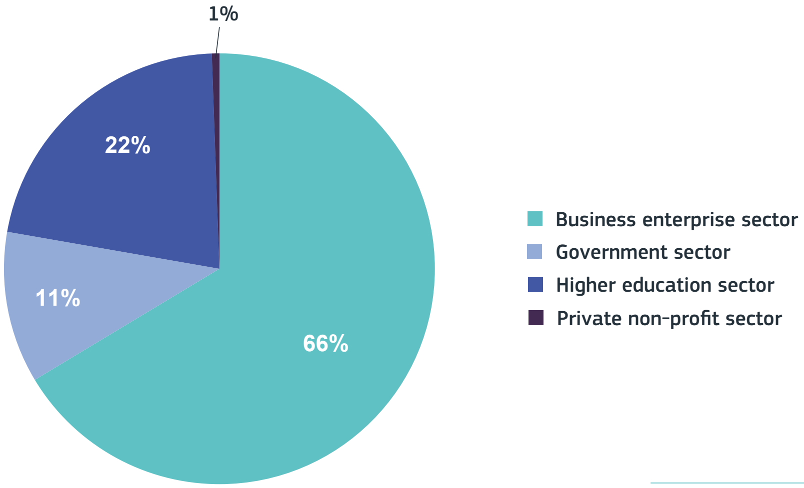
Public R&D expenditure accounts for one third of the total R&D performed in the EU, while the business enterprise sector continues to be the EU's strongest R&D performer, accounting for 66 % of total R&D expenditure in 2018. Research, development and innovation are performed by four main institutional sectors: business enterprise, government, higher education and the private non-profit sector[8] (Eurostat, 2018). Figure 5.1-6 shows the shares of R&D expenditure in Europe, performed by these sectors in 2018. Public R&D expenditure is an aggregate of R&D expenditure performed by government and higher education sectors, while private R&D expenditure represents the sum of the business enterprise and private non-profit sector[9].

Figure 5.1-6 R&D expenditure by sectors of performance (%), EU, 2018



Source: Eurostat (online data code: rd_e_gerdtot)
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter51/figure-51-6.xlsx

Over the last two decades, EU business R&D intensity has been steadily growing, while public R&D intensity has remained close to 0.7 % of GDP (Figure 5.1-7). Despite this obvious progress, EU business R&D intensity is still significantly lower when compared to other main economies: China, United States, Japan and South Korea. On the other hand, among those four countries, only South Korea has a higher public R&D intensity than the EU.

Despite a fall of 4 percentage points from 2000 to 2017, the EU is maintaining its strong position in publicly performed R&D, accounting for slightly more than one fifth of the world's public R&D expenditure. China's increasingly strong presence in the R&D landscape is also evident in the public sector, as its share of world public R&D expenditure increased from 6 % in 2000 to 19 % in 2017. Over the same period, the United States' share declined, from 26 % to 20 % (Figure 5.1-8).

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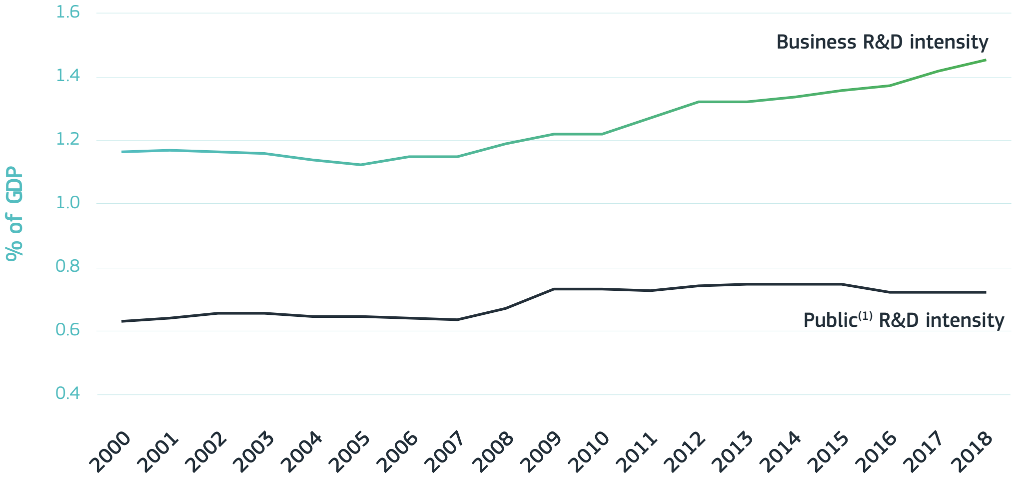
[8] Expenditures by these four sectors are measured by BERD, GOVERD, HERD and PNPRD respectively.

[9] In Europe, the private non-profit sector as an R&D performer is quite small (0.9% of GERD); consequently, when analysing private R&D expenditure, we usually only take business enterprise R&D expenditure into consideration.

Figure 5.1-7 Evolution of Business R&D and Public R&D as % of GDP in the EU, 2000-2018



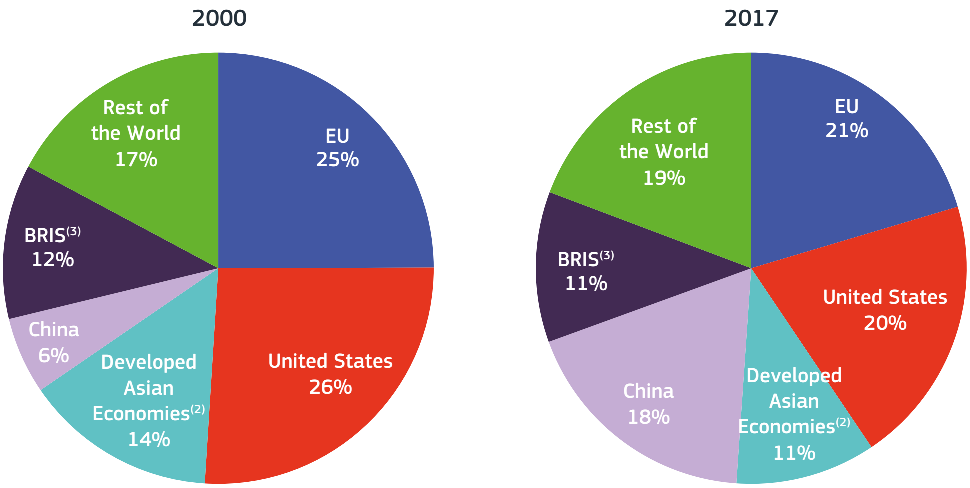
Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on Eurostat (online data code: rd_e_gerdtot)

Note: [1]Public equals to GOVERD plus HERD.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter51/figure-51-7.xlsx

Figure 5.1-8 World public expenditure on R&D -% distribution[1], 2000 and 2017



Science, research and innovation performance of the EU 2020

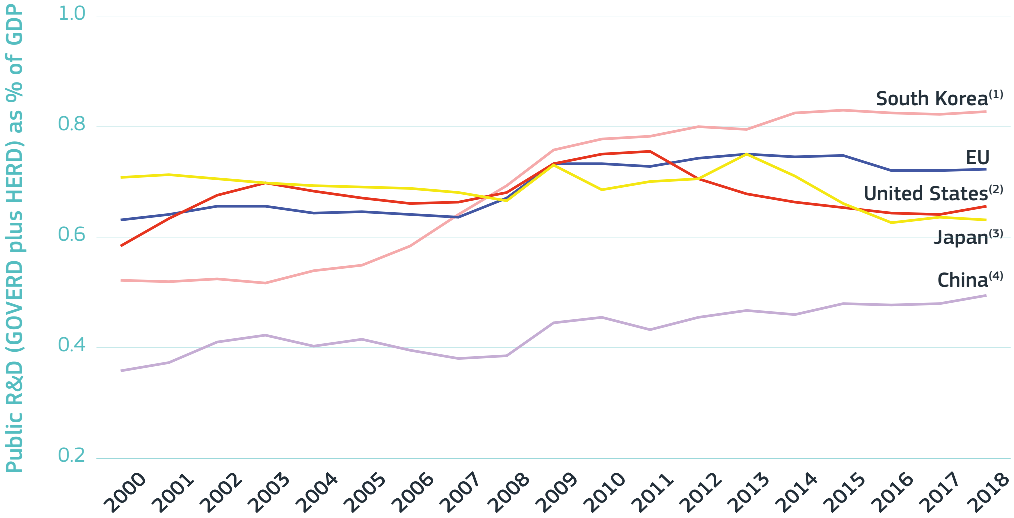
Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on Eurostat, OECD, UNESCO

Notes: [1]The % shares were calculated from estimated values for total GERD in current PPS€. Public equals to GOVERD plus HERD. [2]Japan+South Korea+Singapore+Chinese Taipei. [3]Brazil+Russian Federation+India+South Africa.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter51/figure-51-8.xlsx

With a value of 0.72 % of GDP in 2018, the EU has one of the highest public R&D intensities worldwide. Public R&D intensity is higher in the EU than in the United States, Japan and China. In 2018, the public R&D intensity in the US was 0.66 %, in Japan 0.63 % and China 0.49 %. The only main economy with a higher public R&D intensity than the EU is South Korea with 0.83 % of its GDP (Figure 5.1-9).

Figure 5.1-9 Evolution of public R&D intensity, 2000-2018



Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on Eurostat (online data code: rd_e_gerdtot) and OECD (Research and Development Statistics)

Notes: (1)South Korea: There is a break in series between 2007 and the previous years. (2)United States: (i) R&D expenditure does not include most or all capital expenditure; (ii) There is a break in series between 2003 and the previous years. (3)Japan: There is a break on series between 2008 and the previous years and between 2013 and the previous years. (4)China: There is a break in series between 2009 and the previous years.

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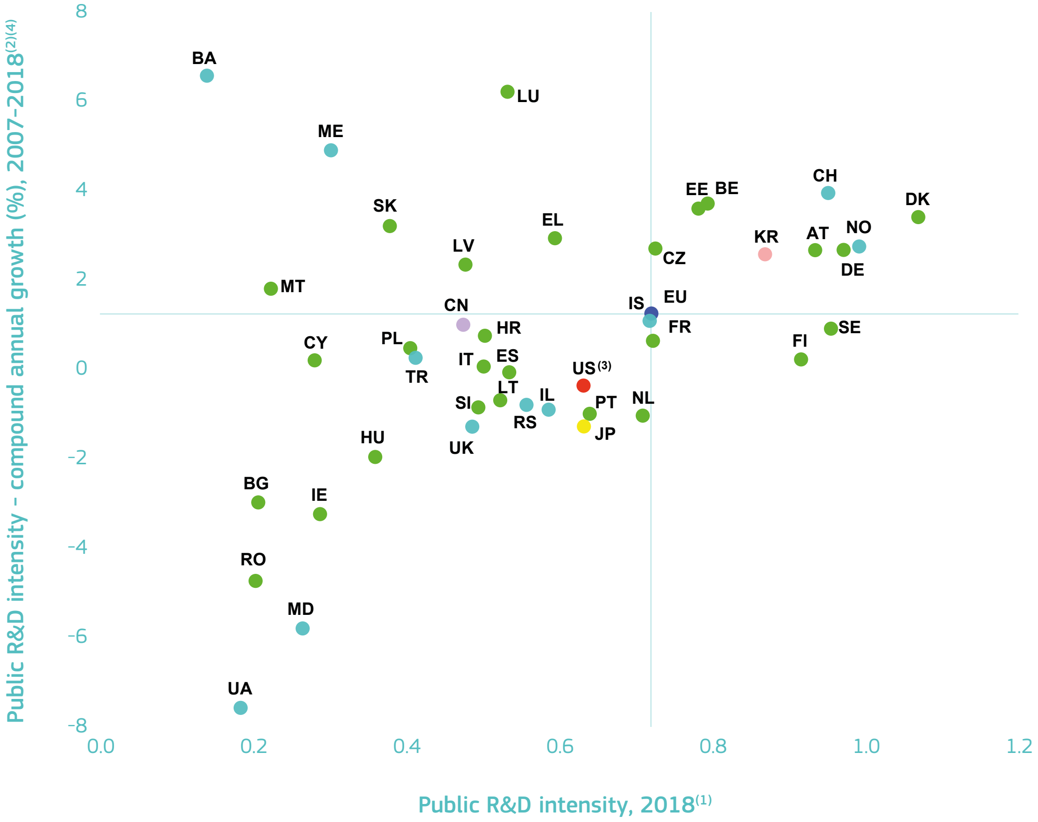
Trends in public R&D intensity are very diverse between Member States. Many Member States which already had a relatively strong public R&D system have kept increasing their investments, notably Denmark, Belgium, Germany and Austria (Figure 5.1-10). Estonia and Czechia boosted their public R&D intensities and are now above the EU average. Since 2007, Luxembourg, Slovakia, Greece, Latvia and Malta have also displayed strong growth rates in public R&D intensity, although they remained below the EU average in 2018. Some Member States which already had public R&D intensity well below the EU average, such as Bulgaria, Romania, Ireland and Hungary, have experienced budget cuts in their public R&D in recent years rather than building R&I capacities through more investments.

Focusing on business R&D, a strong business sector reflects the effectiveness of policies aimed at attracting and fostering business R&D investments and the development and growth of knowledge-intensive firms. Business R&D expenditure is determined to a large extent by a country's industrial structure and how its R&I systems function.

Figure 5.1-10 Public R&D intensity, 2018 and compound annual growth (%), 2007-2018



Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on Eurostat, OECD and UNESCO

Notes: (1)US, JP, CH, KR, CN, TR, IL: 2017; BA, MD, UA: 2016. (2)MD, UA: 2007-2016; CH, JP: 2008-2017; MK: 2015-2018; EL, PT: 2008-2018; RS: 2009-2018; ME: 2011-2018; BA: 2012-2016; (3)US: R&D expenditure does not include most or all capital expenditure. (4)JP, CN, BE, DE, FR, LU, NL, PT, RO, SI, IS, RS: Breaks in series occur between 2007 and 2018; when there is a break in series the growth calculation takes into account annual growth before the break in series and annual growth after the break in series.

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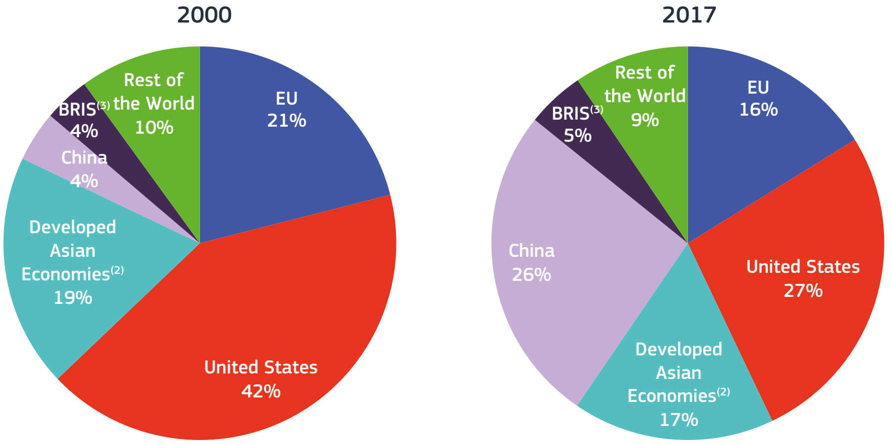
In the world's business R&D landscape, China now accounts for more than one quarter of global business R&D expenditure while the EU's share continues to decline. In 2000, together with the United States, the EU accounted for two thirds of global business R&D expenditure, while in 2017, their joint share was less than half. Since 2000, the EU's share of global business R&D expenditure has shrunk by 5 percentage points while, in parallel, the US share in world business R&D expenditure fell by a record 15 %. At the same time, China's stake rose from 4 % to 26 % (Figure 5.1-11).

Contrary to public R&D intensity, the EU's business R&D intensity is significantly lower compared to other main economies: China, United States, Japan and South Korea. China and South Korea have had continuous and very rapid growth in business R&D intensity since 2007, with annual increases of 4 % and 4.7 %, respectively. In 2018, business R&D intensity in South Korea was 3.64 %, in

Japan 2.59 %, in the United States 2.05 %, and in China 1.69 % (Figure 5.1-12).

Figure 5.1-11 World business enterprise expenditure on R&D – % distribution(1), 2000 and 2017



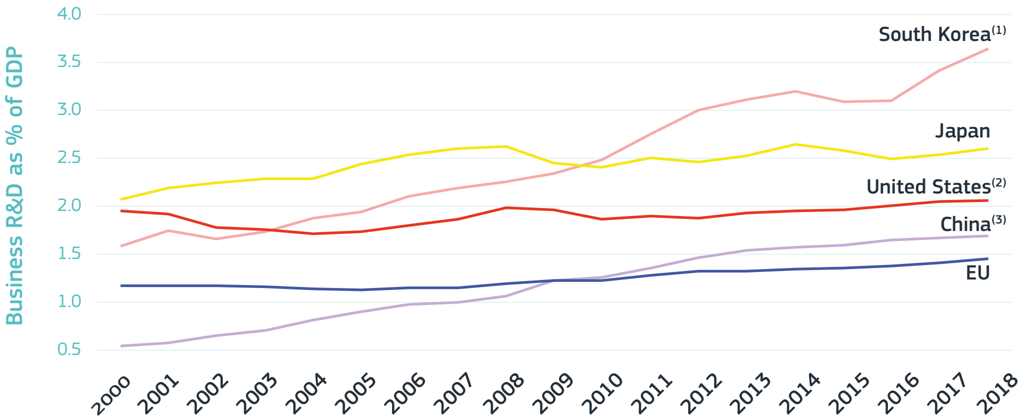
Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on Eurostat, OECD and UNESCO

Notes: (1)The % shares were calculated from estimated values for total GERD in current PPS€. (2)Japan+South Korea+Singapore+Chinese Taipei. (3)Brazil+Russian Federation+India+South Africa.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter51/figure-51-11.xlsx

Figure 5.1-12 Evolution of business R&D intensity, 2000-2018



Science, research and innovation performance of the EU 2020

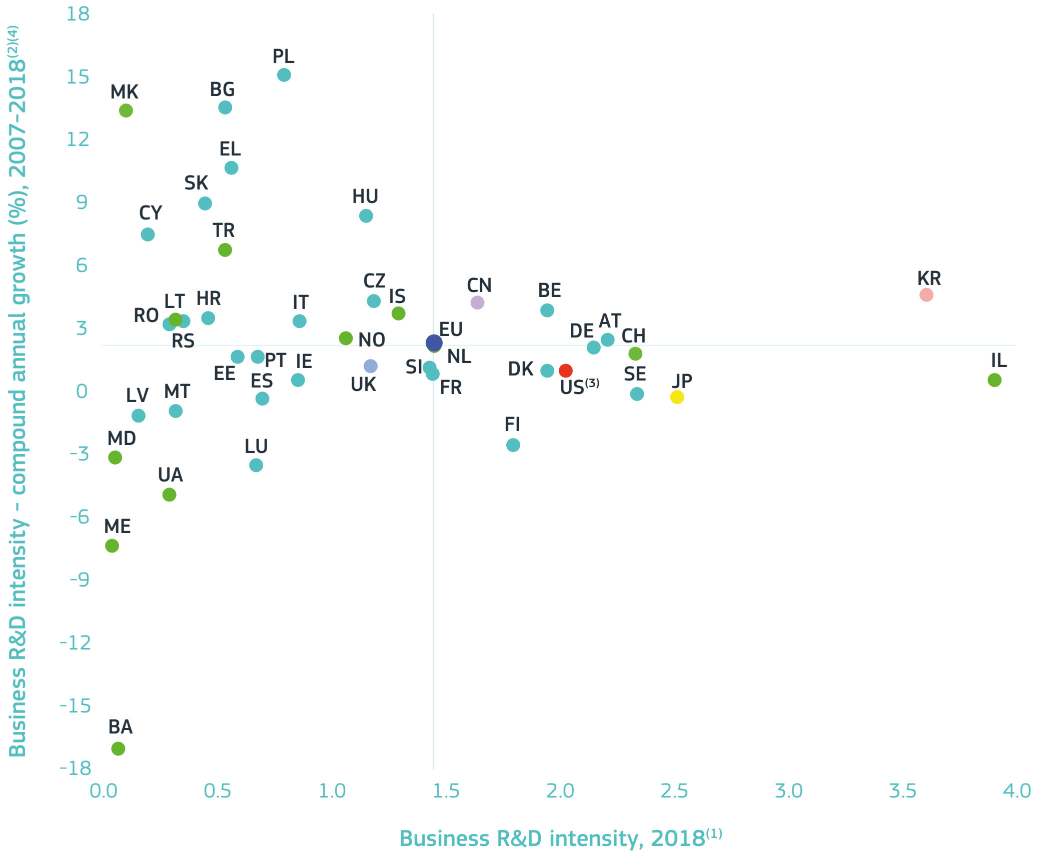
Source: Eurostat (online data code: rd_e_gerdtot), OECD (Research and Development Statistics)

Notes: (1)South Korea: There is a break in series between 2007 and the previous years. (2)United States: Business enterprise expenditure on R&D (BERD) does not include most or all capital expenditure. (3)China: There is a break in series between 2009 and the previous years.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter51/figure-51-12.xlsx

Only a few EU Member States with the best R&D systems (in particular, Austria, Germany, Denmark, Sweden and Belgium) resemble the private R&D intensity achievements of the main world economies, such as the United States, Japan, Switzerland and China (Figure 5.1-13). On the other hand, business R&D intensity increased most in Poland, Bulgaria, Greece and Slovakia between 2007 and 2018. However, their business R&D intensities remained below 1 % of the national GDP in 2018 and well below the EU average.

Figure 5.1-13 Business R&D intensity, 2018 and compound annual growth (%), 2007-2018



Science, research and innovation performance of the EU 2020

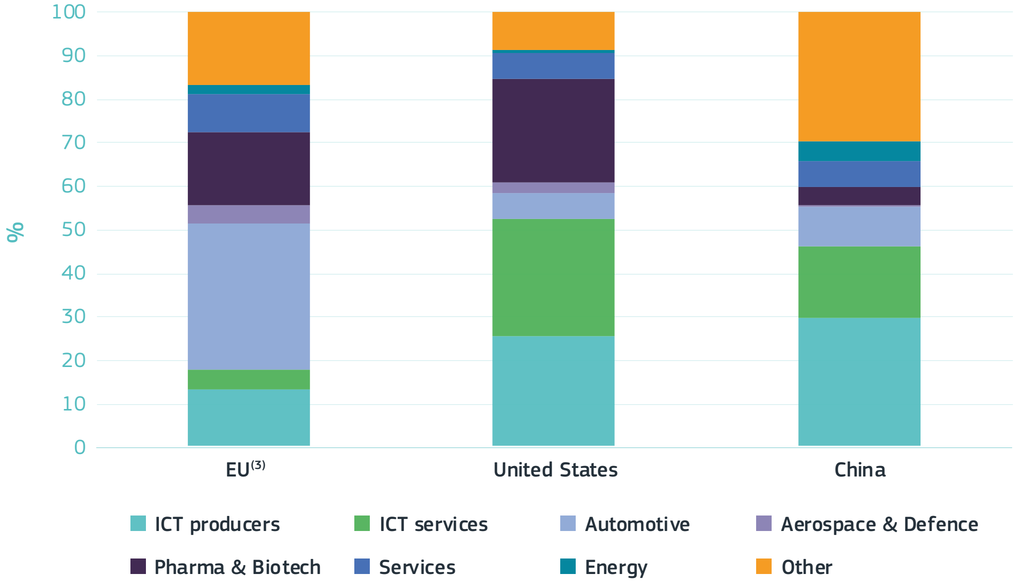
Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on Eurostat, OECD and UNESCO

Notes: (1)US, JP, KR, CN, CH, TR, IL: 2017; BA, MD, UA: 2016. (2)MD, UA: 2007-2016; CH: 2008-2017; EL, ES, SI: 2008-2018; RS: 2009-2018; ME: 2011-2018; BA: 2012-2016; MK: 2015-2018. (3)US: R&D expenditure does not include most or all capital expenditure. (4)CN, IT, LU, NL, RO, SI, UK, IS, RS: Breaks in series occur between 2007 and 2018; when there is a break in series the growth calculation takes into account annual growth before the break in in series and annual growth after the break in series.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter51/figure-51-13.xlsx

To some extent, lower business R&D intensity in the EU compared to its main competitors can be explained by the sectoral composition of the economy. Less than 50% of the EU's industry[10] is in the high R&D-intensity sectors (e.g. ICT producers, ICT services, health industries) and around 40% in the medium-high R&D-intensity sectors (such as automobiles and other transport). Conversely, 80% of R&D investment by US companies, as well as over half of Chinese business R&D investment, is in the high R&D-intensity sectors (Figure 5.1-14).

Figure 5.1-14 Economic sectorial distribution[(1)(2)] of R&D spending by country/region, 2018



Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on the 2019 EU Industrial R&D Investment Scoreboard

Notes: (1)R&D spending corresponding to the top global 2 500 companies. (2)ICT producers: electronic and electrical equipment, technology hardware and equipment. ICT services: software and computer services. Automotive: automobiles and parts. Services: leisure goods, personal goods, banks, life insurance, non-life insurance, financial services, real estate investment and services, media, general retailers, food and drugs retailers, healthcare equipment and services, support services, travel and leisure. Energy: alternative energy, oil and gas producers, oil equipment, services and distribution, electricity. Other: chemicals, general industrials, industrial engineering, household goods and home construction, construction and materials, industrial transportation, mining, industrial metals and mining, food producers, tobacco, forestry and paper, beverages, fixed line telecommunications, gas, water and multi utilities, mobile telecommunications. (3)EU corresponds to the EU Member States shown in the dataset.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter51/figure-51-14.xlsx

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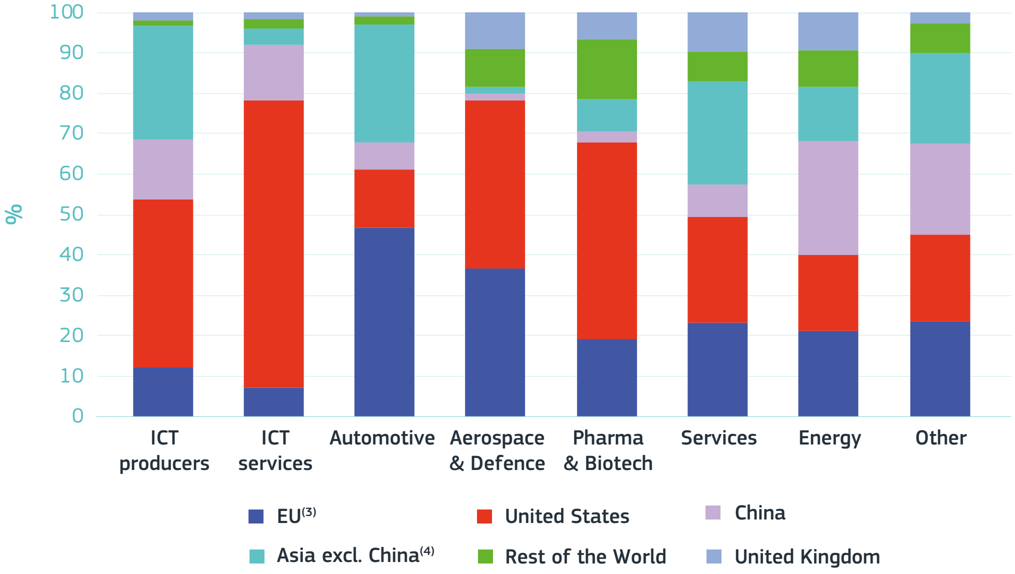
[10] Based on the 2019 EU Industrial R&D Investment Scoreboard (Hernández et al., 2019) which covers more than 90% of business spending on R&D (BERD) worldwide.

In terms of global positioning, the EU largely dominates R&D investments in the automotive sector and shows strong performance in aerospace and defence and in industrial engineering. US companies account for 71 % of the global R&D share of ICT services, 41 % in ICT producers and 48 % in pharmaceuticals and biotechnology – all three are high R&D-intensity sectors. While EU sectors with the largest global weight are automobiles (47 %) and aerospace and defence (37 %), China leads in terms of R&D investments in energy with 28 % of global R&D (Figure 5.1-15).

Figure 5.1-15 Geographical distribution of R&D(1) spending by economic sector(2), 2018



Science, research and innovation performance of the EU 2020

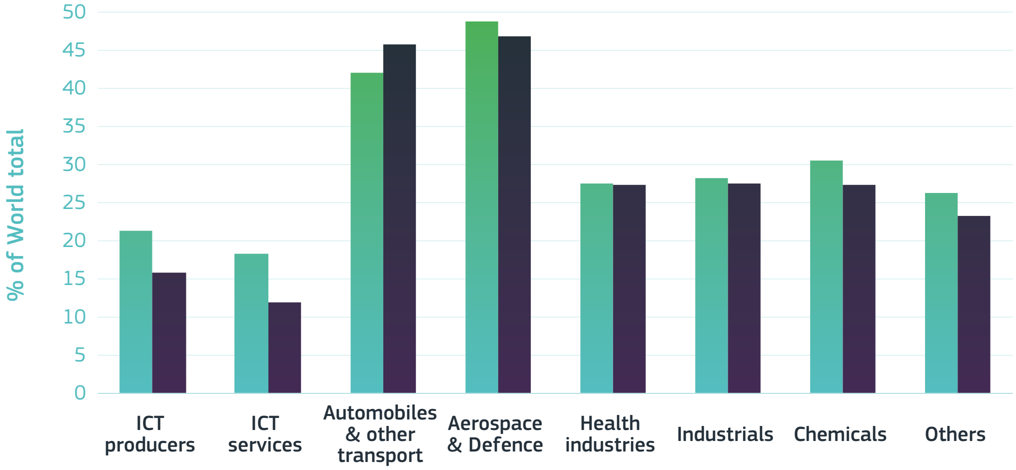
Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on the 2019 EU Industrial R&D Investment Scoreboard and EIB Investment report 2019-2020

Notes: (1)R&D spending corresponding to the top global 2 500 companies. (2)ICT producers: electronic and electrical equipment, technology hardware and equipment. ICT services: software and computer services. Automotive: automobiles and parts. Services: leisure goods, personal goods, banks, life insurance, non-life insurance, financial services, real estate investment and services, media, general retailers, food and drugs retailers, healthcare equipment and services, support services, travel and leisure. Energy: alternative energy, oil and gas producers, oil equipment, services and distribution, electricity. Other: chemicals, general industrials, industrial engineering, household goods and home construction, construction and materials, industrial transportation, mining, industrial metals and mining, food producers, tobacco, forestry and paper, beverages, fixed line telecommunications, gas, water and multi utilities, mobile telecommunications. (3)EU corresponds to the EU Member States shown in the dataset. (4)Asia excl. China includes Japan, South Korea, Singapore, Twain and Malasya.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter51/figure-51-15.xlsx

According to the latest EU R&D Industrial Scoreboard, **EU companies have reinforced their R&D specialisation in automobiles over the last decade**. On the other hand, they have reduced their global R&D share in ICT industries, aerospace and defence and chemicals (Figure 5.1-16). The decline in EU companies' share of global R&D in ICT sectors is taking place in a context where an important sector shift towards these industries has occurred worldwide. Between 2009 and 2018, the share of the global R&D investment in ICT services increased from 10.7% to 15%, and to a lesser extent in ICT producers, from 22.9% to 23.6%. Hence, this shift has not been driven by EU companies but rather by US and Chinese companies.

Figure 5.1-16 Global R&D share of EU28 companies by economic sectors, 2009 and 2018



Science, research and innovation performance of the EU 2020

Source: European Commission, Joint Research Centre and DG Research and Innovation, The 2019 EU Industrial R&D Investment Scoreboard

Note: Shares computed for 386 EU28 and 1 264 non EU28 companies for witch R&D, Net Sales and Operating profits data are available for the all period 2009-2018.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter51/figure-51-16.xlsx

2 EU lags behind its main competitors in business R&D funding

There are five main sources of R&D funding: business enterprise, domestic government, higher education, the private non-profit sector, and the rest of the world. Figure 5.1-17 shows the shares of R&D funding in the EU and where those investments were performed in 2018. Altogether, the public sector finances slightly more than one third of R&D expenditure in the EU and the private sector slightly less than two thirds.

When assessing total public R&D support in Europe, besides domestic government investments, government support to business R&D through tax incentives[11] **and funding from the EU budget should also be included**. In many Member States, a substantial part of government support to business R&D is now made indirectly through R&D tax incentives. On the other hand, for most Member States, the main source of financing from the rest of the

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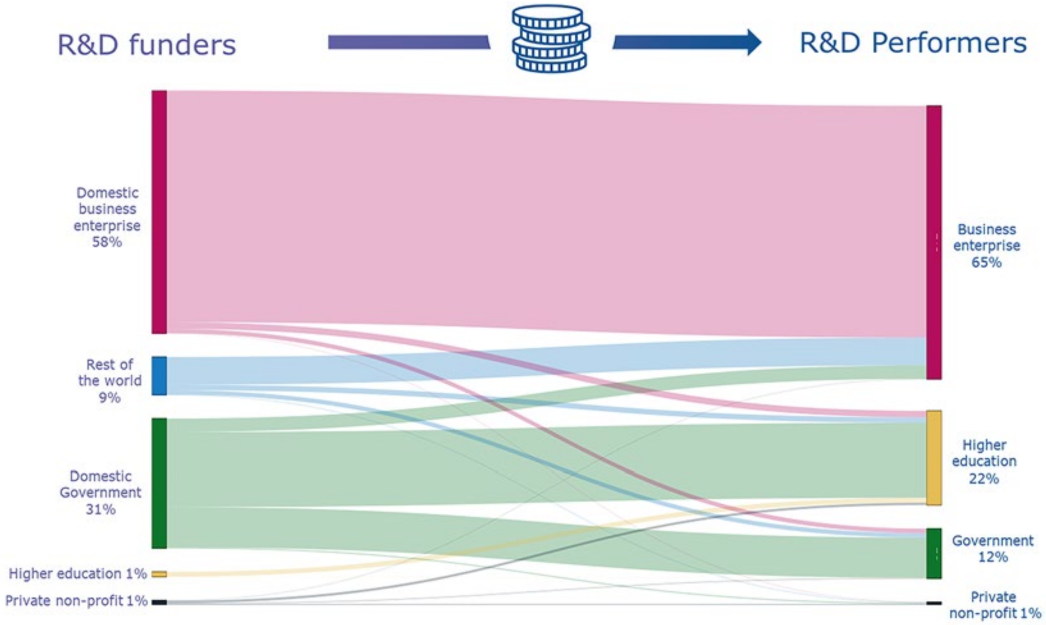
[11] Government-financed R&D includes only direct funding of R&D through grants, loans and procurements that governments give to private firms. Indirect government funding through R&D tax incentives is not recorded in government-financed R&D.

Figure 5.1-17 R&D funding in the EU



Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on Eurostat (online data code: rd_e_gerdfund)

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter51/figure-51-17.xlsx

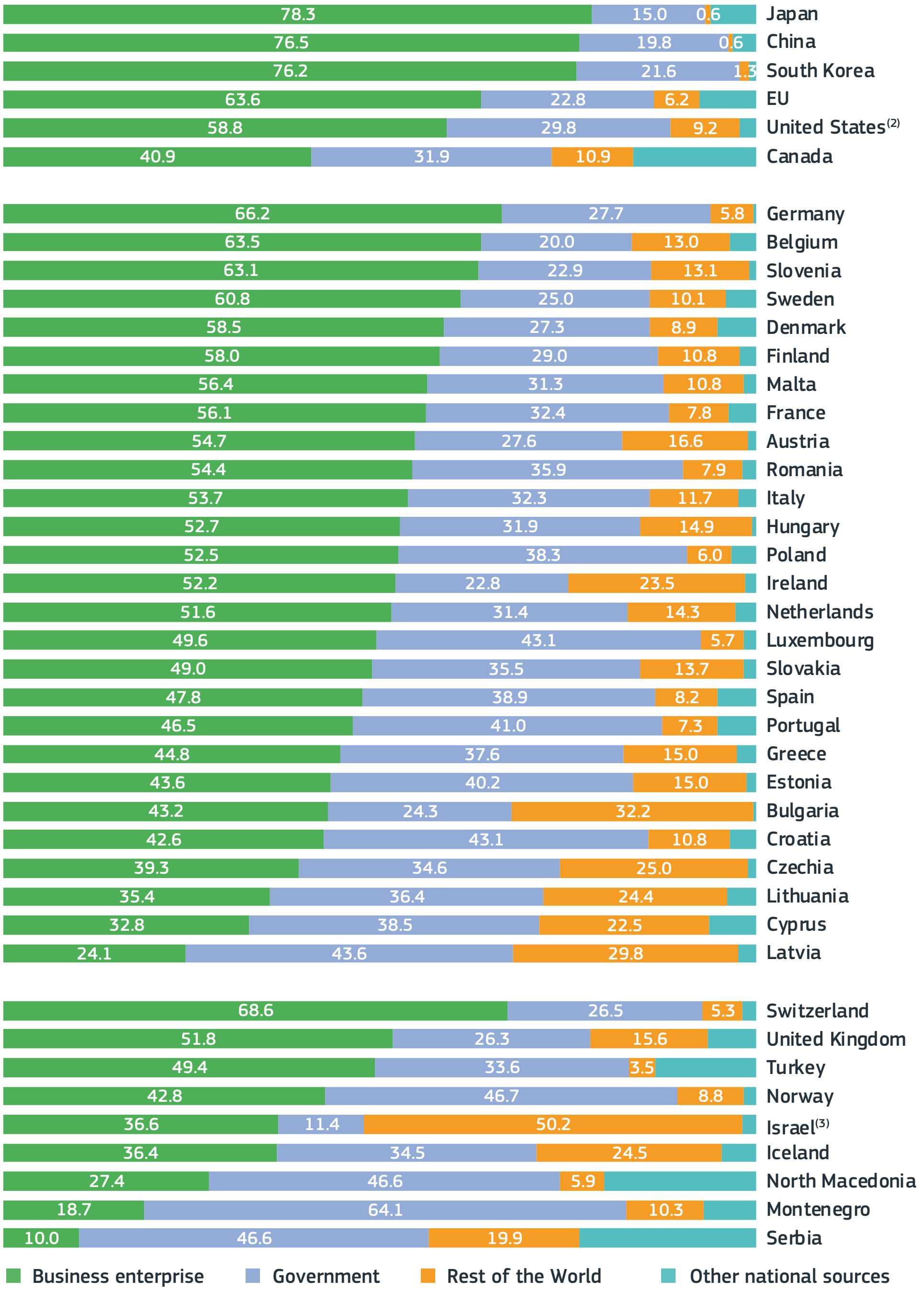
world is the European Commission, through its Horizon 2020 programme and the European Structural and Investment Funds.

The public sector is a main source of funding in less-research-intensive countries, where conditions for business R&D investment are still insufficiently attractive. Conversely, in the most-research-intensive countries, the business sector is the predominant source of funds. Businesses will invest where public policies are best, and where there are sufficient human resources and good research capacities. Hence, how much the private sector invests in a particular country relies largely on the return it can expect and therefore to the framework conditions in place.

Figure 5.1-18 shows the sources of R&D funding broken down into business enterprise, domestic government, rest of the world, and other national sources, while Figure 5.1-19 presents the European Commission's share of R&D funding from the rest of the world. Adding up investments from domestic governments and the EC, we find exceptionally high shares of publicly funded R&D in Latvia, Cyprus and Lithuania. The public sector is also the predominant investor in Greece, Luxembourg, Romania, Portugal, Slovakia and Spain.

In the most-research-intensive Member States (Germany, Sweden, Belgium, Denmark, Finland and Slovenia), the business sector is the predominant source of funds. In those countries, the R&I funding from the business sector is comparable to that in the United States (62 %), although significantly lower than in South Korea, China and Japan, where businesses finance more than 75 % of R&D.

Figure 5.1-18 Gross domestic expenditure on R&D (GERD) financed by sector (%), 2017(1)

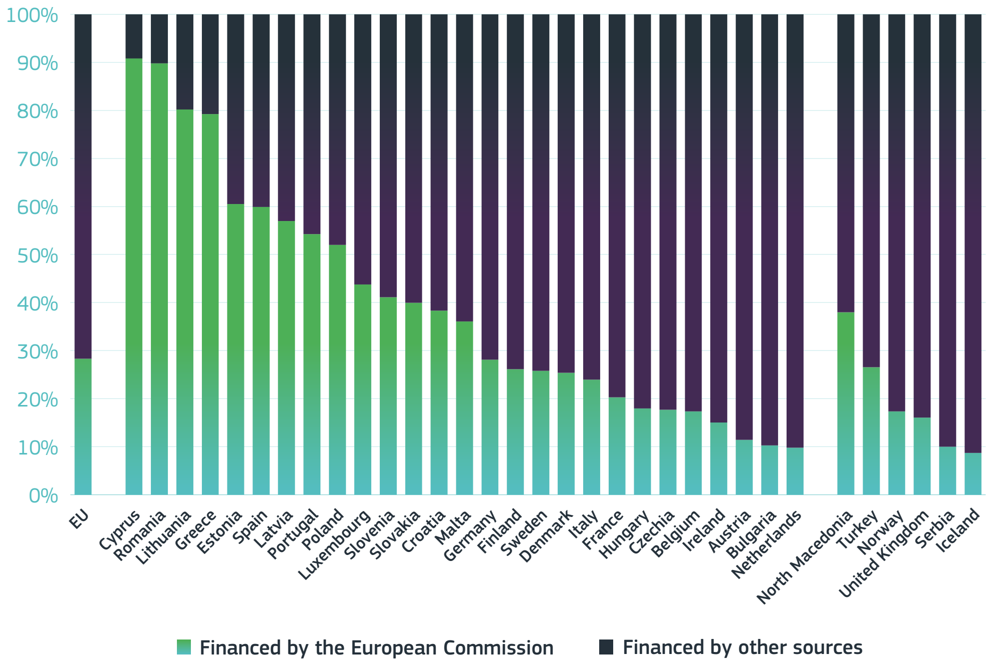


Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on Eurostat (online data code: rd_e_gerdfund) and OECD

Notes: (1)UK, IL : 2016. (2)US: R&D expenditure does not include most or all capital expenditure. (3)IL: Defence (all or mostly) is not included.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter51/figure-51-18.xlsx

Figure 5.1-19 R&D expenditure financed by the Rest of the World, 2017[(1)]



Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on Eurostat (online data code: rd_e_gerdfund)

Note: (1)TR: 2015; UK: 2016.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter51/figure-51-19.xlsx

The European Commission's R&I funding programmes are now responsible for 6.6% of public funding for R&I in Europe and a significantly higher percentage when looking only at competitive funding. Budgets have increased massively over the last programming periods. The budget of almost EUR 100 billion proposed for the next Framework Programme, Horizon Europe, also represents a very strong increase compared to the current programme. Together with the European Structural and Investment Funds, the EC is an important source of R&I funding in many Member States (Figure 5.1-20).

Member States are slowly steering their national budget allocations for R&D towards societal and environmental challenges. Figure 5.1-21 shows an increase in energy-related government budget allocations for R&D (GBARD)[12] at the European level. Growth in the budget allocation for total civil, health and environmental-related R&D is more modest. In contrast, the R&D budget for defence has decreased significantly in recent years.

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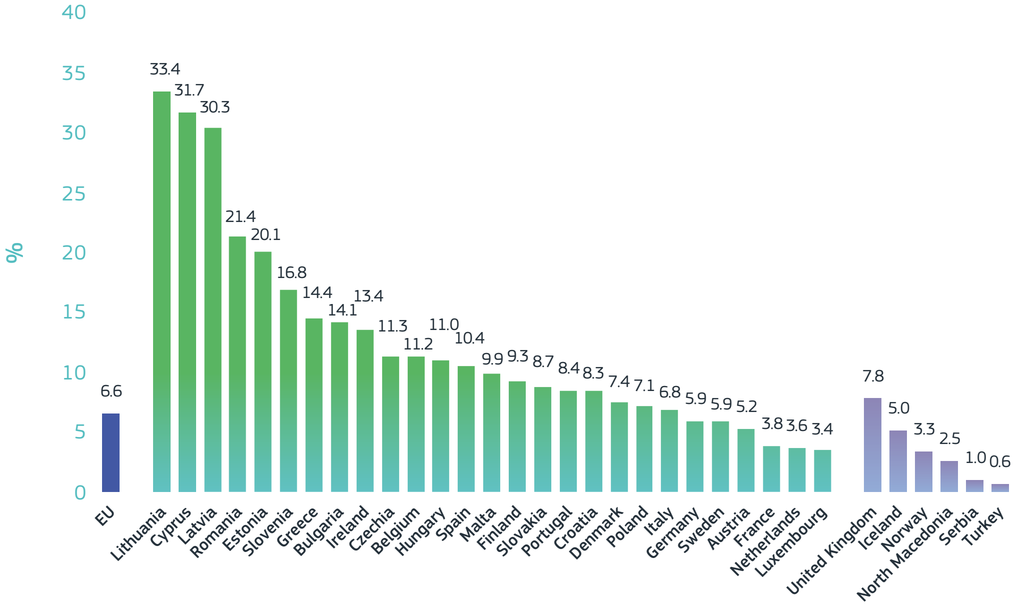
[12] As GBARD measures only direct budget provisions, it does not account for the R&D performed.

Figure 5.1-20 R&D expenditure financed by the European Commission as % of total R&D expenditure financed by the public sector, 2017$^{(1)}$



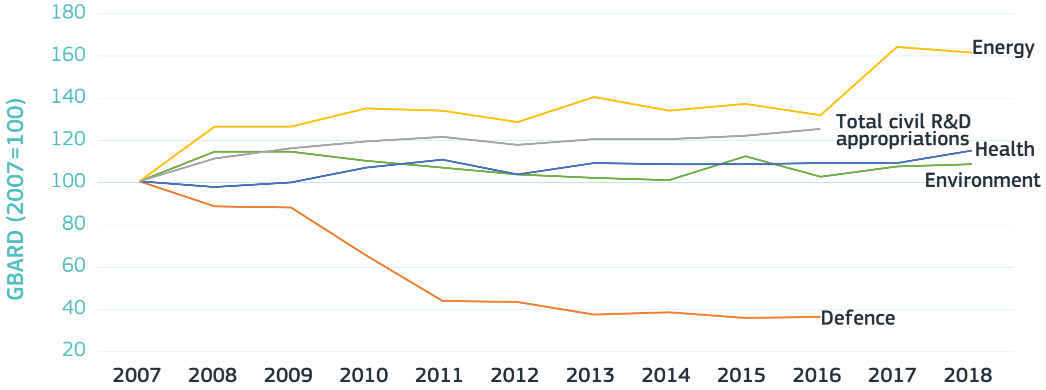
Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on Eurostat (online data code: rd_e_gerdfund)

Note: [(1)]TR: 2015; UK: 2016.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter51/figure-51-20.xlsx

Figure 5.1-21 Evolution of government budget allocations to R&D in the EU, 2007-2018



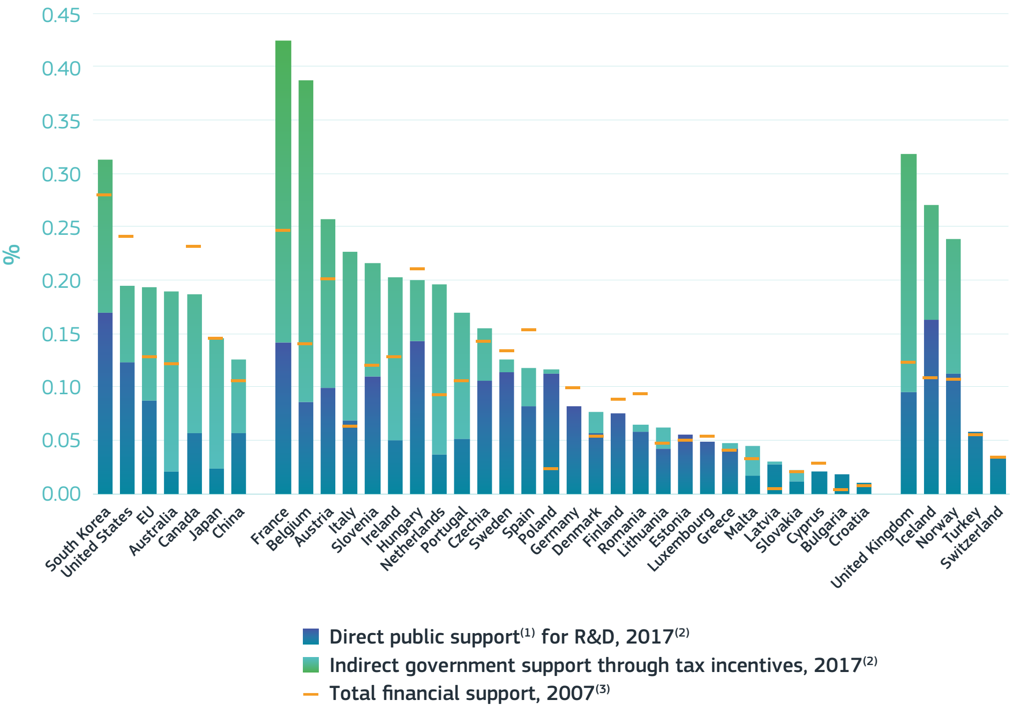
Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on Eurostat (online data code: gba_nabsfin07)

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter51/figure-51-21.xlsx

Business R&D intensity is significantly lower when compared to other main economies: China, United States, Japan and South Korea. **One important driver of business R&D expenditure is the expected return on investment. To improve the expected return, apart from direct support, governments are increasingly using R&D tax incentives**. Total public support for business R&D, comprising direct funding (e.g. grants, loans, procurement) and indirect support (R&D tax incentives[13]) increased substantially in the EU, from 0.13% of GDP in 2007 to 0.2% of GDP in 2017. Figure 5.1-22 shows that the level of public support for business R&D grew in most Member States between 2007 and 2017, particularly through the greater use of R&D tax incentives. Particularly strong increases in total public support for business R&D are evident in Belgium, Italy, France, the Netherlands, Slovenia, Poland, Latvia and Bulgaria.

Figure 5.1-22 **Public support for business R&D as % of GDP, 2007 and 2017**



Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on Eurostat (online data code: rd_e_gerdfund) and OECD (R&D tax expenditure and direct government funding of BERD)

Notes: (1)Estimated direct public support for business R&D includes direct government funding, funding by higher education and public sector funding from abroad. (2)US: 2014 for tax incentives only; AU: 2015; FR: 2016 for tax incentives only; RO, UK: 2016; EL: 2015. (3)CH, TR: 2008; CN, MT: 2009; DE, EL: 2011. (4)The following countries have no tax incenitves for R&D: BG, DE, EE, HR, CY, LU, CH. (5)Elements of estimation were involved in the compilation of the data.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter51/figure-51-22.xlsx

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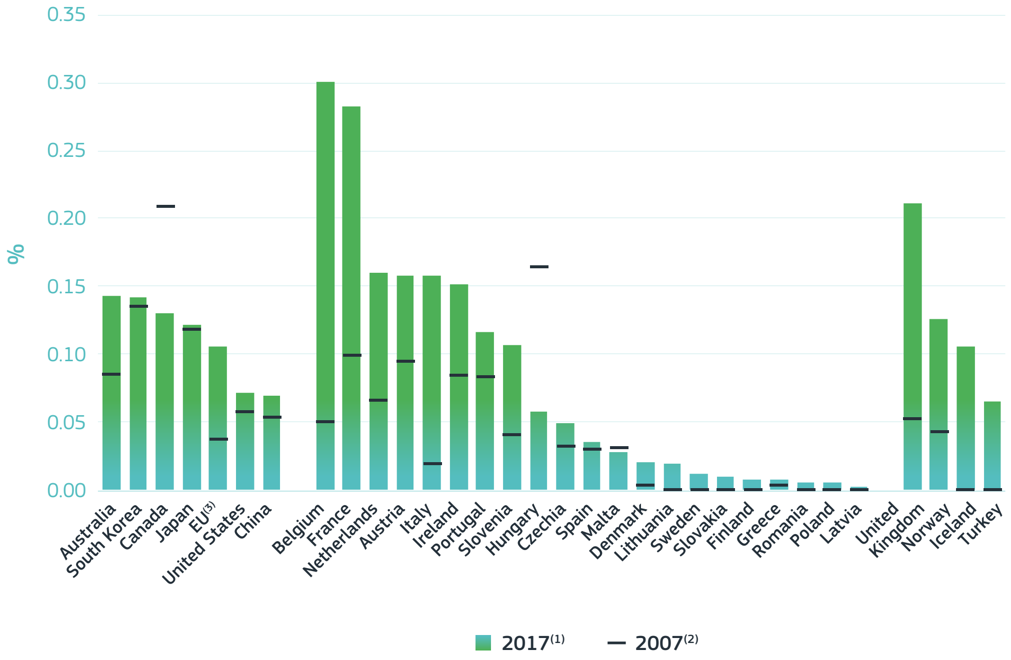
[13] Following the Frascati manual (OECD, 2015), we only focus on expenditure based tax relief, such as: R&D tax credits, R&D allowances, reduction in R&D workers' salary taxes and social security and accelerated depreciation of R&D capital.

In 2017, tax incentives for R&D in the EU accounted for 55 % of all public support for business R&D. The level of the forgone tax revenues in EU almost tripled since 2007, from 0.04 % of GDP in 2007 to 0.11 % in 2017 (Figure 5.1-23). In comparison to the EU, the use of tax incentives is traditionally high and rather stable in South Korea and Japan. China has slightly increased indirect support to business R&D but it is still below the EU level. In the EU, the number of countries offering R&D tax relief increased from 12 in 2000 to 21 in 2018 (Appelt et al., 2019). Trends in forgone tax revenues are very diverse among the Member States. There is an exceptionally high share of tax incentives in total public support for business R&D in the Netherlands, Belgium, Ireland and Italy.

Figure 5.1-23 Tax incentives for R&D as % of GDP, 2007 and 2017



Source: OECD (R&D tax expenditure and direct government funding of BERD)

Notes: (1)US: 2014; FI: 2014; EL, FR: 2016. (2)CN: 2009; EL: 2011. (3)EU was estimated by DG Research and Innovation. (4)BG, DE, EE, HR, CY, LU, CH have no tax incentives for R&D.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter51/figure-51-23.xlsx

Given that coordinated transformation needs coordinated and strategic investment, the question arises as to whether the above-mentioned increased use of R&D tax incentives among the Member States provides the right tools to achieve this goal. Direct measures, such as grants and loans, are effective in provoking certain desired R&D outcomes (Appelt et al., 2019; Ognyanova, 2017) such as innovation that supports a sustainable transition. The downside, however, is the higher administrative burden put on companies. Some countries are considering the possibility to use tax incentives to incentivise private actors' behaviour towards SDGs. This is the case for instance in Belgium[14], where a tax credit granted for environmentally friendly R&D investments was introduced. However, more generally speaking, the tax incentives regime – exactly because of its lack of directionality – may make it difficult for governments to have enough impact on steering private investment towards sustainability and systemic change[15]. Therefore, in order to establish consistency among national reforms and EU policies, a discussion is needed on the best policy mix to provide public support to business R&D expenditure.

Because of the scope, scale and urgency of the societal challenges facing Europe, policy is required to pay more attention not just to the rate (quantity and quality) of R&I investments but also to the overall direction of such investments. This can support the coordinated transformation of a broad range of interconnected systems that are crucial to our economy and society. Systems such as energy, agro-food, health, mobility, production and consumption all include a number of actors that must act together.

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[14] https://www.oecd.org/sti/rd-tax-stats-belgium.pdf

[15] Moreover, while its effect of increasing R&D efforts is undeniable, recent analysis of existing evidence on the impact of tax incentives points to its limited impact on innovation (Mitchell et al. 2020).

3. Conclusions

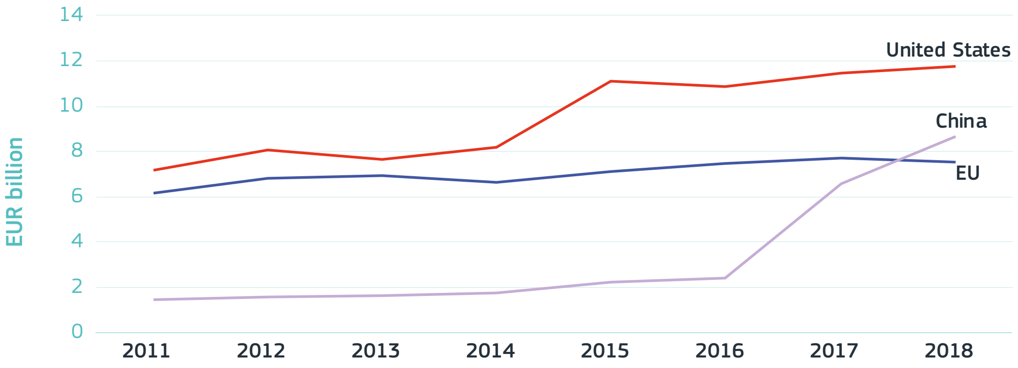
With just over 2% of its GDP in R&D, the EU is still a long way from its 3% target. It is underinvesting in R&D compared to its main competitors, especially in terms of private investments, while Asian countries, in particular China and South Korea, are investing at a rate that is eclipsing both the EU and the United States. If this continues, Europe risks being outpaced irreversibly.

The Commission is committed to focusing R&I investments on delivering the 'European Green Deal', its new strategy for growth (European Commission, 2019). R&I are called upon to play a strong role to support this initiative. Given the size of the challenge and its costly nature, with EUR 1 trillion mobilised for the Green Deal over the next decade, this demands investing record amounts in R&D if Europe is to become the world's first climate-neutral continent and can achieve the Sustainable Development Goals.

For R&I to deliver on Europe's ambitions, including becoming the world's first climate-neutral continent, R&I must also be given a clear sense of directionality[16]. Public investments in R&D can play an essential role in this. Bloomberg data show that, while the United States leads in climate-related R&D spending, China has recently quadrupled its spending, slightly overtaking the EU (Figure 5.1-24). Member States should reinforce their performance in climate-related R&D in order to boost their competitiveness in the novel technologies which are required for transition.

One of the main public investment instruments in Europe is the EU's R&I Framework Programme. The next one, Horizon Europe, will cover 2021-2027 and will continue to create new knowledge and solutions to attain the SDGs. It will provide even greater directionality through its mission-oriented approach (on, for example, climate change, healthy oceans, climate-neutral and smart cities, and soil health and food) and European partnerships. In addition, it has set a 35% spending target for the climate.

Figure 5.1-24 Investment in climate-related R&D, 2011-2018



Source: European Investment Bank based on data from Bloomberg New Energy Finance (BNEF)
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter51/figure-51-24.xlsx

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[16] In the same vein, the 2018 update of the Bioeconomy Strategy aims to accelerate the deployment of a sustainable European bioeconomy in order to maximise its contribution towards the 2030 Agenda and its SDGs, as well as the Paris Agreement (see European Commission, 2018).

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CHAPTER
5.2

INVESTMENT IN EDUCATION, HUMAN CAPITAL AND SKILLS

KEY FIGURES

1/11
ratio of tertiary students in Europe and the world

1 %
of spending on education in the EU is at the European level

7 %
of Europeans used the internet for doing an online course

8 out of 10
firms consider lack of staff with the right skills a barrier to their investment activities

174
robots per 10 000 workers in European manufacturing

What can we learn?

- Europe's **education and training investment** priorities are centred on formal education, while **demographic change** will influence all stages of education. With education and training systems broadening its focus primarily from the first-life decades to the needs of 30 and 70-years old learners, we could put each individual talent to use.

- The **digital skills gap** is particularly visible as **the number of ICT graduates in Europe is not keeping pace** with the continuously increasing demand on the market.

- **EU** countries continue to increase the number of researchers, as do their global competitors. **China is now reaching the EU level** in its total number of researchers.

- Although many European countries have increased their shares **of researchers in the total workforce, the EU lags behind the United States, Japan and South Korea in particular**.

- Although females represent roughly half of EU graduates at the doctoral level, **women represent only about a third of all EU researchers and only one fifth of researchers in the business sector**.

What does it mean for policy?

- EU policies need to develop a stronger sectoral cooperation on skills to adapt skills development in line with emerging technological needs.

- The EU needs to attract talents to research and sustain its excellence in research as **international competitors (in particular China)** are expanding their pools of talents.

- **Gender equality and gender 'mainstreaming'** (integration of a gender perspective in the preparation and evaluation of policies) in research and promotion of these policies in R&I, should be maintained and, where possible, reinforced in order to make further progress. Further efforts are needed to increase shares of female graduates across STEM (science, technology, engineering and mathematics) fields.

1. Acquisition of skills relevant to future labour markets

The growing knowledge orientation of the economy and society, together with changes in the labour market and current demographic trends in Europe, make investment in skills and their lifelong upgrading increasingly important. Skilled human capital for research, innovation and economic development is crucial to sustain the needs of a knowledge economy. The EU is facing a growing demand for skilled labour, including researchers, whilst at the same time, labour related to routine activities appears to be increasingly automated.

An additional challenge comes from ongoing demographic developments, such as the declining number of young people entering the labour market expected in many Member States in the coming years, while the baby boomer generation is set to retire within the next decade. The EU's working age population (15-64) peaked in 2009 at 336 million but has shrunk by 5 million since then. The shrinking labour force trend has been predominantly visible in southern, central and eastern European (CESEE) countries. At the same time, life expectancy continues to rise by about 2 years per decade: the population of 65 years and older in the EU is growing annually by about 2 million, rising from 90 million in 2012 to 101 million in 2018. Consequently, the old-age dependency ratio is growing, directly affecting employment in the healthcare sector and indirectly (longer working life) impacting the labour market.

Other factors are migration and developments outside Europe. While the EU's natural population change in 2017 (births minus deaths) was negative, at -0.3 million, this was more than compensated for by a net migration to the EU of 0.9 million. The demographic shift towards lower shares of young people and larger shares of elderly people is posing important challenges for Europe. Given a global massification in tertiary education, a more favourable demography outside Europe and strong investment in excellence in other world regions such as China and the United States, the EU is facing growing challenges in competitiveness. Any gaps in terms of the quality and quantity of Europe's human capital could endanger its traditional comparative advantage as regards skilled labour. Further investment in skills and their lifelong upgrading will also be necessary to bridge the productivity growth gap between the EU and the United States and South Korea.

Strong growth in employment with high levels of qualification and an increase in low qualifications is expected within the coming decade while, at the same time, the number of jobs at medium levels is likely to shrink. According to the 2018 Cedefop skills forecast (Figure 5.2-1), the labour force (15-64+) will stagnate between 2021 and 2030. At the same time, total EU employment is projected to grow at a rate of 0.4 % per year. However, trends will differ significantly across the Member States, with employment – mainly for demographic reasons – shrinking annually during that period in Lithuania (-0.4 %), Latvia (-0.2 %) and Estonia (-0.2 %). Germany, the EU's largest Member State, will face a decline of 0.2 % per year. The majority of Member States will generate positive employment figures with Ireland and Cyprus (1.4 %), Luxembourg (0.9 %) and Spain (0.8 %) expected to show the highest growth rate.

The European employment outlook follows the job polarisation trend with a strong increase in highly qualified occupations (0.9 % annually within the EU) followed by rises in low qualification levels (0.4 %). It has been forecast that jobs revolving around medium-qualification levels will witness a decline in employment of 0.2 %[1,2].

In the EU, employment growth plus the need to replace people leaving workplaces (retirement, migration and other reasons) will lead to over 100 million job opportunities over the next decade, over 45 million of which will require high qualifications. The highest absolute number of job openings will be in Germany (17.6 million), France (12.4 million) and Italy (11.5 million). The trends shown may contribute to sustaining the gap in unemployment rates between different qualification levels. In 2017, according to Eurostat data, while the EU's overall unemployment rate stood at 7.6 %, it was nearly twice as high for those with low-qualification levels (lower secondary education or less), reaching 14.7 %, while highly skilled people (with at least tertiary education) in the EU reported an unemployment rate of only 4.5 %.

The employment of researchers and engineers will see strong growth, followed by ICT professionals. The forecast growth of both science and engineering as well as ICT professionals is expected to outpace the overall growth rate (Figure 5.2-1). These two groups are also the occupations most demanded by the current labour market with a share of 14 % among the majority of EU Member States[3]. Science and engineering professionals together with technicians, which a somewhat broader term referring to employment in the sector, shows a 12 % share of vacancies across the EU (Figure 5.2-2)[4].

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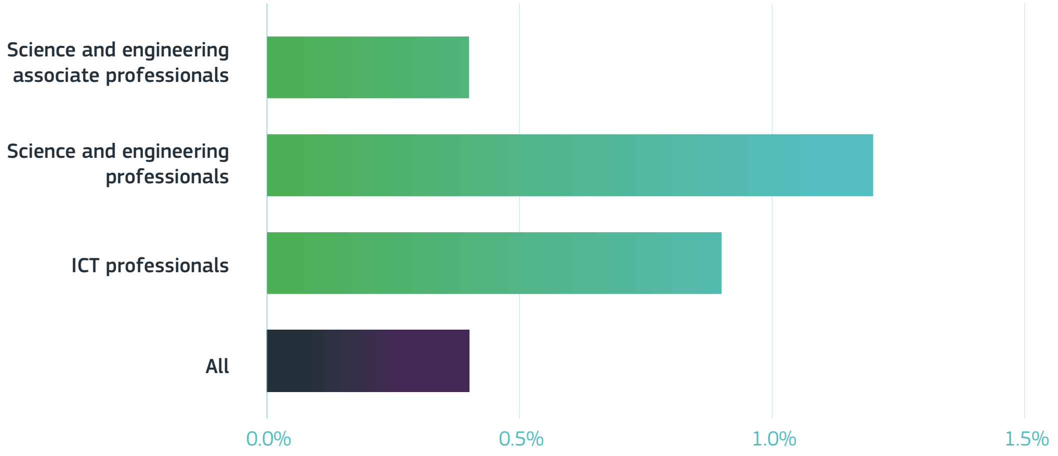
[1] Jobs classified under the ISCO-88 major groups, based on Cedefop Skills Forecast 2021-2030, EU28, annual percentage rate.

[2] According to Cedefop, medium-skill occupations are projected to see slow growth or even a decline in the number of jobs as automation and offshoring take their toll. But new workers will still be needed in these occupations to replace those who leave or retire.

[3] Cedefop project Skills-OVATE gathers data for online vacancies in Europe. It navigates through data for 18 countries: Austria, Belgium, Czechia, Denmark, Germany, Hungary, Spain, Finland, France, Italy, Ireland, Luxembourg, the Netherlands, Poland, Portugal, Sweden, Slovakia and the United Kingdom. Data were gathered between 1 July 2018 and 31 March 2019.

[4] The share includes 2-digit ISCO categories research & engineers professionals and technicians.

Figure 5.2-1 Employment change for selected qualifications (%), 2021 - 2030



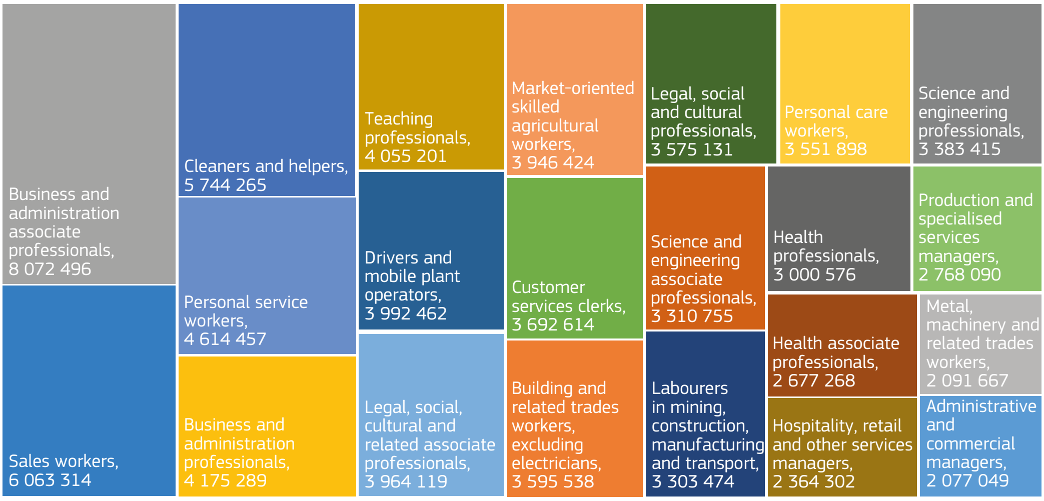
Science, research and innovation performance of the EU 2020

Source: Cedefop Skills - Forecast

Note: Skills forecast accounting for economic developments until May 2017.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter52/figure-52-1.xlsx

Figure 5.2-2 Top job openings by occupations group, EU28 2021-2030



Science, research and innovation performance of the EU 2020

Source: Cedefop Skills - Forecast

Notes: Skills forecast accounting for economic developments until May 2017.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter52/figure-52-2.xlsx

The manufacturing sector is characterised by a growing use of industrial robots. European countries with a large car industry tend to have high numbers of industrial robots per person employed. The ongoing debate on the impact of technical progress on employment concentrates on the levels of robots in the manufacturing sector, which supposedly is affected more by automation and rationalisation than the service sector. Yet it remains to be seen whether the effect of robots on employment in manufacturing will be disruptive (Klenert et. al, 2020). The replacement of workers by machines is ongoing with even more complex manual tasks being increasingly taken over by robots now. However, it is not only routine manual tasks that are being replaced. Future advances in artificial intelligence could have repercussions in the service sector, where jobs are not facilitating worker autonomy but are demanding a higher degree of planning, teamwork and customer-service skills (Pouliakas, 2019).

Currently, over 0.3 million industrial robots (of a worldwide stock of 2.1 million) are deployed in EU Member States, a number which is increasing by about 40 000 per year. The degree of robotisation varies significantly across Member States – for example, Germany's automotive industry is about twice as robot intensive as that in Czechia and Portugal[5]. Germany also has the highest number of industrial robots per 10 000 people employed in the manufacturing industry, followed by Sweden and Denmark. The EU has a similar density as the United States, but lags behind Japan and South Korea (Figure 5.2-3). Although China is catching up quickly, it still has a much lower density than the EU. The 138 000 industrial robots installed in China in 2017 represent an increase of 59 % compared to the previous year. This was considerably more than the total volume of robots installed in Europe and the United States together (91 000 units). Such a leap has helped China to compensate for its initially low levels. With the current number of 539 multipurpose industrial robots per 10 000 people employed in the automotive industry, China ranks among countries such as Portugal (613), Czechia (483) and Malaysia (427). Find out more on robotics in Chapter 7 - R&I enabling artificial intelligence.

As regards the increasingly important digital skills, although the EU is progressing, there is a divide between Member States in internet user skills and more advanced digital skills. Eurostat's ICT household survey (Figure 5.2-4) shows big differences among Member States in shares of the population aged 16-74 with above-average digital skills. The Nordic countries, Luxembourg, the Netherlands and the UK perform best in this area. Nearly all their households have internet access (Figure 5.2-5) and these countries tend to have relatively high shares of ICT start-ups. The lowest performers in the EU as regards their populations' digital skills are Romania and Bulgaria. European Commissions' Digital Economy and Society Index monitors human capital, which consists of internet user skills and advanced skills with development. According to the latest data, the top performing countries differ in both indicators (EC, 2019).

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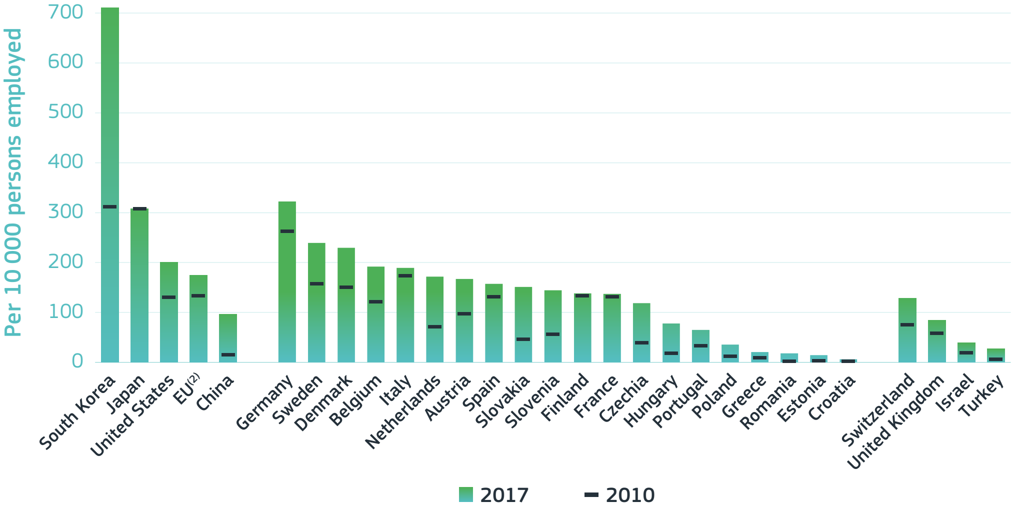
[5] Estimated number of multipurpose industrial robots per 10 000 people employed in the automotive industry (ISIC rev.4: 29).

Figure 5.2-3 Robot density in manufacturing[1], 2010 and 2017



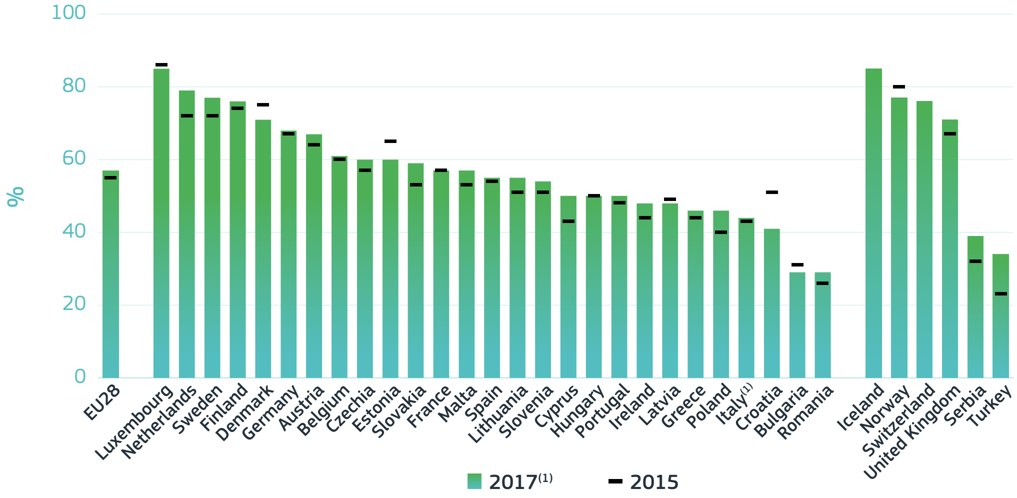
Science, research and innovation performance of the EU 2020

Source: International Federation of Robotics (IFR)

Notes: [1]Robot densities are defined as the number of robots in operation per 10,000 persons employed in the manufacturing (ISIC rev.4: C). [2]EU: employment weighted average of the available data for Member States and includes UK. Revised employment data according to ILO Employment by econmic activity 2015.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter52/figure-52-3.xlsx

Figure 5.2-4 Share of individuals who have basic or above basic digital skills in the population, 2015 and 2017



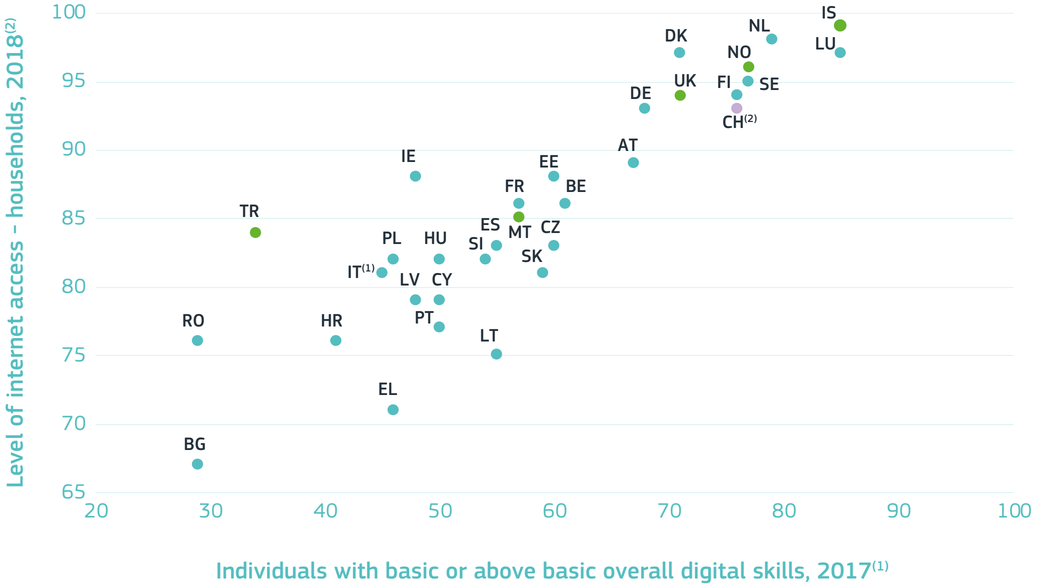
Science, research and innovation performance of the EU 2020

Source: Eurostat (online data code: TEPSR_SP410)

Note: [1]IT: 2016.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter52/figure-52-4.xlsx

Figure 5.2-5 Individuals with basic or above basic digital skills and level of internet access in households, 2017 and 2018



Science, research and innovation performance of the EU 2020

Source: Eurostat (online data code: TEPSR_SP410 and isoc_ci_in_h)
Notes: (1)IT: 2016. (2)CH: 2017.
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter52/figure-52-5.xlsx

Within the last decade or so, the steep increase in the share of Europeans who use the internet resulted in 85 % of Europeans having online access in 2018 (based on internet use in the last three months). In many European countries, almost the entire population is active on the internet. However, the data show that there is a wide gap between basic internet usage and the development of advanced digital skills. While 70 % of Europeans go online for information about goods and services, only 7 % have used the internet to follow an online course. The share of individuals with digital skills in the EU population is growing slowly. As regards individuals with more than the basic overall digital or software skills, Europeans have recently improved to reach population shares of about 30 % and 40 %, respectively. Greece and Sweden have shown the greatest progress in digital skills over the last three years. On the other hand, the lack of at least basic digital skills appears on the labour market in several member states and the 'use of computer' ranks as a number one demanded skill on the job market in Poland and Slovakia[6]. The increasing levels of digital skills is important to ensure a broad range of opportunities to enter and remain in the labour market. At the same time, with the rise in e-government, online shopping, banking and smart mobility, acquisition of these skills will prevent individuals not only from being locked out of work but also out of society (EPSC, 2019).

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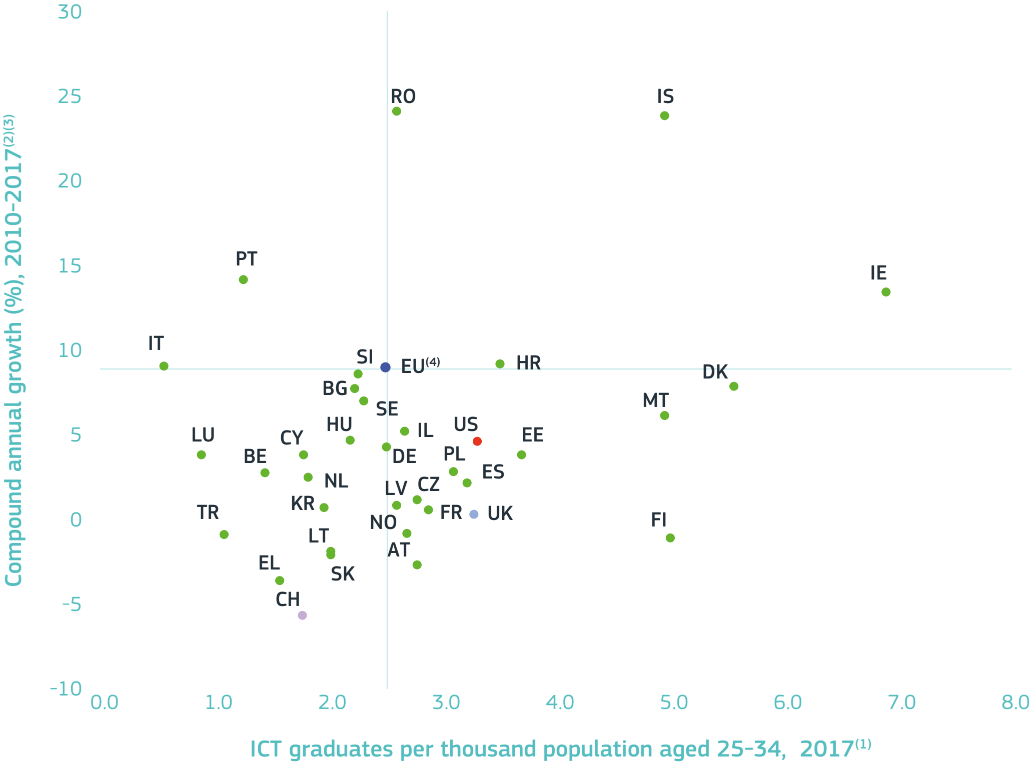
[6] Cedefop project Skills-OVATE - skills sorted by their frequency across all online job vacancies.

In the period 2014-2017, the number of ICT graduates in the EU rose on average by about 4% per year. However, much lower growth in previous years and stagnation or even decline in several Member States resulted in a gap in the labour market (Figure 5.2-6). Member States with a high number of computing graduates per 1 000 population aged 25-34 include Ireland (where many US digital giants have their European headquarters), Malta (where an online gaming cluster has developed), Finland (with its important video-game sector) and Denmark. Italy, the worst European performer seems to be on a growing trajectory, although one reason for concern is the continuous decline in the number of graduates from computing studies in countries like Greece, Lithuania and Slovakia.

Figure 5.2-6 Graduates in the field of ICT per thousand population aged 25-34, 2017 and compound annual growth, 2010-2017[(1)]



Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on Eurostat (online data code: educ_uoe_grad02), OECD (Graduates by field) and United Nations data

Notes: (1)US, KR, IS, CH, IL: 2016. (2)US, KR, IS, CH, IL: 2010-2016; NL: 2010-2012; EU, FR, HR: 2014-2017. (3)Break in series between 2013 and the previous years due to change of classification (ISCED97 / 11 replaced by ISCED-F 2013). US, KR, IL: data based on ISCED11. (4)EU was estimated from the available data.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter52/figure-52-6.xlsx

Although the number of ICT graduates has increased, it is not keeping pace with continuous growth in employment in ICT and is not meeting market demand. While the population's basic ICT skills are improving, there is a growing need for practitioners with a solid base in ICT skills. In 2018, the share of such professionals was 3.9 % of total European employment, and their total number has been increasing by more than 3 % annually over the last decade (Figure 5.2-7). Sweden, Finland, Estonia, Luxembourg and the Netherlands maintain the highest shares. Growth in these jobs is fuelled by new developments such as big data, the Internet of Things, the cloud, and the expanding app economy. In Bulgaria in particular, together with Belgium Cyprus and Ireland, the number of such jobs has increased significantly in the last ten years. Looking at the performance over the last five years, strong growth in Bulgaria is followed by Lithuania, Estonia, Romania and Greece. The lack of graduates to fill such vacancies is, to a certain extent, reflected by 56.8 % of companies facing difficulties when trying to recruit ICT specialists – and there are already over 1 million vacancies for ICT specialists in the EU[7].

Aligning the provision of education and training with changing labour market and social needs is a persistent issue facing every country, in particular as regards coordinating investment strategies with the private sector. It is well accepted that general investment in education and training together with investment in R&D are complementary (Cedefop, 2012; OECD, 2013) and that investment in human capital leads to more innovation at the firm level, including on-the-job training (Dostie, B., 2018). However, challenges persist in aligning the role and actions of public-sector actors with the actions of the private sector. This is difficult enough even in a single sector – as testified by challenges faced in aligning public investment priorities and fundamental research with the needs and applied research carried out by enterprises. At the European level, despite evolving statistical instruments, actually tracking investment levels (particularly as regards skills investment) faces significant barriers due to the misalignment of available data sources in their timing, scope and definitions. Nevertheless, recent assessments by the Commission (EC, 2019a) enables a more comprehensive picture to be drawn. Total investment in skills for labour market and social purposes – which would probably have the most direct link to companies' skills needs and innovation performance in the EU in reference year 2015 – totalled EUR 203 billion, which is less than the total investment in R&D at EUR 259 billion that same year. The private share in this expenditure varies significantly from 72 % in Slovenia to 22 % in Finland. Only about 20% of these investments at the EU level represent publicly funded formal adult education, which depicts the complex nature of adult learning and its funding sources. See more information on the importance of economic competencies and investment in Chapter 5.3 - Investment in economic competencies.

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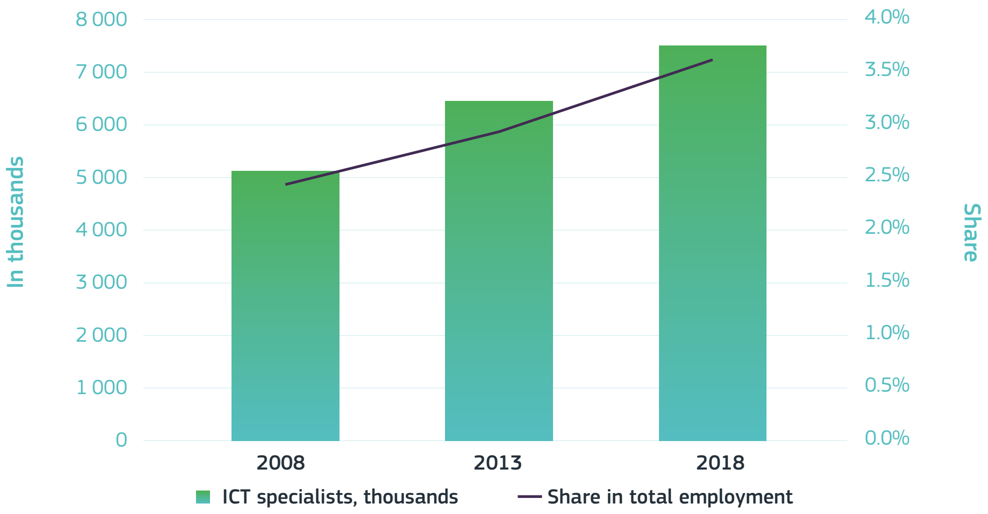
[7] An assessment by IDC and Empirica estimated a shortage of 749 000 by 2020 (2018); the estimation, based on the European Commission's VICTORY project (2019), refers to currently available vacancies.

Figure 5.2-7 Employment of ICT specialists in the EU28, 2008, 2013 and 2018

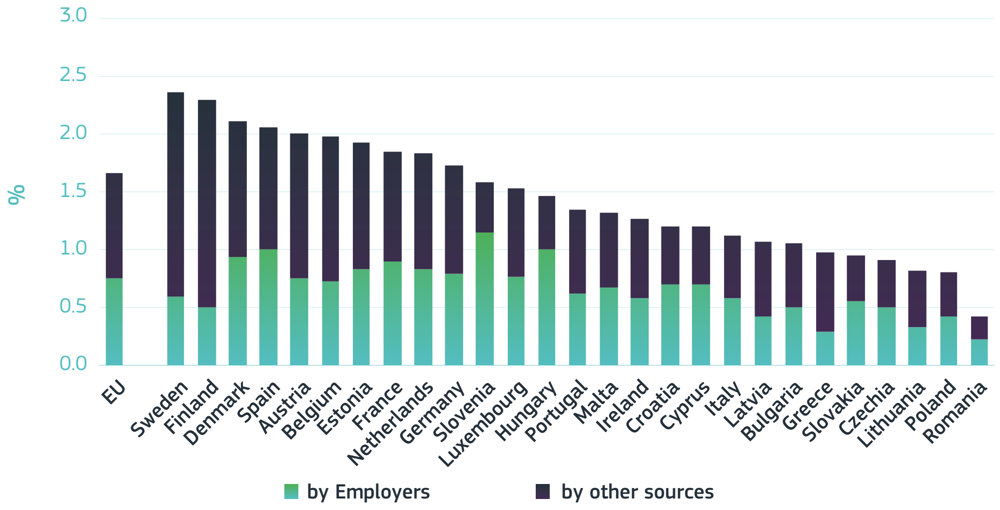


Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on Eurostat (online data code: isoc_sks_itspt)

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter52/figure-52-7.xlsx

Figure 5.2-8 Investment in adult learning (estimated) across EU in 2015[1] as % of GDP



Science, research and innovation performance of the EU 2020

Source: European Commission, DG Employment, Social Affairs & Inclusion based on Eurostat - EU Adult Education Survey (reference year - 2016), special data extraction for DG EMPL; Eurostat - EU Continuing Vocational Training Survey (reference year – 2015), special data extractions for DG EMPL; Eurostat - UOE data (reference year 2015)

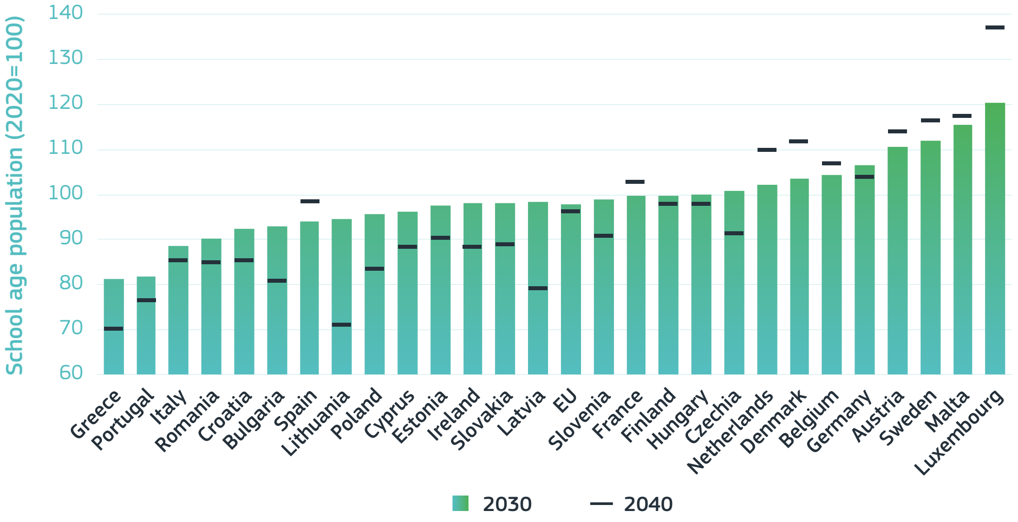
Note: (1)Investment in skills by Employers includes all economic sectors, data for the public sector employers was estimated using AES participation data and CVTS cost data per country per participant. Investment in Formal VET includes public and private expenditure on formal vocational education and training at ISCED 3 and ISCED 4 education levels. Investment in skills also includes spending on training as part of ALMPS and spending by individuals for non-formal education and training.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter52/figure-52-8.xlsx

2. Education will face demographic change and other challenges

Investment in tertiary education in the EU lags behind that of the United States and South Korea, despite significant public efforts. With only a marginal share of private investment and the bulk of public expenditure centred on school education, the EU invests much less in tertiary education than its competitors. a closer look at EU demographic predictions reveals that public funding of education must equip students for the future. Although we can assume that low levels of spending on school education are somewhat reflected in educational outputs, as evidenced by an international skills test in compulsory education, non-financial factors play an important role, too. High levels of spending per pupil do not necessarily translate into corresponding educational outcomes, although there is a consensus that investment in higher participation rates (a higher number of learners) has both social and economic benefits. Thus, any assessment of education expenditure must consider the main features of the funding system and demographic developments which affect the number of students in the system and the expenditure per student. As we can see in Figure 5.2-9, the size of school-age population is expected to decline in most Member States in the next two decades. Such a development will force many governments to reassess how to handle the teaching staff mismatch, ensure an adequate school network with a proper infrastructure and deploy new technologies for educational purposes.

Figure 5.2-9 School-age population predictions, 3 to 18-year-olds (index 2020 = 100)



Science, research and innovation performance of the EU 2020

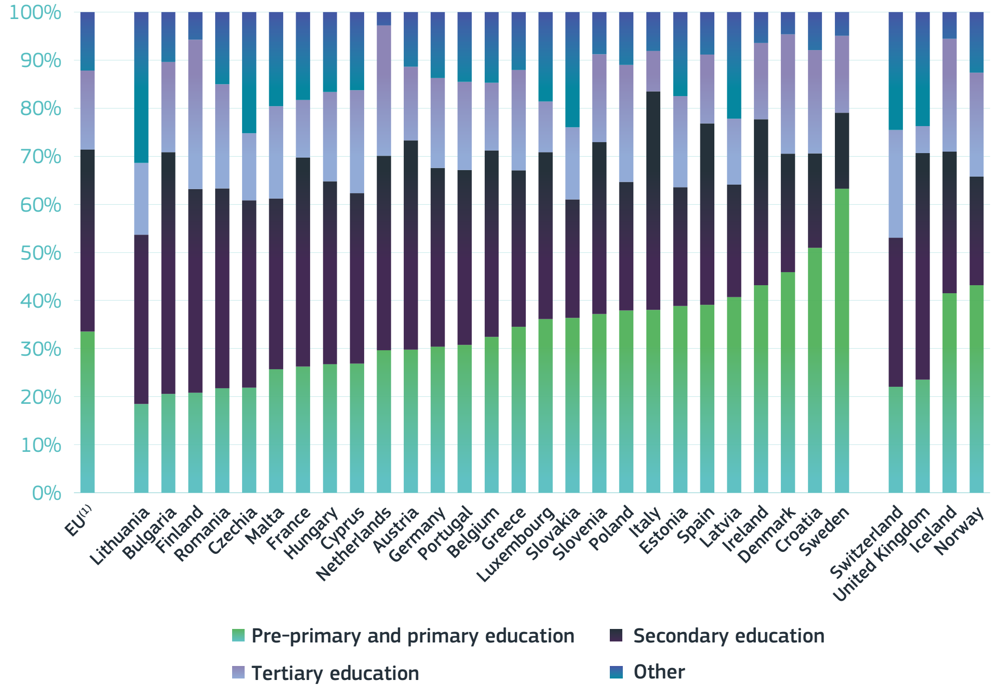
Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on Eurostat (online data code: proj_18np)

Note: Baseline projections.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter52/figure-52-9.xlsx

Total investment in education in the EU is at a similar level to that in the United States and South Korea but higher than in Japan. However, there are large differences in spending levels between EU Member States, reflected both in primary/secondary education and in tertiary education. European public investment in education is driven by two major trends. First, non-tertiary education (mostly pre-primary, primary and secondary) absorbs the bulk of expenditure on education across the EU (Figure 5.2-10). The second point is that public funding is shaped by expenditure on teaching staff which accounts for 60 % of total expenditure in the EU and exceeds 70 % in countries such as Greece, Belgium, Italy and Bulgaria.

Figure 5.2-10 Share of public expenditure on education by level (%), 2017



Source: Eurostat (online data code: gov_10a_exp)

Note: [1]EU was calculated by DG Research and Innovation.

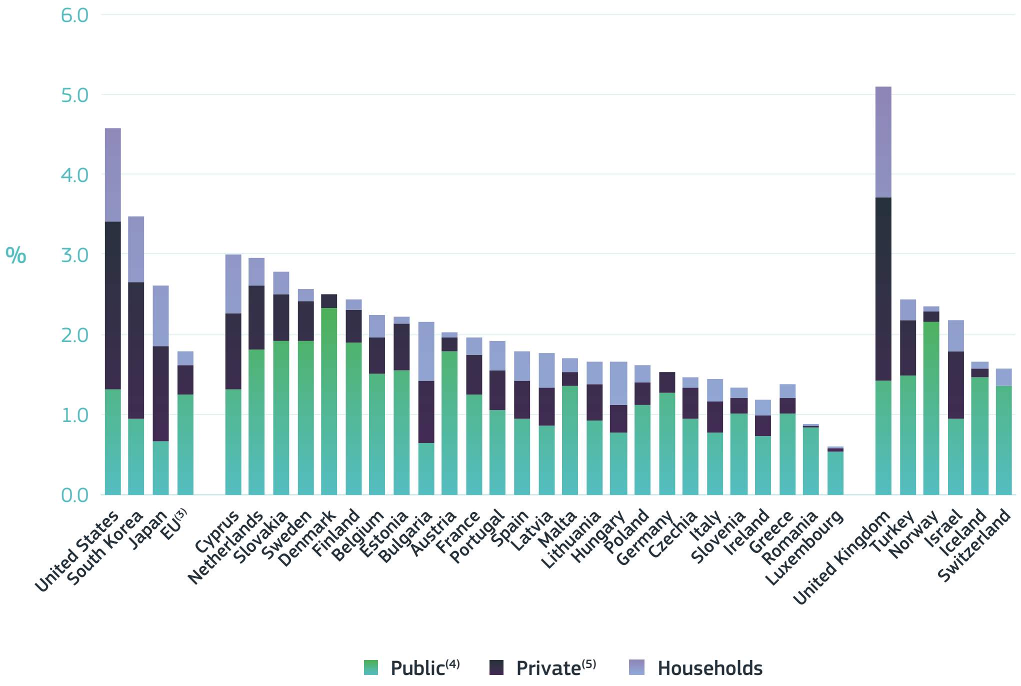
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter52/figure-52-10.xlsx

There is general consensus among education economists that early investment in education gives the highest returns, since outcomes from the earlier stages of education also determine results at later stages. For example, high levels of numeracy at lower secondary level are important for the outcomes of learning at upper secondary level and have an impact on the take-up of science and technology studies at the tertiary level – fields of study where there is a potential gap in the future supply of graduates.

While spending on school education in the EU is comparable to the levels found in North America and East Asia, there is a remarkable gap in tertiary education. The EU is spending less on tertiary education compared to all of its competitors and the gap is not closing over time. The spending gap compared to international competitors seems to be driven primarily by private sources of funding. With the exception of a few European countries (Bulgaria, Cyprus, Hungary and Latvia), public expenditure constitutes most tertiary education expenses (Figure 5.2-11).

Given the fact that European countries invest predominantly in earlier levels of education (pre-primary, primary and secondary, see Figure 5.2-10) and demographic developments in many states suggest lower numbers of children entering early levels of education, certain countries may have to reassess the structure of their expenditure on education.

Figure 5.2-11 Total educational expenditure on tertiary education(1) from public and private sources as % of GDP, 2016(2)



Source: Eurostat (online data code: educ_uoe_fine01) and OECD (Educational expenditure by source and destination)

Notes: (1)ISCED 2011 levels 5-8. (2)US, JP, KR, EU, CZ, DK, EL, LU, MT, PT, RO, SK, IS, TR, IL: 2015. (3)EU was estimated and does not include HR. Other estimations were done for some countries. (4)Public sources include General government and International organisations. (5)Private sources include Non-educational private sector and Other non-educational private entities.

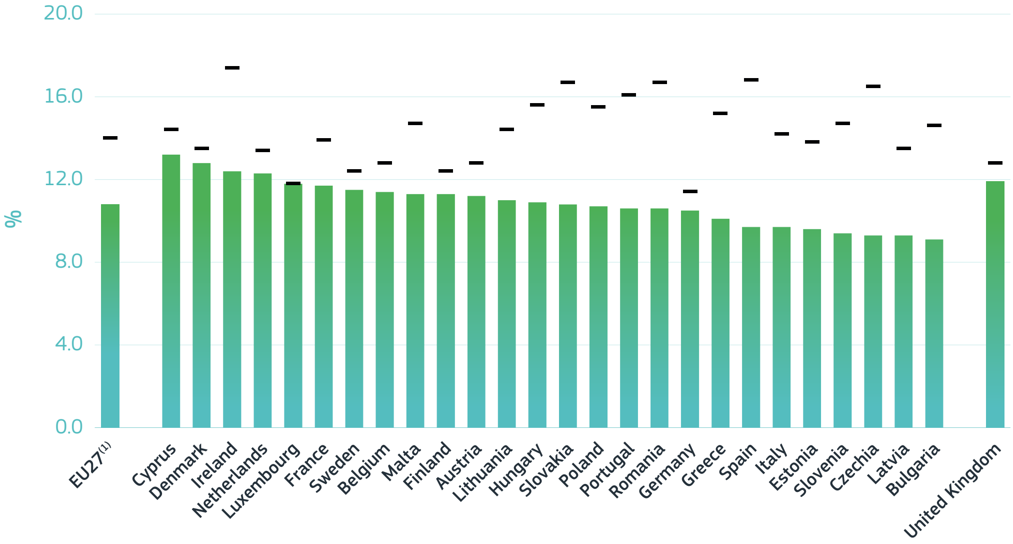
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter52/figure-52-11.xlsx

The absolute number of students in EU tertiary education remains rather stable despite the gloomy demographic outlook in many countries. This anticipates a decline in the number of tertiary graduates in the medium term, especially in central and eastern European countries. As tertiary participation rates have increased in Member States and the size of younger cohorts has shrunk, the number of tertiary students in the EU started to decline in 2014 and could continue to do so due to demographic developments in the near future. The decline in tertiary students is strongest in central and eastern European countries where the small cohorts of the post-1990 demographic crisis have now reached tertiary student age. In addition, other Member States in southern Europe have observed a declining share of the young population (Figure 5.2-12), although these have not translated into fewer tertiary students since there participation in tertiary education has increased. Based on favourable participation rates combined with a reduction in early leavers, in 2018, Member States hit the 40.7 % share, thereby exceeding the Europe 2020 target (Figure 5.2-13 with EU headline target).

While a scientific debate continues about the optimal number and share of university graduates in the population and their relevance for balanced R&I systems, available statistical data show that returns from tertiary education in terms of average earnings and the risk of unemployment are high. Various explanations are possible, such as mismatches in the fields of expertise being demanded, or a general oversupply of tertiary graduates, etc. However, manufacturing-oriented economies, like Germany and Austria, traditionally also rely on a strong supply of graduates from vocational education and training, most of them at an upper-secondary levell.

The latest statistics reveal that the number of students is shrinking faster in Estonia (-26.3 %), Slovakia (-25.5 %), Lithuania (-21.2 %), Hungary (-20.1 %), Slovenia (-18.6 %), Poland (-18.5 %), Czechia (-17.4 %), Romania (-14 %), Latvia (-12.2 %) and Bulgaria (-12 %). In the EU15, since 2013, the decline has been strongest in Finland (-4.4 %) and Portugal (-3.8 %). The number of tertiary students continues to increase in the majority of the EU15 Member States and in Cyprus (+41.6 %) and Malta (+14.7 %). In both these countries, the relatively new higher education systems are still in the expansion phase. Despite an unfavourable demography, student numbers are still rising in Germany (+11.2 %) as the result of a growing number of foreign students and an ongoing increase in participation rates.

Figure 5.2-12 Proportion of population aged 15-24 years old (%), 1995 and 2018



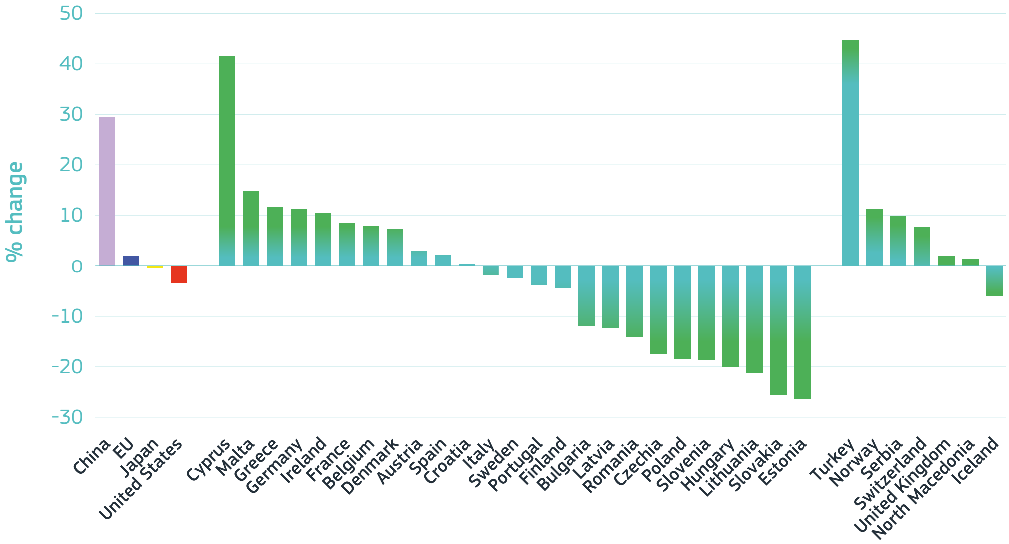
Science, research and innovation performance of the EU 2020

Source: Eurostat (online data code: demo_pjanind)

Note: (1)EU27 includes UK, but excludes Croatia.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter52/figure-52-12.xlsx

Figure 5.2-13 % change in the number of tertiary students between 2013 and 2017(1)



Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on Eurostat (online data code: educ_uoe_enrt02) and UNESCO data

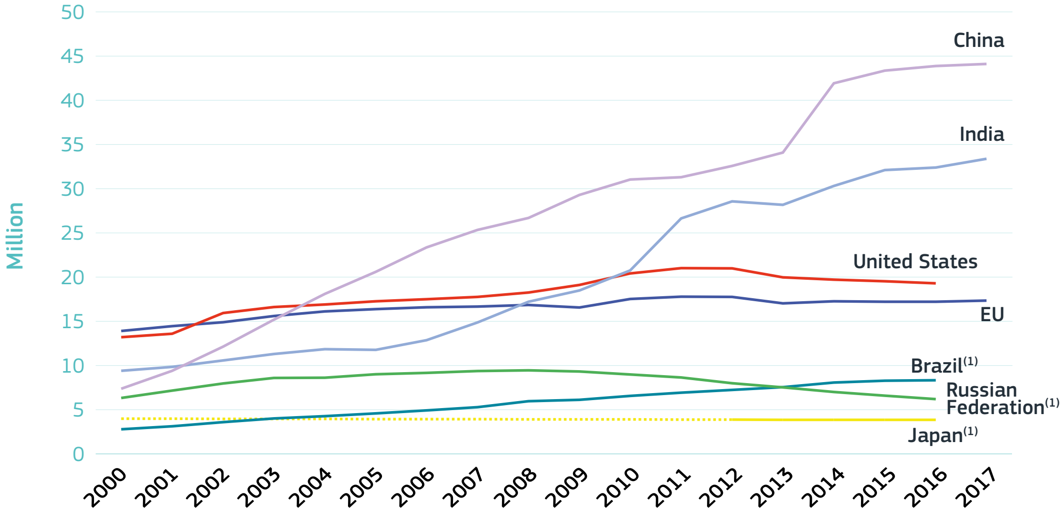
Note: (1)US, JP: 2013-2016; IE: 2014-2017.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter52/figure-52-13.xlsx

Recently, in terms of the absolute number of tertiary students, the EU and the United States have shown similar levels of participation in tertiary education. The steep growth in China and India over the last decade means a growing pool of well-educated individuals coming from these emerging economies. While the EU had 16 % of the world's tertiary student population at the beginning of the millennium, the share dropped to 9 % in 2017. In the period 2000 to 2016, the shares of China and India increased by 6 and 13 percentage points, respectively, to reach 15 % for India and 20 % for China. In terms of the absolute number of tertiary graduates, China overtook the EU in 2005 and India in 2010. The United States and EU demonstrated growth in the noughties followed by stagnation over the last decade.

As in the United States, the European student population has become progressively more international, showing to some extent that European universities are attractive on the global stage. However, Europe could better capitalise on pools of talent outside of Europe, and come closer to the 5.5 % of international students in the United States' higher education system[8]. The number of mobile students from abroad increased in Europe from 992 000 in 2013 to 1.21 million in 2016 (+22 %), although only about half of these international students came from outside Europe. In 2017, the largest groups of non-European students came from Asia (267 000) and Africa (180 000)[9]. The highest numbers of international students are in Germany and France. The United Kingdom seems to be particularly popular among Asian students, educating some 220 000 coming from Asia, which is almost the same as the number of Asian students in the EU.

Figure 5.2-14 Total number of tertiary students, 2000-2017



Science, research and innovation performance of the EU 2020

Source: Eurostat (online data code: educ_uoe_enrt02) and UNESCO data

Note: (1)EU, Brazil: 2006 value, Russian Federation: 2010 value and Japan: period 2000-2012 estimated by DG Research and Innovation.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter52/figure-52-14.xlsx

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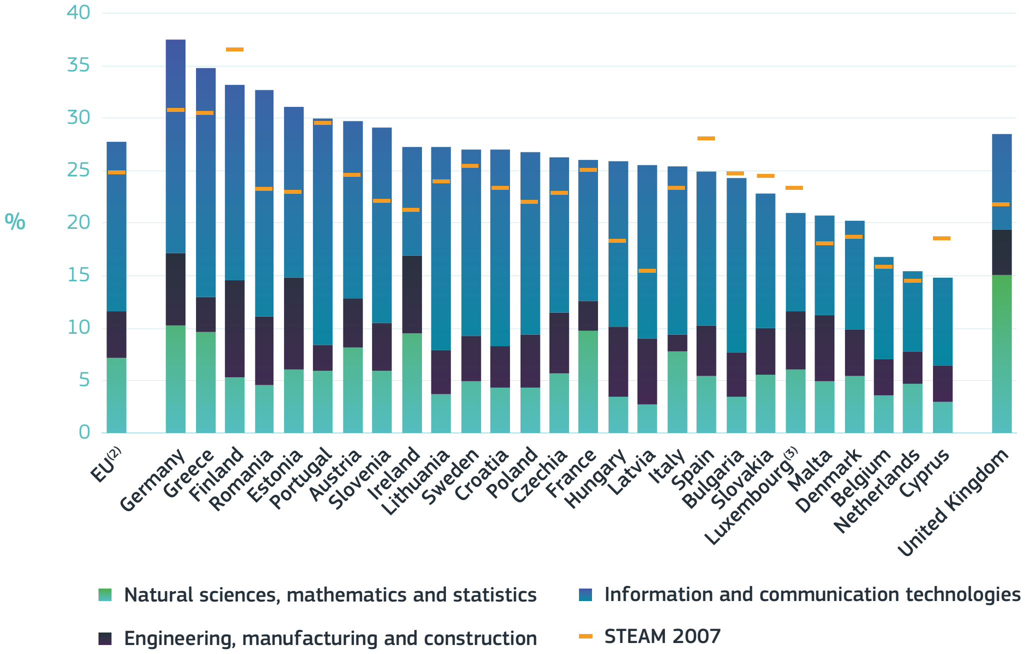
[8] US higher education enrolment data from 2018/19 based on the National Center for Education Statistics (NCES).

[9] Furthermore, there were 220 000 Asian, 30 000 African and 23 000 Northern American students in the United Kingdom in 2017.

The share of STEM (science, technology, engineering and mathematics) students has increased since 2007, with strong improvements in many central and eastern European states. Between 2007 and 2017, the share of STEM students grew from 22 % to 28 %, with particularly high shares in Germany, Greece, Finland, Estonia, Romania and Portugal (Figure 5.2-15). With more attention being given to the role of design in product marketing and product innovation, arts and design students are becoming an important asset in modern economies as these are contributing to the emergence of 'creative industries'. Correspondingly, STEM education often uses the STEAM approach, i.e. teaching STEM in environmental, economic and cultural contexts with the infusion of the arts, humanities and social sciences. The intention is to apply more creative thinking in the design of innovative products and, in general, to involve new insights and perspectives in scientific progress. The enhanced STEAM approach to STEM education also raised expectations that graduates utilise their artistic talents to generate innovative thinking, while the definition of 'art' education in STEAM often spreads across visual arts to liberal arts and humanities. Ongoing research is seeking more conceptual clarity in STEAM terminology (Colluci-Gray et al., 2017) and investigating different methods for merging STEAM methodologies (Perignat and Katz-Buonincontro, 2019).

Figure 5.2-15 Tertiary students in science, technology, engineering and mathematics (STEM) as % of total tertiary students, 2017(1) (and for 2007 without breakdown)



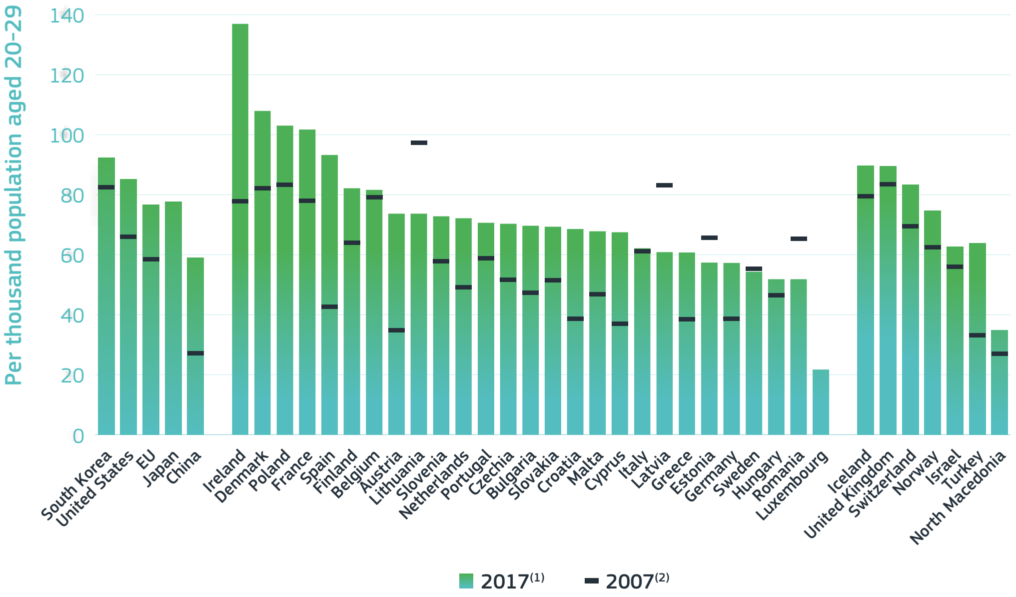
Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on Eurostat (online data code: educ_uoe_enrt03)

Notes: (1)SI: 2016. (2)EU estimated and does not include IT and NL. EU: 2016. IT, NL: 2014. (3)LU: 2006. EU average does not include LU.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter52/figure-52-15.xlsx

The shares of new graduates among young populations only increased because of the shrinking EU population of 20- to 29-year-olds. The stagnating numbers of tertiary graduates in the EU population suggest that the EU will not reach the levels of its competitors, the United States and South Korea, in the short term. As regards new tertiary graduates per thousand population (Figure 5.2-16), the EU performs at a similar level to Japan, but below the United States and South Korea. While figures in China and the United States continue to increase, in the EU, the number of new tertiary graduates per population has hardly grown over the last decade and has fallen in South Korea and Japan. Ireland's outstanding performance can be explained by a 20% increase in 2017 on the previous year. Combined with a decline in the young population since 2007, Ireland shines as an outlier. a group of leading Member States is following Ireland with trends that are more genuine and with overall improvements that are comparable to Ireland. While many central and eastern European countries experienced high growth rates in the past, the number of graduates in these countries has fallen – dramatically in some of them – within a few years. This is due to demographic developments, occasionally reinforced by students' preferences. For example, 17% of Slovak students enrolled abroad[10]. Most went to Czechia where the trend is growing: the share of Slovak students among all the students at Czech universities rose from 5% in 2007 to 7% in 2017.

Figure 5.2-16 New graduates from tertiary education per thousand population aged 20-29, 2007 and 2017



Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on Eurostat (online data code: educ_uoe_grad01) and UNESCO data

Notes: (1)US, JP, KR, IS, IL: 2016. (2)LU, IL: 2011; JP: 2013.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter52/figure-52-16.xlsx

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[10] The percentage of national tertiary students enrolled abroad, 2016; OECD (2018), Education at a Glance.

Gender imbalances among graduates are greater compared to the number of enrolled students as 54 % of students in higher education were women. In 2017, the share of women reached 57.6 % when considering tertiary graduates in the EU (Figure 5.2-17). Germany is the EU country with the most equal gender balance (female share of tertiary graduates is 51.1 %), while men represent fewer than 40 % of tertiary graduates in many central and eastern European countries. At the level of enrolled students, female students outnumbered men by about 1.3 million and represented 54 % of the EU tertiary student population following a rather stable trend over the last five years.

Women represent only about one third of all STEM graduates in the majority of EU countries. More precisely, they represent only about 33 % of all science, technology, engineering and mathematics graduates in the EU, a share which has not changed in recent years. In 2017, there were remarkable differences within the main STEM areas with a higher share of female graduates (53 %) in natural sciences, mathematics and statistics, but a significantly lower share (19 %) in information and communication technologies. The European share of female science and technology graduates reaches comparable values in Canada (32 %) and the United States (37 %), while South Korea only achieved 26 % of female graduates.

The under-representation of women in certain STEM occupations as well as in related study areas has persisted over time. The proportion of males interested in STEM grew from 2006 to 2015, but not of females. Dedicated studies in STEM-related vocational plans demonstrate that adolescent plans are broadly segregated by gender. Earlier data from PISA-participating countries[11] show that, across all the OECD and partner countries, a much higher proportion of males express an interest in engineering and computing occupations than females, whereas the opposite trend exists in the preference for health careers (Han, 2017). The low participation of women observed across STEM occupations contributes to talent loss and limits the beneficial effects of social diversity. The persistence of women's under-representation in particular fields of STEM also contributes to reproducing economic gender inequalities, as STEM occupations represent some of the best paid and most prestigious jobs in the labour market (Blasko et al., 2018

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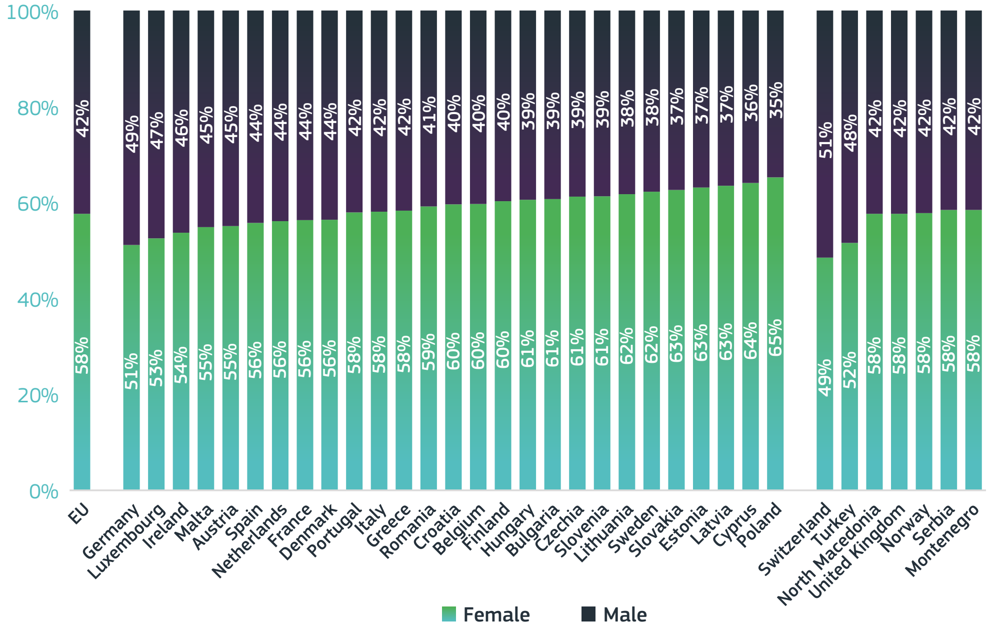
[11] PISA is the OECD's Programme for International Students Assessment.

Figure 5.2-17 Share of tertiary graduates by sex (%), 2017



Science, research and innovation performance of the EU 2020

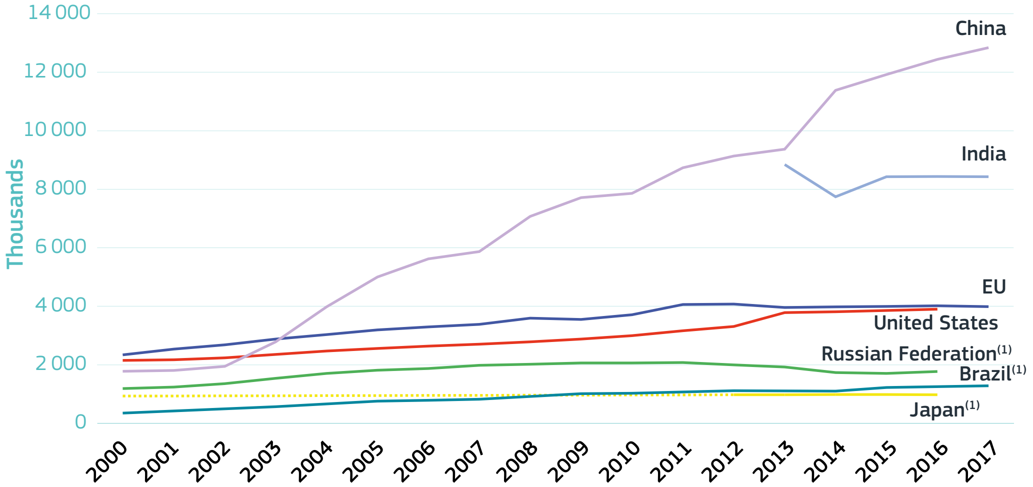
Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on Eurostat (online data code: educ_uoe_grad01)

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter52/figure-52-17.xlsx

The numbers of tertiary graduates are very similar in the EU and the United States, while China is reinforcing its position as the world's largest producer of tertiary graduates (Figure 5.2-18).

The EU has a worse performance in the share of science and technology (S&T) graduates than several years ago, remaining roughly at 2005 levels. In 2015, although there was a higher share of S&T students at over 25 %, the following years showed a deterioration in these values. As regards science and technology graduates (Figure 5.2-19), the EU countries now reach approximately the same level as in 2005. South Korea has seen shares which continue to decline, although it still has a much higher share of science and technology graduates among all tertiary graduates. As regards the number of tertiary graduates per thousand population, South Korea has almost been caught up by the United States, while Canada is also climbing to similar levels. Data from years 2014-2017 suggest that the share of EU graduates stagnated at a level considerably lower than these three listed competitors.

Figure 5.2-18 Total number of tertiary graduates, 2000-2017



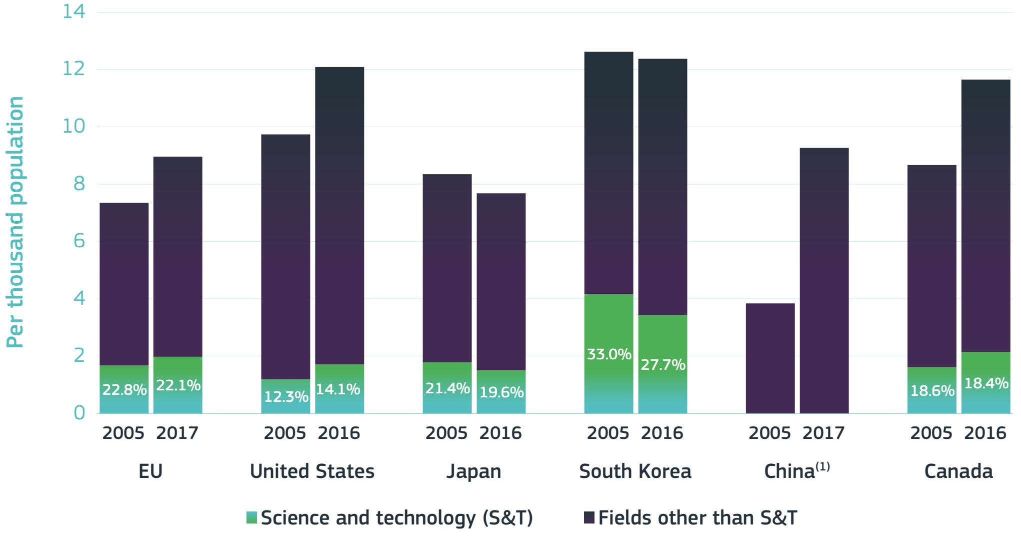
Science, research and innovation performance of the EU 2020

Source: Eurostat (online data code: educ_uoe_grad01) and UNESCO data

Note: (1)EU, Brazil: 2006 and 2013 values, Russian Federation: 2008 and 2010 values and Japan: period 2000-2012 estimated by DG Research and Innovation.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter52/figure-52-18.xlsx

Figure 5.2-19 Tertiary graduates per thousand population broken down by science and technology and other fields, 2005 and 2017



Science, research and innovation performance of the EU 2020

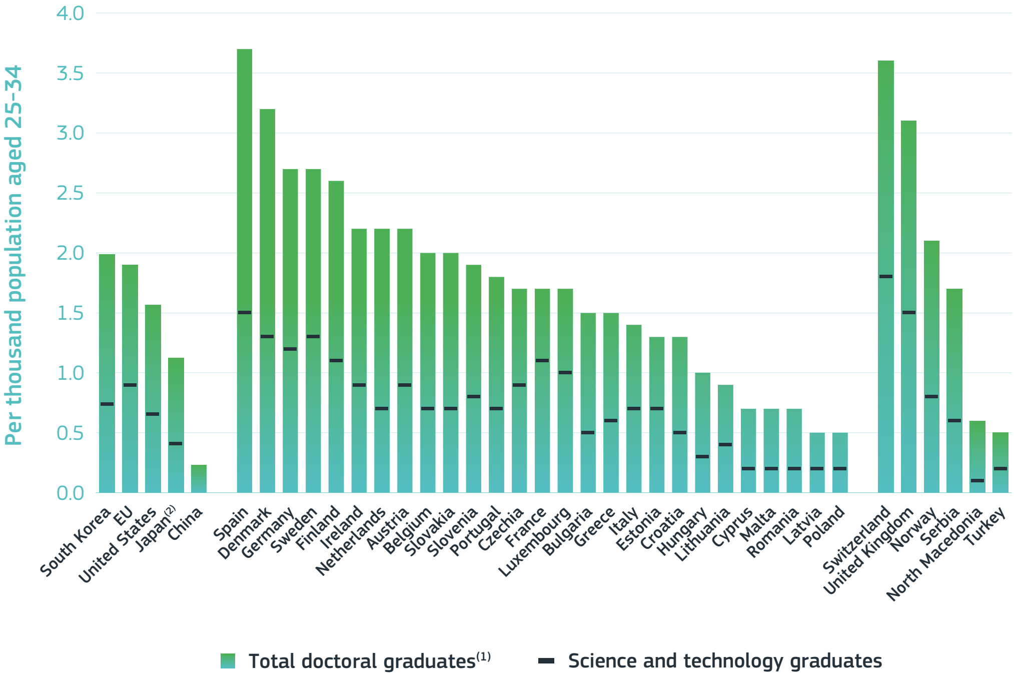
Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on Eurostat (online data code: educ_uoe_grad02), OECD (Graduates by field), UNESCO and World Bank data

Note: (1)CN: the data refer to total graduates (a breakdown between S&T and non-S&T is not available).

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter52/figure-52-19.xlsx

The EU performs well in the education of new doctoral graduates, including in science and technology. Some EU countries are among the best performers worldwide, together with Switzerland. As regards new graduates at the doctoral level, the EU achieves at the same level as South Korea in general but maintains a higher share of science and technology graduates. Other competitors, such as Japan and the United States have lagged behind with little progress in recent years. Spain, the UK, Germany and the Nordic countries perform well, but smaller countries tend to have a high share of doctoral students being awarded their degrees abroad, thus the available data could understate their performance. Many eastern and southern European countries produce a relatively low number of doctoral graduates, where a mixture of factors could contribute to the lower attraction of academic careers perceived (EC/EACEA, 2017)[12].

Figure 5.2-20 New doctoral graduates per thousand population aged 25-34, 2017



Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on Eurostat (online data code: educ_uoe_grad06 and educ_uoe_grad07), OECD, UNESCO and World Bank data

Notes: (1)US, JP and KR: 2016. (2)Share of science and technology graduates of Japan does not include Information and Communication Technologies graduates.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter52/figure-52-20.xlsx

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[12] Characterised through a combination of factors, such as employment conditions in academia, duties and working time of academic staff, remuneration of academic staff, or continuing professional development.

In 2018, the EU reached its target for the share of people with tertiary attainment, and also made progress in achieving the target for early leavers from education and training. Progress in the number of tertiary graduates (with some time lags) contributed to achieving the EU's headline target for tertiary attainment (Figure 5.2-21). The Europe 2020 strategy's target demands that at least 40 % of 30- to 34-year-olds in the EU should have completed tertiary education by 2020 (EC, 2019c). Reaching the level of 40.7 %, the EU crossed this threshold in 2018. With the initial level at 23.6 % in 2002, there was a steady increase to 32.3 % in 2009 and beyond. This growth pattern was even more significant for women (from 24.5 % in 2002 to 45.8 % in 2018) than for men (from 22.6 % to 35.7 %), meaning that there is a gender gap with women above and men still below the overall Europe 2020 target.

Lithuania, Cyprus, Ireland, Luxembourg and Sweden already have tertiary education attainment rates of over 50 %. Italy and Romania still show relatively low tertiary attainment rates. After Mexico, Italy has the lowest tertiary attainment rate among OECD countries (based on the population of 25- to 34-year-olds from 2017). Despite the progress achieved, the EU still lags behind the tertiary attainment levels of the United States (48 %), Japan (60 %), Canada (61 %) and South Korea (70 %).

Although tertiary attainment has become more accessible, some challenges remain relevant. Studies, such as the OECD PIAAC survey[13], show big differences between the skill levels of tertiary graduates in EU countries and hence the need to focus more on the quality of education in some countries. Although the EU reached its target for educational attainment rates at the tertiary level, other challenges, such as the quality of education and the acquisition of skills relevant to the labour market, remain relevant. Furthermore, reducing dropout rates from education and training would help to mitigate difficulties early leavers have in joining the labour market and improve the efficiency of public investment in education. As set out by the EU 2020 strategy, the share of early leavers from education and training in the EU should not exceed 10 %. With 10.6 % reported in 2018, the EU was 0.6 percentage points away from its target.

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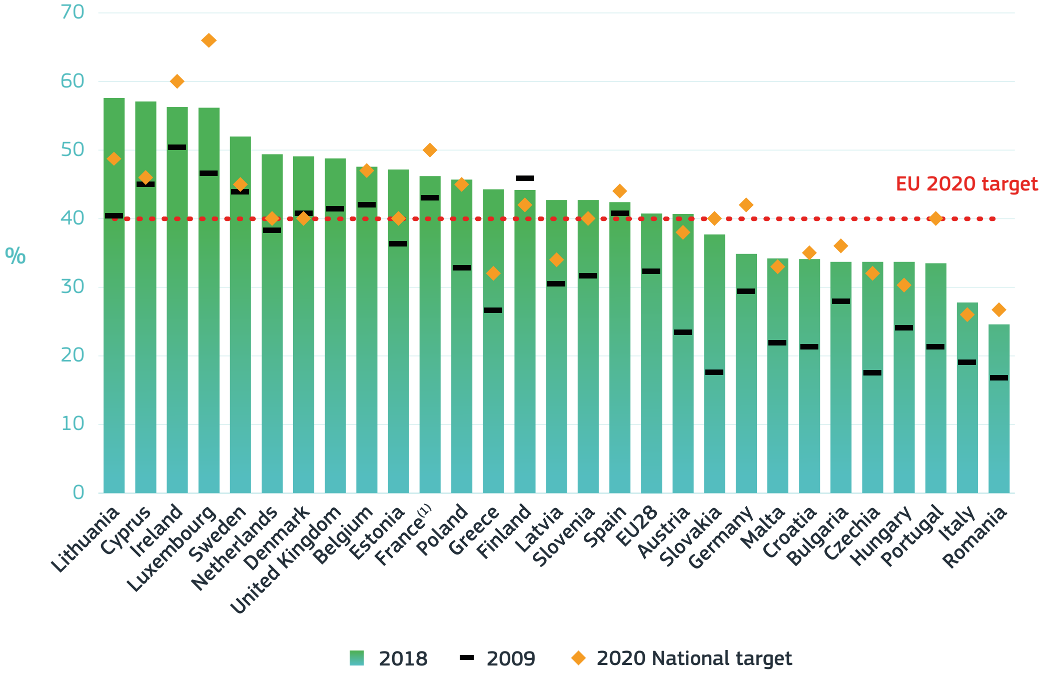
[13] Programme for the International Assessment of Adult Competencies (PIAAC) is an OECD programme of assessment and analysis of adult skills based on international survey conducted in over 40 countries/economies.

Figure 5.2-21 EU headline target on the tertiary attainment of population aged 30-34, 2009 and 2018



Science, research and innovation performance of the EU 2020

Source: Eurostat (online data code: edat_lfse_03)

Note: (1)FR: the 2020 national target includes persons aged between 17 and 33 years.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter52/figure-52-21.xlsx

3. Research personnel and gender equality show low dynamics

Although the number of researchers and R&D personnel in Europe grew to 1.77 million in 2018, business R&D employment remains at low levels. In 2018, the EU's active population reached around 213 million of whom 198 million were employed[14]. Human resources in science and technology (HRST) accounted for 110 million people in the EU, or 56% of total employment, a share that has been increasing constantly. People employed in science and technology who had successfully completed tertiary-level education accounted for 23% of total employment and over the last decade their shares have been growing, in particular, in Austria, Malta, Portugal and Luxembourg.

The retiring baby boomer generation and the potential risk of sectoral and regional bottlenecks in the supply of skilled workers could aggravate the demographic challenges, which were described earlier,

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[14] Active population includes the total labour force of 20- to 64-year-olds which includes both employed and unemployed people. Source: Employment - annual data [lfsi_emp_a].

in the coming decades when small young cohorts enter the labour market. An adequate supply of skilled human resources is vital for knowledge absorption and for the development of science and technology-intensive economic sectors. However, rapid technological progress and a change in workplace requirements, growing interdisciplinarity and the resulting low predictability of future skills needs in combination with fluctuating migration levels make planning and foresight difficult. To better grasp and capitalise on the latest developments, the European Institute of Innovation and Technology plays an important bridging role between the European R&I framework and education policies and programmes. The Institute contributes to reshaping innovative and entrepreneurial education at both master and doctoral levels, although its Skills for the Future initiative intends to rethink approaches to education programmes at lower educational levels, too. Their higher-education partners focus on developing innovative curricula that provide students, entrepreneurs and business innovators with the knowledge and skills anticipated for a knowledge and entrepreneurial society. Any broader response is limited by interacting forces of growing internationalisation of the labour markets and greater competition for highly skilled people. While the first tends to make regional or national skill gaps less severe, the growing international and intersectoral demand for highly trained professionals, including scientists and researchers, lacks regions or countries that are further developing their R&I systems.

Figure 5.2-22 Key data on human resources in science and technology in the EU

	Total (000s) 2018	As % of total employment 2018	Compound annual growth (%) 2007-2018[1]
Active population	213 624	108	0.32
Total employment (LFS)	198 032	100	0.34
HRST - Human Resources in Science and Technology	110 473	55.8	2.23
HRSTE - Human Resources in Science and Technology - Education	85 764	43.3	3.10
HRSTO - Human Resources in Science and Technology - Occupation	69 959	35.3	1.68
HRSTC - Human Resources in Science and Technology - Core	45 250	22.8	2.94
SE - Scientists and engineers	14 759	7.5	2.52
Total R&D personnel (FTE)	2 795	1.4	2.97
Researchers (FTE)	1 773	0.9	3.57

Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on Eurostat (online data code: hrst_st_ncat and rd_p_persocc)

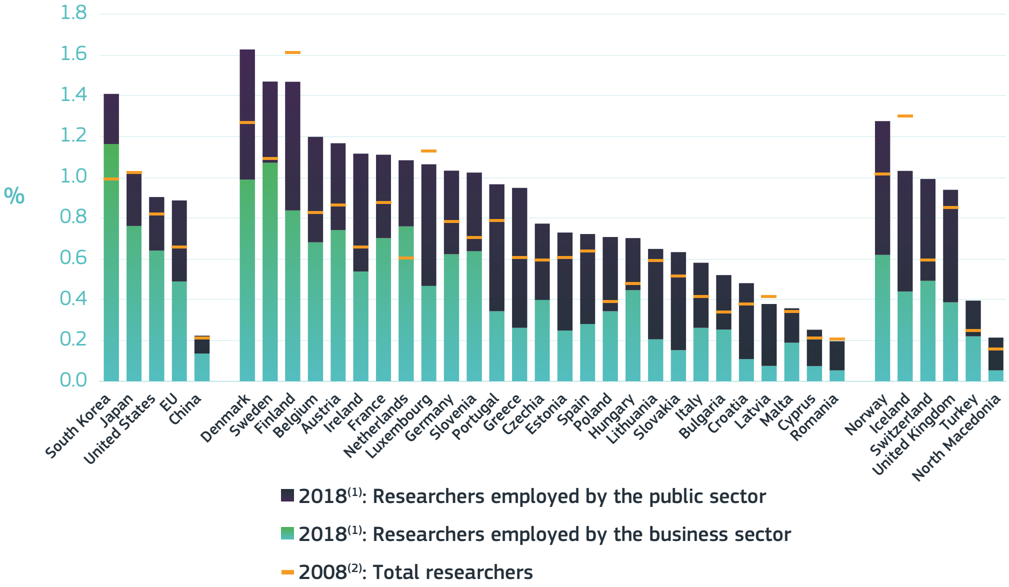
Note: (1)Breaks in series occur between 2014 and the previous years and between 2011 and the previous years for HRST data.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter52/figure-52-22.xlsx

Human resources in science and technology have grown faster than total employment in the past and jobs in this area were more resilient during the crisis. Whilst total employment increased on average by 0.3% each year between 2007 and 2018, HRST increased annually by 2.2%, or by nearly 20 million over the whole period, research personnel by 3% and the number of researchers by 3.6%. This reflects the labour force's rising educational attainment, as well as the shift to skill-intensive jobs and a knowledge-intensive economy. In absolute terms, the stock of human resources in science and technology is still growing, partly because of increasing attainment rates. As yet, there is no evident overall skills gap although the situation might change in the future and there are already bottlenecks in certain regions and sectors, such as ICT.

The share of researchers in the workforce reflects countries' economic structures and shows dynamic developments. Countries with high shares of researchers in total employment tend to be innovation leaders. In terms of researchers, as a percentage of total employment the EU still lags behind the United States, Japan and, in particular, South Korea. The share remains worryingly low when it comes to researchers employed in the business sector (see Figure 5.2-23). However, the percentage of researchers employed in the EU has outpaced the growth rates of China, the United States and Japan's stagnating values. None of the international competitors have been able to keep pace with South Korea, where the share is pulling further ahead.

Figure 5.2-23 Total researchers (FTE) as % of total employment, 2008 and 2018



Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on Eurostat (online data code: rd_p_persocc), OECD and Statista based on National Bureau of Statistics of China

Notes: (1)US: 2016; JP, KR, CN, CH, TR: 2017. US value for public sector estimated. (2)EL: 2011.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter52/figure-52-23.xlsx

EU countries keep increasing the number of researchers (in relative and absolute terms), as do their global competitors. In the EU, the highest share of researchers in total employment as well as those employed by the business sector are in the Nordic countries. While Cyprus and Romania show relatively low levels of researchers (roughly on the same level as China), the group of low performers extends to Croatia and Latvia, when looking only at researchers in the business sector. The good news is that many EU countries are showing a positive trend in the employment of researchers. These are in central and eastern European countries (notably Croatia and Poland) plus Greece and Portugal, which seem to have recovered from the crisis and have increased the number of researchers significantly since 2007. However, the picture changes when comparing the total number of researchers worldwide. Since 2015, China has had the largest number of business researchers in absolute terms and is competing with the EU in the total number of researchers; in 2017, there were 1.68 million in the EU and 1.74 million in China.

Although females represented 48 % of EU graduates at the doctoral level in 2017, they represent about a third of all EU researchers and only about a quarter of those in the business sector. The share of female researchers is still far from balanced, depending to a large extent on the sector of activity, with relatively higher shares of female researchers in education – 46 % in 2016 – while the business enterprise sector is performing worse with female researchers still severely under-represented with a share of about a quarter of researchers. Previously, as the number of women researchers in the EU increased at a higher rate on average than men, the situation improved slightly, although this was not the case for all Member States. Czechia has one of the lowest numbers of female researchers in the EU with their share in 2017 (23.1 %) reaching 2 percentage points lower than in 2007 (25.4 %). The best EU performers, such as Latvia and Bulgaria, show values for equal gender splits in the research population.

Figure 5.2-24 Total researchers (Full-Time Equivalent)

	2018 (thousands)(1)	Compound annual growth (%) 2007-2018(2)	% of female researchers, 2007(3)	% of female researchers, 2017(3)	As % of total employment, 2018(1)
EU	1773	3.57	:	30.2	0.90
Belgium	58	4.29	31.1	34.8	1.21
Bulgaria	16	3.58	47.8	46.4	0.52
Czechia	41	3.61	25.4	23.1	0.78
Denmark	46	3.99	29.3	35.5	1.64
Germany	433	3.69	18.6	22.6	1.03
Estonia	5	2.74	41.5	40.7	0.75
Ireland	25	6.46	30.3	35.4	1.12
Greece	37	5.81	36.7	37.8	0.96
Spain	140	1.22	37.9	38.8	0.72
France	306	2.89	18.9	28.6	1.13
Croatia	8	2.43	47.2	47.7	0.48
Italy	140	3.54	33.8	34.6	0.60
Cyprus	1	2.95	34.0	38.0	0.27
Latvia	4	-1.08	49.6	50.8	0.41
Lithuania	9	0.32	48.6	46.1	0.64
Luxembourg	3	5.22	22.3	27.3	1.07
Hungary	31	5.53	31.7	26.8	0.70
Malta	1	5.11	25.0	29.4	0.36
Netherlands	96	3.59	25.5	27.1	1.09
Austria	51	4.42	20.6	23.7	1.18
Poland	118	6.10	39.4	35.4	0.71
Portugal	47	2.91	43.9	43.1	0.96
Romania	17	1.19	43.8	46.3	0.20
Slovenia	10	2.60	33.7	30.9	1.03
Slovakia	16	2.57	41.4	40.1	0.64
Finland	38	0.06	31.5	33.2	1.49
Sweden	75	2.33	29.4	28.6	1.47
United Kingdom	309	1.85	36.8	38.7	0.96
Iceland	2	3.65	37.8	46.4	1.03
Norway	35	3.22	33.5	38.1	1.29
Switzerland	46	6.97	30.2	34.9	0.99
North Macedonia	2	4.39	52.5	56.4	0.22
Turkey	112	8.46	34.1	32.8	0.40
United States	1 371	2.11	:	:	0.91
China	1 740	6.00	:	:	0.22
Japan	676	0.10	13.0	16.2	1.04
South Korea	383	5.61	14.9	20.1	1.43

Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on Eurostat (online data code: rd_p_persocc and rd_p_femres), OECD and Statista based on National Bureau of Statistics of China

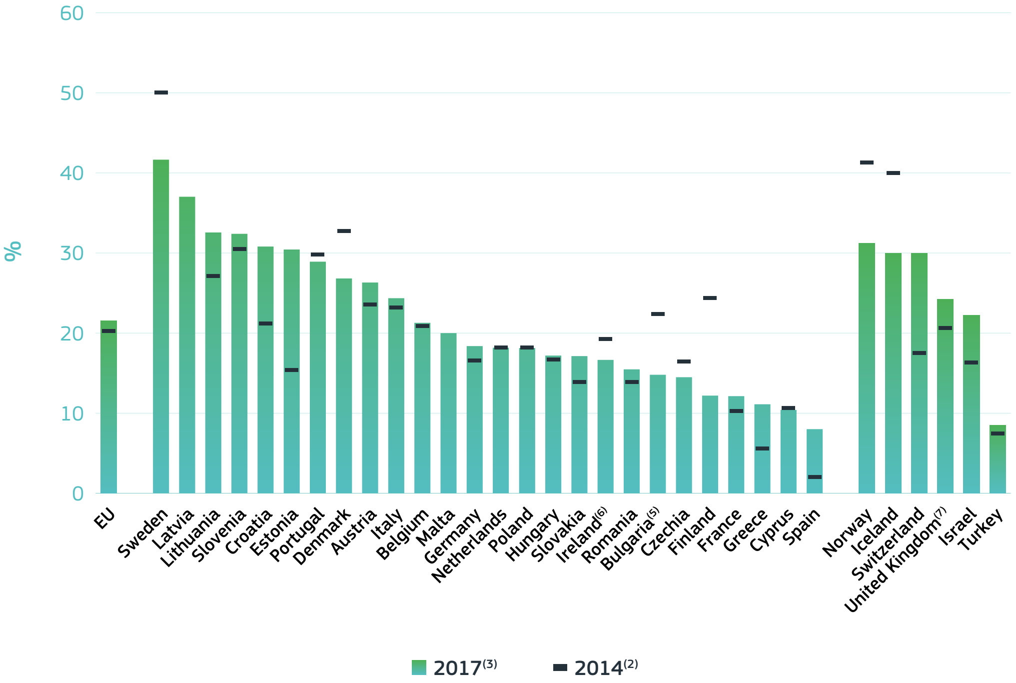
Notes: (1)US: 2016; JP, KR, CN, CH, TR: 2017. (2)US: 2007-2016; JP, CH: 2008-2017; KR, CN, TR: 2007-2017; PT, SI: 2008-2018; EL: 2011-2018. JP, CN, FR, IT, LU, NL, PT, RO, SI, FI, SE, IS: show break in series between 2007-2018. (3)CH: 2008; LU: 2009; FR: 2010 EL, NL: 2011. (4)EU aggregate estimated and does not include BE and FI. (5)JP, KR, BE, EL, FI, UK, IS, NO, CH - head counts (HD) for share of females.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter52/figure-52-24.xlsx

Women are in a minority in the top academic grade and in recent years their position has only improved slightly. Across the EU, the proportion of women among heads of institutions in the higher-education sector rose from 20.2% in 2014 to 21.7% in 2017 although, at the same time, several countries experienced a fall in the number of women heading up institutions (Figure 5.2-25). The under-representation of women in leadership positions has wide implications for both scientific advancement and for industries with a strong need for a technologically educated workforce (EC, 2018). In recent years, growing numbers of scientific institutions have adopted a variety of measures to make improvements, such as leadership training, implicit bias training, and broader gender equality plans (Cameron et al., 2015).

In recent decades, the ratios of women to men in senior academic and decision-making positions have fallen below expectations given the growing number of women among higher-education graduates. For example, in the life sciences at the EU level, women make up the majority of graduates up to doctoral level but are less successful than men in securing research grants (ERC, 2018), and their numbers progressively decline at each progressive career stage (Helmer, 2017).

Figure 5.2-25 Share of females as heads of institutions in the higher education sector (HES)[(1)], 2014 and 2017



Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on Women in Science database

Notes: [(1)]Data are in headcounts (HC). [(2)]BE (French speaking community universities), BG, SI: 2013. FR: 2012. [(3)]BE (French speaking community universities), CZ, PT, RO, SI, UK: 2016. CY: Academic Year 2015-2016. ES: 2015. [(4)]LU excluded due to lack of data. [(5)]BG: Data about heads of scientific organisations are not available. [(6)]IE: Private colleges and other smaller institutions are not included. [(7)]UK: Figures rounded to the nearest multiple of 5.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter52/figure-52-25.xlsx

4. Conclusions

Investment into human capital is important as it is one of the main factors influencing the competitiveness of European R&I systems. R&I are systemically linked processes within the framework of a larger, knowledge-driven socio-economic system (EC, 2009). The accumulation and transformation of knowledge provides input for R&I activities and, within that context, it is of key importance that R&I are well connected to a number of other areas, such as the **education system**.

The education system **provides the knowledge base** and can **foster creativity**, both of which support the ability to perform high-quality research. It is the interpretation, the combination and recombination of information into new knowledge, and the upgrading of the existing knowledge base that make our R&I systems competitive. In addition to scientific excellence, education is an important way to **transfer knowledge** derived from R&I to society and equip young people with **the right skills** for their future professional development.

The supply of **human resources in science and technology** ranks among the most important factors determining the competitiveness of the EU in the long term. The demand can vary depending on concrete industry or technology sectors and thus the focus on 'R&D expenditure' must be complemented by indicators such as 'R&D personnel' and 'researchers' to fully understand the EU's comparative advantage. In that context, the **under-representation of women** in both public and private research presents an unused potential of talents and deprives women of the opportunity to contribute towards R&I on an equal footing. Given the negative effects of gender imbalance in all scientific fields and the necessity to accelerate the progress towards gender equality in R&I, there must be more tangible role models for potential women scientists to encourage more women to pursue a **scientific career** and presence in scientific **decision-making bodies**.

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CHAPTER
5.3

INVESTMENT IN ECONOMIC COMPETENCIES

KEY FIGURES

2 %
of EU investments in economic competencies as a % of GDP

5/30
most valuable brands are in the EU

What can we learn?

- **Economic competencies, such as management quality, organisational structure and workforce training, are essential ingredients** to reap the full productivity benefits from investments in both tangible and other intangible assets, especially in a fast-changing world.
- **Economic competencies are contributing to economic and labour productivity growth** in Europe.
- **The EU underinvests in economic competencies relative to the United States**.
- **Intra-EU differences in investments in economic competencies persist** which may exacerbate inequalities in innovation.
- **Brand strength and recognition is increasingly bringing value to companies**. Over time, there has been an enormous rise in brand value especially in technology and disruptive digital industries where Europe has a 'weaker' presence. Today, the 'top 30 brands' are mainly found in the United States and China.
- **Many software and digital applications behind the widespread success of digital disruptive industries have some 'EU origin'**.

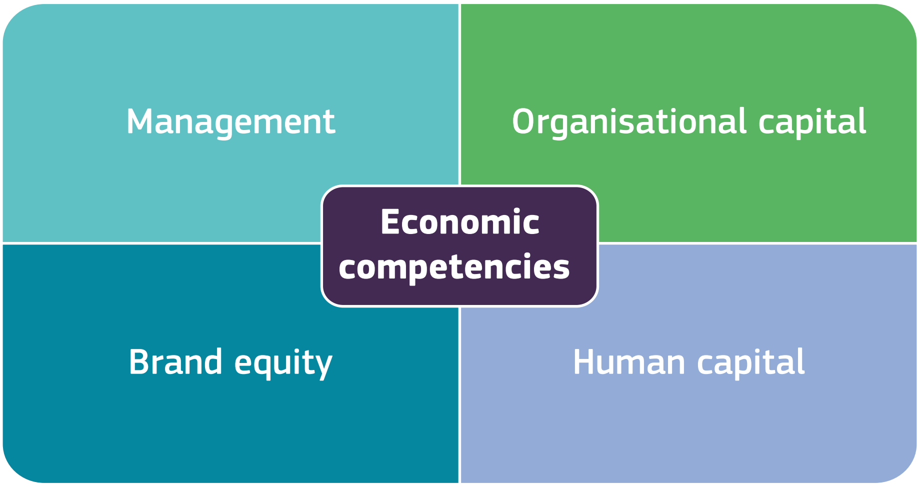
What does it mean for policy?

- **Incentivise investments in training, mentoring, coaching and other activities that promote lifelong learning and soft skills**, such as the capacity to adapt and adopt new technologies in a fast-changing world.
- **Support the strength of the 'made in EU' technological brand on the global scene**, including the communication of successful EU innovations that underpin widespread software and tech applications in the digital age.
- **Produce further cross-country and cross-sector evidence** as well as analytical work **on management quality and its impact** on business productivity.

Economic competencies, such as management quality, organisational structure and workforce training, are essential ingredients for reaping the full productivity benefits from investments in both tangible and other intangible assets, especially in a fast-changing world. As highlighted in Chapter 2 - Changing innovation dynamics in the age of digital transformation, because of digitalisation, innovation is moving at an unprecedented speed. In such a fast-changing world, organisations need to increasingly adapt and create structures that are flexible enough to accommodate new market and technology trends that could put them in the lead in the new era. This includes building a company culture that promotes 'resilience in discomfort', allowing for experimentation, collaboration, creativity and critical thinking and, if necessary, acquiring new competences to cope with change. Managers play a key role in shaping just how strategic and agile an organisation is. In other words, good management provides a vision for the company, defines strategic objectives and the right incentive structure to guide and motivate the workforce. In this context, higher management quality has been documented to be productivity-enhancing for a company (see, for example, Bloom, Sadun and Van Reenen, 2016). In addition, management quality correlates positively with both larger ICT adoption rates and productivity resulting from using ICT capital (see, for example, Andrews et al. (2018)). Furthermore, the uptake of advanced technologies affects the production process workflow and the relative costs of acquiring or communicating information, which implies that implementing such technologies often needs organisational innovations that match technological innovation (OECD, forthcoming). In this respect, skills and competences should be aligned with the production process and the changes it may be subject to. Thus, training and preparing the workforce is essential.

The so-called 'economic competencies' include brand aspects (advertising and market research), knowledge embedded firm-specific human capital and organisational capital following the framework in Corrado et al. (2005), as represented in Figure 5.3-1. This chapter highlights the importance of exploring complementarities between economic competencies and other intangible and tangible assets for firm performance and productivity. These competencies relate to the resilience and agility of teams and companies to recognise and embrace the opportunities brought by new technologies. Stehrer et al. (2019) analysed the role of these supplementary intangibles and found that economic competencies (which are outside the boundaries of national accounts) have a statistically significant impact on growth, which is robust both before and after the crisis and more visible in business services than in manufacturing.

Figure 5.3-1 Visual representation of different economic competencies



Science, research and innovation performance of the EU 2020

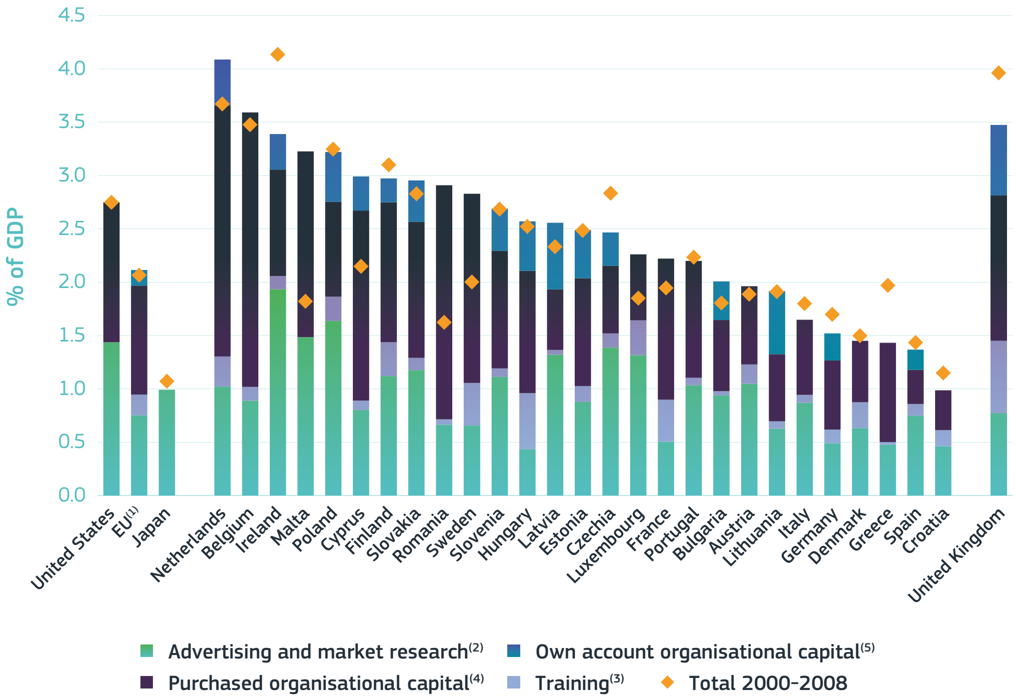
Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on Corrado et al. (2015)
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter53/figure-53-1.xlsx

1. Europe appears to underinvest in economic competencies relative to the United States despite the positive contribution of these intangibles for growth

The United States appears to outperform the EU in investing in economic competencies. Moreover, intra-EU differences persist which may hinder future productivity developments and exacerbate innovation inequalities. Figure 5.3-2 compares countries in terms of gross fixed capital formation in economic competencies – purchased and own-account organisational capital, brand aspects (advertising and market research) and (vocational) training – as a percentage of GDP over the periods 2000-2008 and 2009-2017. Overall, relative investments in these supplementary intangibles seem to have slightly increased in the EU as a whole, although this only appears to be the case in half of the EU Member States. Despite this increase, the United States still outperforms the EU with aggregate investments in advertising and market research and organisational capital of 2.8 % of GDP compared to only 2.1 % in the EU in the period 2009-2018. Heavier investments in relative terms by US companies to promote their brands contribute to this gap.

Within the EU, the highest shares of investments in economic competencies are in the Netherlands, Belgium, Ireland, Malta and Poland where investments were higher than 3 % of GDP between 2009 and 2017. The United Kingdom also stands out as a top investor in economic competencies in Europe, investing 3.5% of GDP. On the contrary, the shares of investments were lowest (below 1.5% of GDP) in Croatia, Spain, Greece and Denmark. Relative investments in brand equity were the largest in Ireland where large multinational companies are also present. In addition, Hungary had the largest relative investments in training, while purchased organisational capital investments were the highest in relative terms in Belgium. These intra-EU disparities call for an assessment of the bottlenecks to firm investments in the lowest-investing countries. This is crucial to boost both absorption capacity and the uptake of new, productivity-enhancing technologies.

Figure 5.3-2 **Investment in economic competencies as a percantage of GDP, 2009-2017 with breakdown and total for 2000-2008**



Science, research and innovation performance of the EU 2020

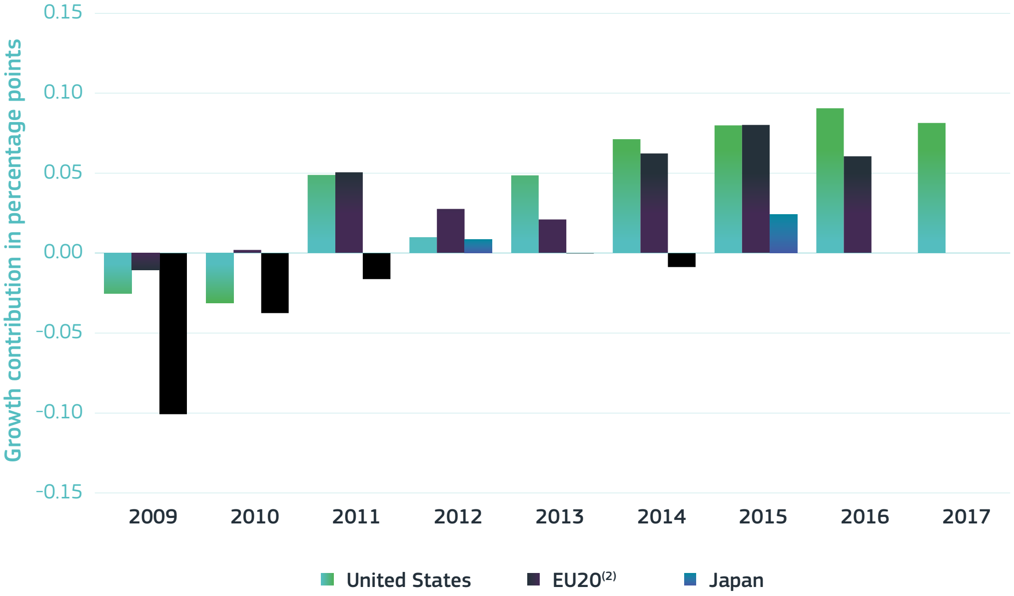
Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on EU KLEMS 2019 (analytical database)

Notes: (1)EU was estimated by DG Research and Innovation. (2)JP: 2009-2015; HR: 2009-2016. (3)Data not available for US, JP and MT. HR, UK: 2009-2016. (4)Data not available for JP. HR: 2009-2016. (5)Data not available for US, JP, BE, DK, EL, FR, HR, IT, LU, MT, AT, PT, RO and SE. UK: 2009-2016.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter53/figure-53-2.xlsx

Overall, the contribution of economic competencies to both economic growth and productivity growth has increased over time in Europe. When looking at the contribution of economic competencies as a whole to value-added growth as well as labour productivity growth per hour worked, it is possible to observe that overall it has increased since 2009 (Figure 5.3-3 and Figure 5.3-4, respectively) even though the contribution remains small when compared to other assets (see, for example, Chapter 3.1. Productivity puzzle and innovation diffusion). Stehrer et al. (2019) found a statistically *significant role tangible ICT and intangible economic competencies play in facilitating both value-added growth and labour productivity growth*. In 2015, a one percentage point increase in economic competencies resulted in almost a 0.1 percentage point increase in value added and productivity growth in the EU. Moreover, when compared to the United States and Japan, it seems that the contribution of economic competencies to labour productivity growth remained more resilient and stable in Europe as the post-crisis period appears to have had a less favourable effect in the United States and Japan than in Europe.

Figure 5.3-3 **Contribution of intangible economic competencies[1] to value-added growth in the EU, United States and Japan in percentage points, market economy, 2009-2017**



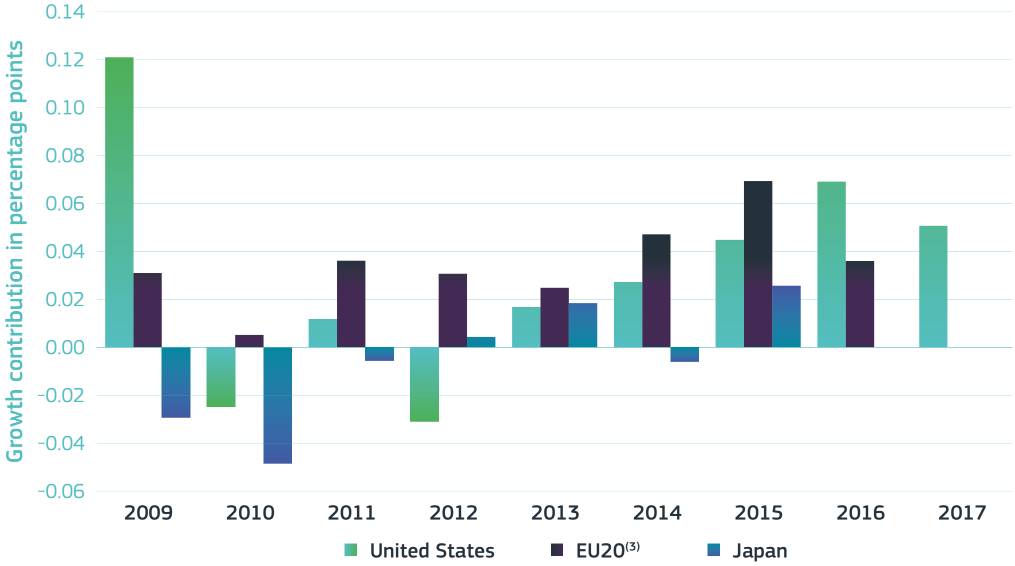
Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on EU KLEMS 2019 (analytical database)

Notes: [1]Economic competencies include: advanced and market research, purchased organisational capital, and (vocational) training. [2]EU20 average includes BE, CZ, DE, DK, EE, ES, FR, IT, LV, LT, LU, HU, NL, AT, RO, SI, SK, FI, SE and UK.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter53/figure-53-3.xlsx

Figure 5.3-4 Contribution of intangible economic competencies[(1)] to labour productivity growth[(2)] in the EU, United States and Japan in percentage points, market economy, 2009-2017



Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on EU KLEMS 2019 (analytical database)

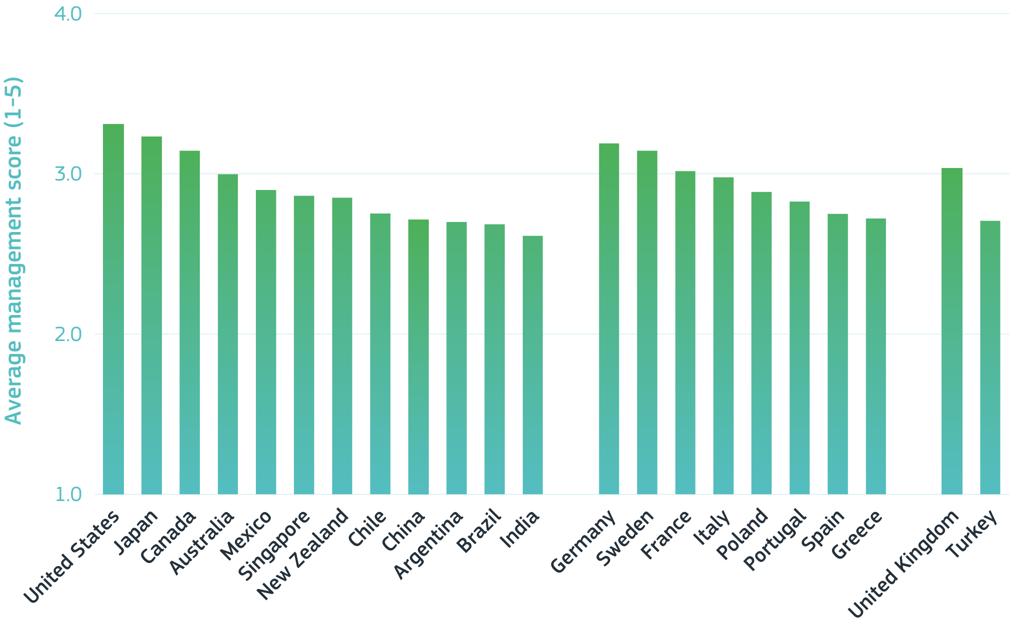
Notes: (1)Economic competencies include: advanced and market research, purchased organisational capital, and (vocational) training. (2)Labour productivity growth is measured as value added per hour growth. (3)EU20 average includes BE, CZ, DE, DK, EE, ES, FR, IT, LV, LT, LU, HU, NL, AT, RO, SI, SK, FI, SE and UK.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter53/figure-53-4.xlsx

Stronger management capabilities can foster the adoption of new productivity-enhancing technologies and thus help to cope faster with change within an organisation. Research points to the existence of differences in management quality across countries, although more recent and wider cross-country coverage is needed. Bloom and Van Reenen (2016) put forward the idea that some forms of management practices can be seen as a '*technology*', since they can be instrumental in increasing total factor productivity (TFP). OECD (forthcoming) lists other studies that have found that the *dispersion in managerial practices can account for up to one third of TFP differences between countries and across firms within countries*. Bloom et al. (2019) investigated management practices in US manufacturing plants and found a large dispersion of management across plants. In addition, the authors concluded that these management practices explained more than 20 % of the variation in productivity, *a similar, or greater, percentage than that accounted for by R&D, ICT, or human capital*. Finally, right-to-work laws and learning spillovers were found to improve management scores.

Overall, management quality in the manufacturing sector was found to be higher in the United States, Japan, Canada, Germany and Sweden. At the same time, there seems to be room for improvement in how businesses are managed in southern Europe, notably in Greece, Spain and Portugal (Figure 5.3-5). Unfortunately, the availability of cross-country and comparable data on management practices is still limited, which means more research is needed to identify and address bottlenecks in management quality in Europe.

Figure 5.3-5 Average management scores in manufacturing by country, 2004-2014



Source: Bloom, N., Sadun, R., & Van Reenen, J. (2016)

Note: Unweighted average management scores; all waves pooled (2004-2014): management scores are between 1 and 5.

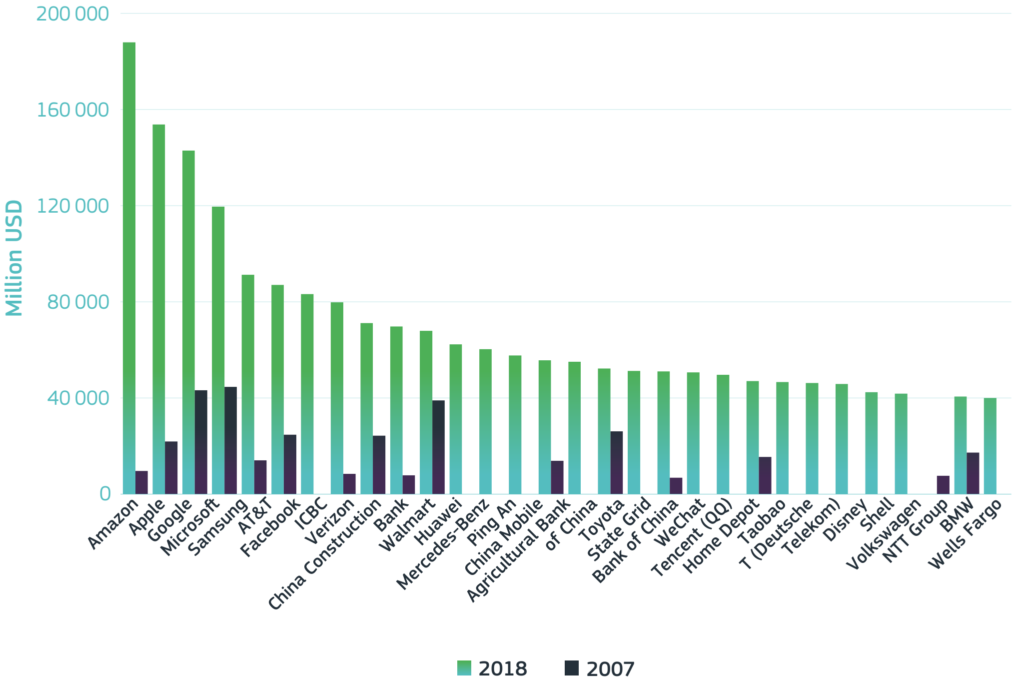
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter53/figure-53-5.xlsx

2. Efforts to promote 'made in EU' brands on the global scene lag behind international competitors

Brand strength and recognition is increasingly bringing value to companies by boosting customers' loyalty and attracting new ones. As indicated in Corrado (2005), firms can increase their brand equity by advertising their brands or by researching the market. This is an important strategy to ensure consolidation of the customer' base and to work towards expanding it. In addition, digital firms care as much (if not more) about their brand since the pace of change is unprecedented due to digitalisation. As noted in Blix (2015), speed in building brand recognition and consumer loyalty is essential for the survival of digital firms especially because services in some areas may be very similar and the need to stand out from the competition may therefore be even stronger.

Over time, there has been an enormous rise in brand value, especially among companies operating in the digital and tech space. Figure 5.3-6 highlights the remarkable increase in brand value between 2007 and 2018, in this case in the top 30 most valuable brands. In particular, it is interesting to see that some companies like Amazon were not in the top 30 in 2007, while the company's brand was the leader in value in 2018, with the brand value increasing by 1 856% in just one decade. Moreover, Facebook was created in 2004 and has made it into the top most-valuable brands. Others, such as Huawei, were not in the list of most valuable brands in 2007 but became highly valuable in 2018. The EU is mainly represented in the rankings by companies in the automotive and oil industry from Germany and the Netherlands.

Figure 5.3-6 **Brand value change in the top 30 most valuable brands in 2018 relative to their value in 2007**



Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on Brand Finance- Global 500 2019 and Brand Finance - Global 500 2008

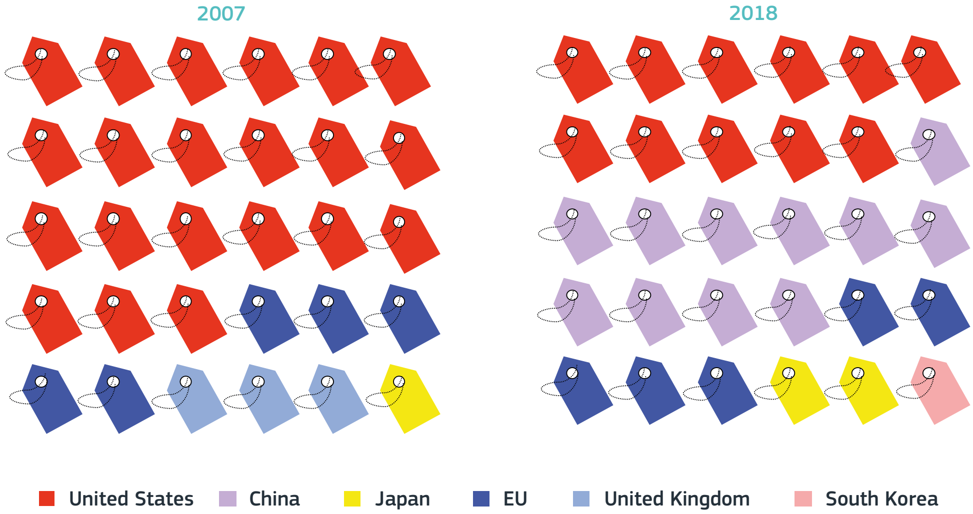
Note: Brand value is the net present value of the estimated future cash flows attributable to the brand. Brands are ranked by brand value according to Brand Finance methodology.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter53/figure-53-6.xlsx

When focusing on the European market only, the EU's top 20 most valuable brands only include two technology companies. Statista (2019)[1] shows that besides the automotive and oil industries which dominate the top 10 EU most valuable brands, only Bosh and Siemens (both from Germany) represent technology companies in the top 20. This contrasts with the reality in the United States where tech companies such as Apple, Google, Amazon, Microsoft, Facebook and IBM dominate the top 10[2].

Today, most of the 'top 30 brands' are found in the United States and China. Figure 5.3-7 shows the distribution of the top 30 brands by brand value in 2007 and in 2018, according to Brand Finance. While in 2007 the top valuable brands were found in the United States (21 out of 30), in 2018, Chinese brands were also leading in brand value. In particular, in 2018, both the United States and China each had 11 brands in the top 30, compared to only five in the EU (Mercedes-Benz, Deutsche Telecom, Shell, Volkswagen, BMW) – i.e. four from Germany and one from the Netherlands. Tech companies dominate the top 10 brands, most coming from the United States.

Figure 5.3-7 Geographical distribution of the 'top 30 brands'(1), 2007 and 2018



Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on Brand Finance- Global 500 2019 and Brand Finance - Global 500 2008

Note: (1)Brand value is the net present value of the estimated future cash flows attributable to the brand. Brands are ranked by brand value according to Brand Finance methodology.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter53/figure-53-7.xlsx

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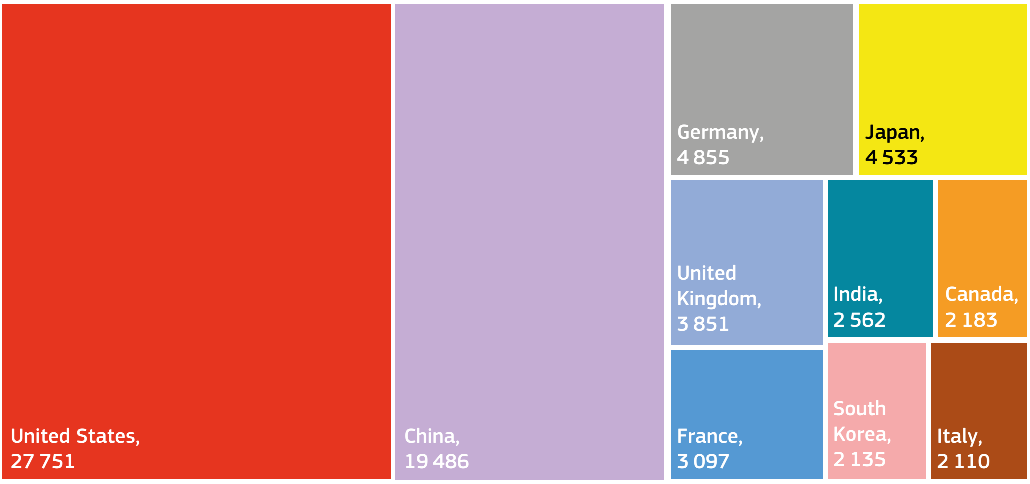
[1] https://www.statista.com/statistics/643747/brand-value-of-the-leading-20-most-valuable-euro-brands/

[2] https://www.statista.com/statistics/259061/10-most-valuable-north-american-brands/

The combined nation brand value is the largest in the United States, followed by China. In the EU, the brand value of German, French and Italian brands positions these three Member States in the top 10 most valuable nation brands. Cumulatively, US brands are worth more than USD 27 trillion, the largest value worldwide. This compares with around USD 19 trillion in China and USD 10 trillion in the EU which aggregates the brand value in Germany, France and Italy.

Figure 5.3-8 Most valuable nation brands worldwide in 2019, USD billion



Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit, based on Statista and Brand Finance Nation Brands 2019, (https://www.statista.com/statistics/322423/most-valuable-nation-brands/)

Note: Brand Finance measures the strength and value of the nation brands of 100 leading countries using a method based on the royalty relief mechanism employed to value the world's largest corporate brands.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter53/figure-53-8.xlsx

Better communicating Europe's excellent science and innovation not only improves the public perception of science and technology but also contributes to a stronger 'EU identity' and the upgrade of the 'EU brand' on the global scene. As discussed in Chapter 6.1 - Scientific performance, Europe produces excellent science. In this context, communicating scientific results and their impact on society is key. Box 5.3-1 describes how the live showcase of the first-ever image of a black hole mobilised European and international attention. The image was taken by the Event Horizon Telescope, a global scientific collaboration involving EU-funded scientists. The Community Research and Development Information Service (CORDIS)[3] is the European Commission's primary source of results from the projects funded under the EU's Framework Programmes for Research and Innovation (FP1 to Horizon 2020). In this way, impactful projects and success stories of EU-funded research projects can be shared around the world. Horizon Europe will build upon the many achievements of its predecessors.

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[3] https://cordis.europa.eu/en

BOX 5.3-1 Communicating science: the first-ever image of a black hole taken by Event Horizon Telescope, unveiled live to the world by the European Commission

Extract from EC press release – First-ever image of a black hole, 10 April 2019

'(On 10 April 2019), the Commission revealed the **first-ever image of a black hole taken by Event Horizon Telescope, a global scientific collaboration involving EU-funded scientists**. This major discovery provides visual evidence for the existence of black holes and pushes the boundaries of modern science.

Black holes are extremely compressed cosmic objects, containing incredible amounts of mass within a tiny region. Their presence affects their surroundings in extreme ways, by warping spacetime and super-heating any material falling into it. The captured image reveals the black hole at the centre of Messier 87, a massive galaxy in the constellation of Virgo. This black hole is located 55 million light-years from Earth and has a mass 6.5-billion times larger than our sun.

This major scientific achievement marks a paradigm shift in our understanding of black holes, confirms the predictions of Albert Einstein's General Theory of Relativity and opens up new lines of enquiry into our universe. The first image of a black hole successfully captured was unveiled in six simultaneous press conferences across the globe today.

EU funding through the European Research Council (ERC) has provided crucial support to the EHT. In particular, the EU has provided funding for three of the leading scientists and their teams involved in the discovery, as well as supported the development and upgrading of the large telescope infrastructure essential to the success of the project.'

Many software and digital applications behind the widespread success of digital disruptive industries have some 'EU origin'. Box 5.3-2 illustrates three examples – Linux (open source programme), MP3 (audio and media format) and Python (programming language).

BOX 5.3-2 Communicating innovation: examples of EU innovations behind widespread digital products and services – Linux, MP3, Python

LINUX: created by Linus Torvalds (Finland)

Extract from https://en.wikipedia.org/wiki/History_of_Linux, hyperledger.org and https://opensource.com/article/19/8/everyday-tech-runs-linux

'In 1991, while studying computer science at **University of Helsinki**, Linus Torvalds began a project that later became the **Linux kernel**. He wrote the program specifically for the hardware he was using and independent of an operating system.

The **largest part of the work on Linux is performed by the community**: the thousands of programmers around the world that use Linux and send their suggested improvements to the maintainers. **Various companies have also helped not only with the development of the kernels, but also with the writing of the body of auxiliary software**, which is distributed with Linux. Some examples are Dell, IBM and Hewlett-Packard.

The **Open Source Development Lab** (OSDL) was created in 2000, as an independent non-profit organization which pursues the goal of optimizing Linux for employment in data centers and in the carrier range. On 22 January 2007, OSDL and the Free Standards Group merged to form The Linux Foundation, narrowing their respective focuses to that of promoting Linux in competition with Microsoft Windows.

Many companies, organizations and technologies run on Linux: NASA's Pleiades supercomputer, Amazon's services – from Amazon Elastic Compute Cloud (Amazon EC2) to Fire TV – SteamOS (gaming), Instagram, Facebook, YouTube, Twitter, New York Stock Exchange, the Pentagon, Apple's iCloud, Google's Chrome OS, Android, and many others.'

The Linux Foundation is also pioneering important developments in the field of blockchain. In particular, the Foundation hosts the 'Hyperledger' project – an open source and global collaborative effort created to advance cross-industry blockchain technologies.

Figure 5.3-9 Examples of software and applications running on Linux

Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit, based on opensource.com and Wikipedia.org

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter53/figure-53-9.xlsx

MP3: developed by the Fraunhofer Institute (Germany)

Extracts from https://www.mp3-history.com/

‘mp3 encodes and stores music. An mp3 file takes up just 10 percent of the storage space of the original file, meaning music can be quickly transferred over the Internet and stored on mp3 players.

The idea for audio encoding and initial basic research in the field arose at Friedrich-Alexander University Erlangen-Nuremberg. Starting in 1987, a large team drawn from the university and the Fraunhofer Institute for Integrated Circuits IIS in Erlangen worked on developing the mp3 standard.

Marketing the new technology was just as important as its development in the late 1980s and early 1990s. Developers at **Fraunhofer** searching for mp3 technology applications came up with the **vision of portable music players that would allow music fans to store their entire music collections**. Though their ideas were initially ridiculed, the Fraunhofer team overcame the established industry’s resistance and turned mp3 into a global success.

Fraunhofer does not sell any mp3 products to end users and does not provide end user support for mp3 devices and software. **iTunes (Apple) and Windows Media (Microsoft) integrate the Fraunhofer mp3 software**. In 2017, Technicolor's mp3 licensing program for certain mp3 related patents and software of Technicolor and Fraunhofer IIS has been terminated.

mp3 is more than a technology; mp3 is a cultural phenomenon and an example for successful research, development and marketing in Germany.’

Figure 5.3-10 Examples of audio and media applications running on MP3

Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit, based on Fraunhofer

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter53/figure-53-10.xlsx

PYTHON: designed by Guido van Rossum (Netherlands)

Extracts from https://medium.com/@johnwolfe820/a-brief-history-of-python-ca2fa1f2e99e, https://en.wikipedia.org/wiki/Python_(programming_language

'Python is an interpreted, high-level, **general-purpose programming language**. It was originally conceptualized by Guido van Rossum in the late 1980s as a member of the **National Research Institute of Mathematics and Computer Science situated in the Netherlands**. Initially, it was designed as a response to the ABC programming language that was also foregrounded in the Netherlands. The language was released in 1991. Rather than having all of its functionality built into its core, Python was designed to be highly extensible. This compact modularity has made it particularly popular as a means of adding programmable interfaces to existing applications.

Since 2003, **Python has consistently ranked in the top ten most popular programming languages** in the TIOBE Programming Community Index where, as of December 2018, it is the third most popular language. It was selected **Programming Language of the Year** in 2007, 2010, and 2018. An empirical study found that scripting languages, such as Python, are more productive than conventional languages, such as C and Java, for programming problems involving string manipulation and search in a dictionary.

Large organisations that use Python include Wikipedia, Google, Yahoo!, CERN, NASA, Facebook, Amazon, Instagram, Spotify. The social news networking site Reddit is written entirely in Python.'

Figure 5.3-11 Examples of organisations using Python

Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit, based on medium.com and Wikipedia.org

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter53/figure-53-11.xlsx

3. Conclusions

Economic competencies are important complementary intangible assets to other intangibles, such as R&D, and to tangible assets like investments in machinery. For example, strategic management can lead to the uptake of novel technologies that can make a company lead in the future. Moreover, investing in the workforce's cognitive and soft skills makes organisations more resilient when coping with change. At the macro level, evidence shows that **economic competencies are indeed contributing to both labour productivity and economic growth**. As regards that growth-enabling role, the fact that the **EU underinvests in economic competencies relative to the United States** may limit its productivity growth.

Furthermore, the era of globalisation and digitalisation means fiercer competition than ever. Hence, companies better at boosting their reputation and marketing their products, services and business models are likely to attract a larger market share. For this reason, **the United States' clear leadership position in brand value, particularly in technology companies, means that the EU needs to step up its game and become better at promoting its brands on the global scene**. At the same time, it needs to reinforce its technology and digital leadership by enabling the right business environment for EU digital companies to flourish, which are also very R&D-intensive.

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CHAPTER
5.4

INVESTMENT IN ICT

KEY FIGURES

2%
share of ICT investments in GDP estimated in the EU

4%
share of the ICT sector in total value added in the EU

3%
share of employees in the ICT sector in the EU

17%
share of ICT patents in total EU patents

1 in 10
enterprises performs big data analytics in the EU

What can we learn?

- **Europe underinvests in ICT** compared to other major economies.
- The **ICT-producing sector's contribution to productivity growth in the EU has declined**. However, the **contribution from the most-intensive ICT-using industries to labour productivity growth has picked up** in recent years and is **above that of the United States**.
- **The weight of the ICT sector in the European economy has stabilised at around 4 %** of total value added, which is below other international players.
- Overall, **ICT employment has slightly increased in Europe** and ICT services are the key component.
- The **share of ICT patents in the EU patenting landscape is considerably smaller** than among its international competitors.
- Although an **intra-EU gap persists in digital competitiveness, laggard countries are catching up**.
- **Company size seems to matter for firms' digital transformation** and differences are striking in some EU Member States.
- **ICTs can provide solutions to address climate change**. At the same time, R&I is key to reducing the global footprint of ICT – R&I for 'green ICT'.

What does it mean for policy?

- **Boost the level of investments in ICT** and the convergence of ICT with other 'physical' technologies.
- **Accelerate ICT diffusion**, including digital competencies, skills, technologies, and access to infrastructure across sectors, firms and individuals, in an inclusive manner.
- **Prioritise funding for R&I solutions to improve the energy** efficiency of data centres, high-performance computers, infrastructure of telecommunications, etc.

The expansion of ICT has enabled the digital revolution and contributed to productivity and economic growth. ICTs can also provide solutions for sustainable growth. At the same time, there is still room to improve ICT diffusion across sectors, firms and individuals in an inclusive way. Information and communication technologies (ICTs) play an important role in economic growth and in transforming societies by connecting ideas and people all over the world. ICT boosts firms' productivity by improving communication, enabling knowledge management and reducing production costs. Moreover, the use of ICT may create network effects across sectors, lower transaction costs and increase the speed of innovation, which can boost overall economic efficiency and thus total factor productivity (Pilat, 2004). In addition, technological progress leading to new ICT goods and services can also enhance productivity growth in the ICT sector. Furthermore, ICT can bring social benefits by allowing generalised access to information and knowledge, while bringing people together even if they are geographically apart. The use of ICTs can also be determinant for achieving the Sustainable Development Goals (SDGs) in areas such as energy efficiency, water management and in supporting the overall transition to a low-carbon economy. ICT-related projects are also an important part of EU Framework Programmes to spur R&I in ICT[1] in Europe.

However, ICT diffusion has not happened at the same pace across firms and individuals. The gap between frontier and laggard companies remains large (although there is some catching-up), which is partly explained by the insufficient diffusion of innovation, notably digital technologies (see Chapter 3.1- Productivity puzzle and innovation diffusion). At the same time, the access, adoption and uptake of digital technologies has yet to become widespread across individuals which illustrates the need to continue the efforts to make the access to ICT more inclusive. Skills and, in particular, digital skills are crucial to navigate this new paradigm. Chapter 5.2 - Investment in education, human capital and skills analyses differences across the EU in this respect.

In this chapter, we look at trends in ICT investment and its contribution to growth. Moreover, an analysis of the evolution of the ICT-producing sector, notably its value-added contribution, employment, innovation and R&D intensity, is provided alongside some reflections for policy.

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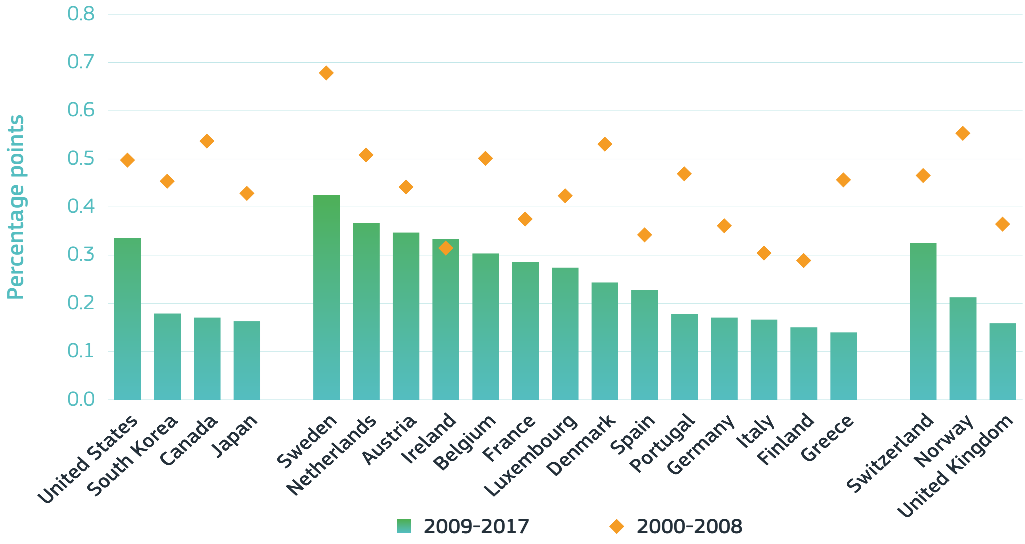
[1] https://ec.europa.eu/digital-single-market/en/research-development-scoreboard

1. Europe underinvests in ICT

ICT capital deepening contributes to economic growth, although its contribution seems to have decreased in the last decade. The OECD (2016) points to the drop in ICT price relative to GDP price. Moreover, research shows a significant contribution from ICT to growth; the major impact on productivity occurred between 1995 and 2005 but the diffusion of ICT seems to have stabilised now. van Ark (2016) put forward the idea that we currently live in the 'installation phase' of the new digitalisation wave, which may imply that its impact on productivity may be 'on hold' until we effectively enter the 'deployment phase' of these digital technologies. Figure 5.4-1 provides a comparison between the contribution of ICT capital-deepening to GDP growth between 2000 and 2008, and 2009 and 2017. Overall, its contribution has declined worldwide. Similarly, Adarov and Stehrer (2019) found a declining role of ICT assets in growth across Japan, the United States and the EU15 as a whole.

In the EU, over the period 2009-2017, the contribution was the highest in Sweden, the Netherlands and Austria, and the lowest in Italy, Finland and Greece (of those Member States with available data). Ireland was the only EU Member State where the contribution from ICT capital has actually increased in recent years. Within the major economies listed below, the United States seems to be the economy where the slowdown was least pronounced, which could be evidence of greater ICT diffusion in the country in line with the OECD (2016).

Figure 5.4-1 Contribution of ICT capital[(1)] to GDP growth (percentage points), average over 2000-2008 and 2009-2017



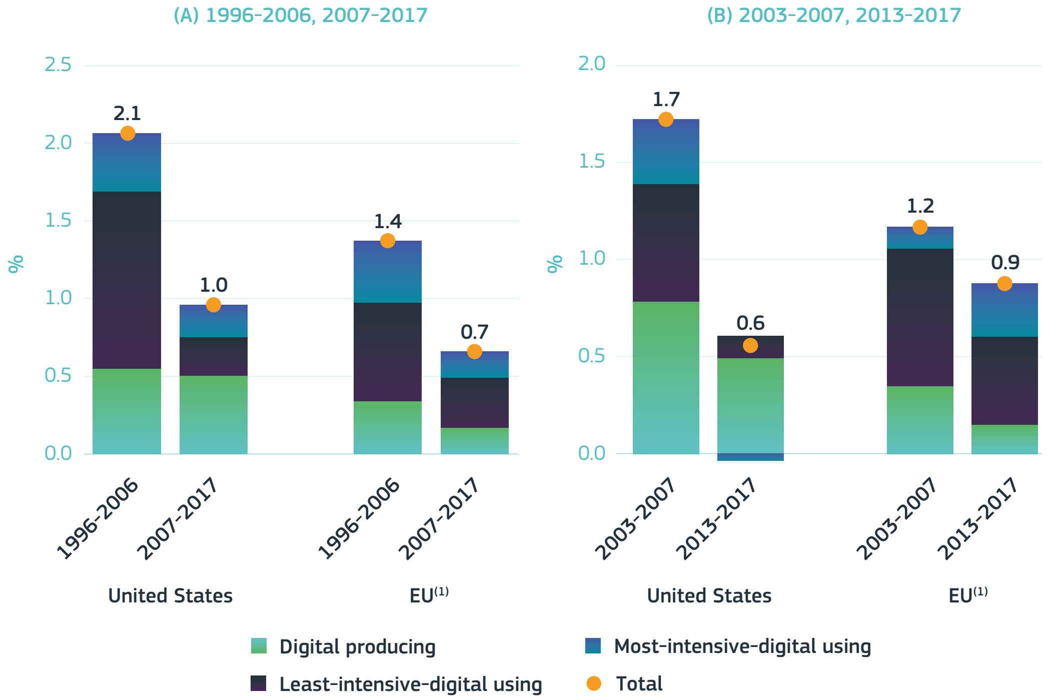
Source: OECD Productivity Database

Note: (1)ICT capital includes computer hardware, telecommunications equipment, and computer and software databases.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter54/figure-54-1.xlsx

However, new research shows that Europe appears to have an advantage compared to the United States in the most-intensive ICT-using sector, which accounts for the largest contribution to labour-productivity growth in recent years. van Ark et al. (2019) look at the contributions of ICT-using and ICT-producing sectors to labour-productivity growth over time in 19 EU Member States and in the United States. Overall, the authors found that the contribution from the digital-producing sector to productivity growth has declined in the EU and, to a lesser extent, in the United States (Figure 5.4-2). However, in recent years in the EU, the contribution to growth in labour productivity in ICT-using sectors seems to have picked up, notably over the period 2013-2017. In fact, the most-intensive digital-using sectors make the largest contribution to labour-productivity growth in the EU. On the contrary, in the United States, the role of ICT-using sectors for productivity has declined in a very pronounced way, while the ICT-producing sector has not seen a marked decline (as is the case in the EU). Thus, the authors suggest that Europe has an opportunity from its ICT-using sectors to boost productivity growth while, in the United States, the ICT-producing sector, including the big 'tech' companies, may be making use of many of the available resources that could be limiting extending productivity benefits to the ICT-using sectors in the country.

Figure 5.4-2 Labour productivity growth and contributions from digital-producing and most- and least-intensive-using sectors, in %



Source: van Ark et al. (2019), Conference Board calculations using data from Eurostat; BEA; BLS

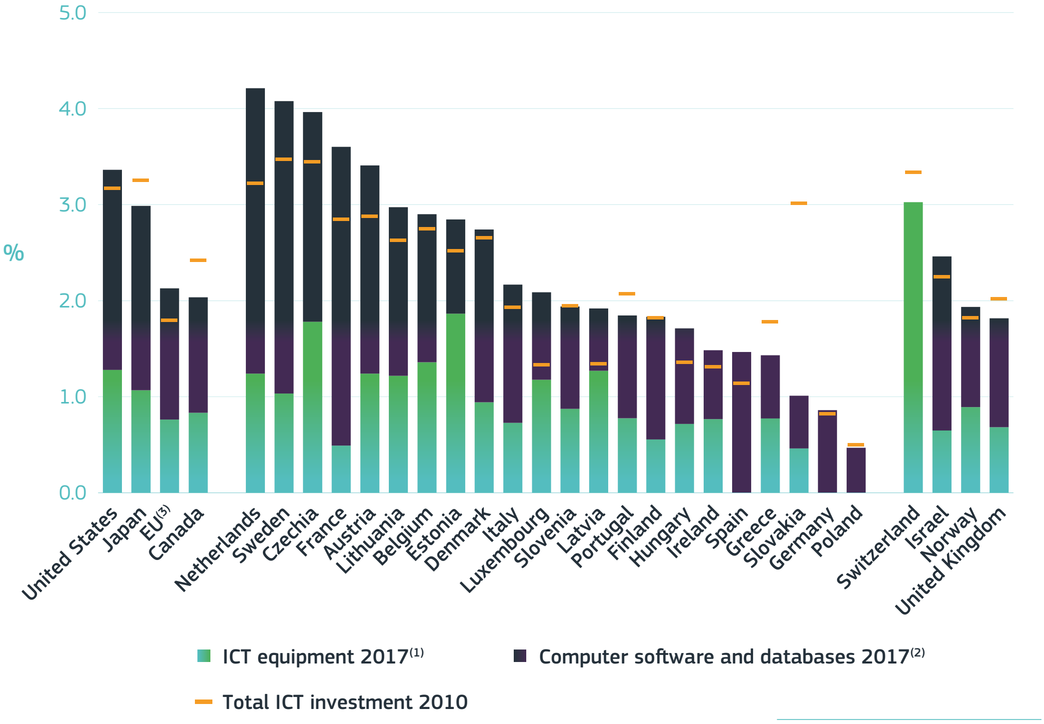
Notes: (1)EU aggregate is based on 19 countries and euro area aggregate on 16 countries, as data for BG, EE, IE, HR, CY, LV, LT, LU and MT were not available for the entire period. Taxonomy for the identification of sectors defined as in Bart van Ark et al. (2019). Labour productivity growth concerns the growth of output per hour.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter54/figure-54-2.xlsx

The EU underinvests in ICT in comparison with other major economies such as the United States and Japan, even though estimates point to an increase in the share of ICT investments in GDP more recently. Figure 5.4-3 depicts the evolution of ICT investments by country – i.e. the sum of ICT equipment and computer software and databases. Estimates for the EU aggregate show that Europe invests less as a percentage of GDP than its international competitors, notably the United States and Japan. Indeed, in 2017, the EU invested around 2% of GDP in ICT compared to almost 3.5% in the United States and 3% in Japan. However, it is important to mention that compared to 2010, there has been an increase in the share of ICT investments in GDP in the EU while, for example, there has been a relative decline in Japan and Canada.

Member States that invested the most are the Netherlands, Sweden and Czechia, at around 4% of GDP. Overall, the share of ICT investments in GDP increased between 2010 and 2017 in most EU Member States, the exceptions being Portugal, Greece and Slovakia.

Figure 5.4-3 Investment in ICT as % of GDP by country, 2010 and 2017



Source: OECD (Capital formation by activity ISIC Rev4) and Eurostat (online data code: nama_10_gdp)

Notes: [1]DK: 2015. LV, NO: 2016. [2]DK, EE, EL, PL: 2015. IE, ES, LV, PT, SE, NO: 2016. [3]EU value estimated with the available countries. The number of countries is not the same in both categories.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter54/figure-54-3.xlsx

2. The ICT sector in Europe: weight stable over time, increasing employment share, less R&D-intensive, less productive, and lower patenting activity than other global players

Value added

Since 2000, the weight of the ICT sector in the European economy has stagnated at close to 4% of GDP, a much lower contribution than in South Korea, Japan and the United States. Whilst in most major economies ICT value added has more or less stabilised, in China it has been on the rise since 2000. In the EU, the weight of the ICT sector stabilised at 3.9% of GDP between 2000 and 2018, compared to a much higher share of over 8.5% in South Korea and around 6% in Japan and in the United States (Figure 5.4-4). The value added in ICT in China increased remarkably from 3.7% of GDP in 2000 to 4.9% in 2018.

Figure 5.4-4 Value added in ICT as% of GDP by region[1], 2000, 2009 and 2018

Science, research and innovation performance of the EU 2020

Source: DESI report ICT Sector and its R&D Performance, PREDICT project

Notes: [1]The operational definition of ICT, as defined in the PREDICT project, was used. The operational definition of ICT allows for international comparison with non-EU countries. [2]CN: 2016, JP: 2017.

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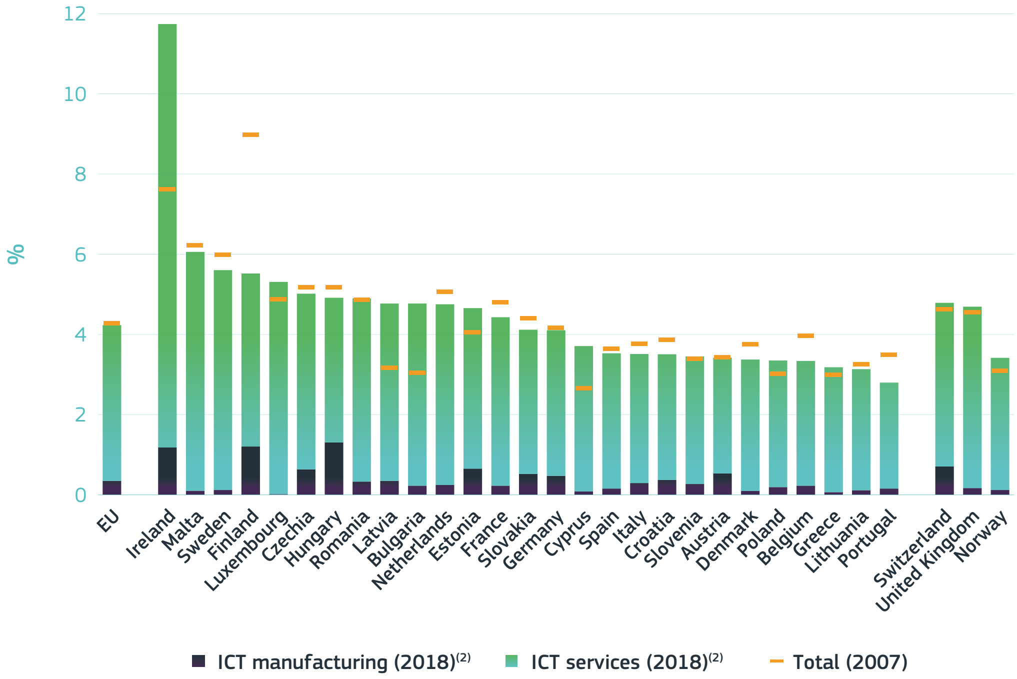
In most EU Member States, the share of value added in ICT as a share of GDP has slightly declined over the last decade. ICT services are the key components of the ICT sector. Figure 5.4-5 shows the evolution of the ICT sector (manufacturing and services) by country between 2007 and 2018. Ireland stands out as the EU Member State with the highest ICT share – of almost 12% of GDP – in the country. The Member States with the lowest share of ICT were Greece, Lithuania and Portugal. ICT services is the most important component of the ICT sector in all countries. ICT manufacturing had the highest share in Hungary, Ireland and Finland.

Figure 5.4-5 **Value added in ICT(1) as % of GDP broken down by manufacturing and services, 2018 (and for 2007 without breakdown)**



Science, research and innovation performance of the EU 2020

Source: DESI report ICT Sector and its R&D Performance, PREDICT project

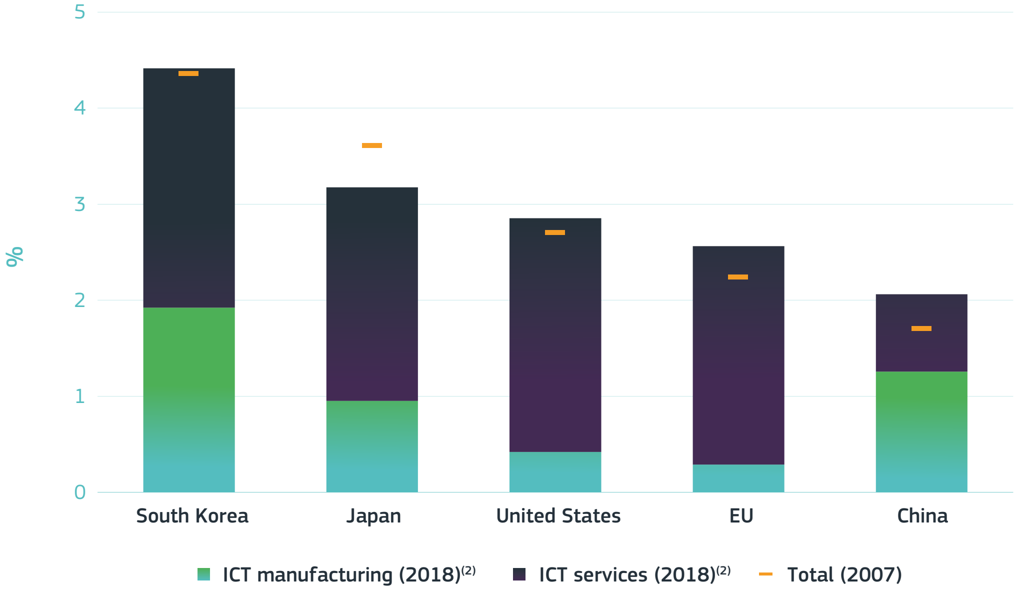
Notes: (1)The comprehensive definition of ICT, as defined in the PREDICT project, was used. (2)IE: 2014; NO, CH: 2015.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter54/figure-54-5.xlsx

Employment

The ICT sector employs the most people in South Korea, followed by Japan, the United States, the EU and, finally, China. In the EU, the share of employment in the ICT sector rose between 2007 and 2018. The relevance of ICT value added in the economy was previously demonstrated as being highest in South Korea and, in 2018, was also visible in terms of employment contribution of around 4.5% of the country's total employment (Figure 5.4-6). It is also important to note the relevant size of ICT manufacturing. Japan comes next with slightly more than 3% of its active population employed in the ICT sector, although the share has declined relative to 2007. The United States, the EU and China have seen increases in the importance of the ICT sector in employment over the last decade. In 2018, the EU's ICT share in employment was around 2.5% compared to around 2.8% in the United States and slightly more than 2% in China. In both the EU and the United States, ICT services are the leading employer within the ICT sector, while in China, ICT manufacturing stands out as the top sector.

Figure 5.4-6 Employment in ICT[(1)] as % of total employment broken down by manufacturing and services, 2018 (and for 2007 without breakdown)



Science, research and innovation performance of the EU 2020

Source: DESI report ICT Sector and its R&D Performance, PREDICT project

Notes: (1)The operational definition of ICT, as defined in the PREDICT project, was used. (2)CN: 2016; JP: 2017.

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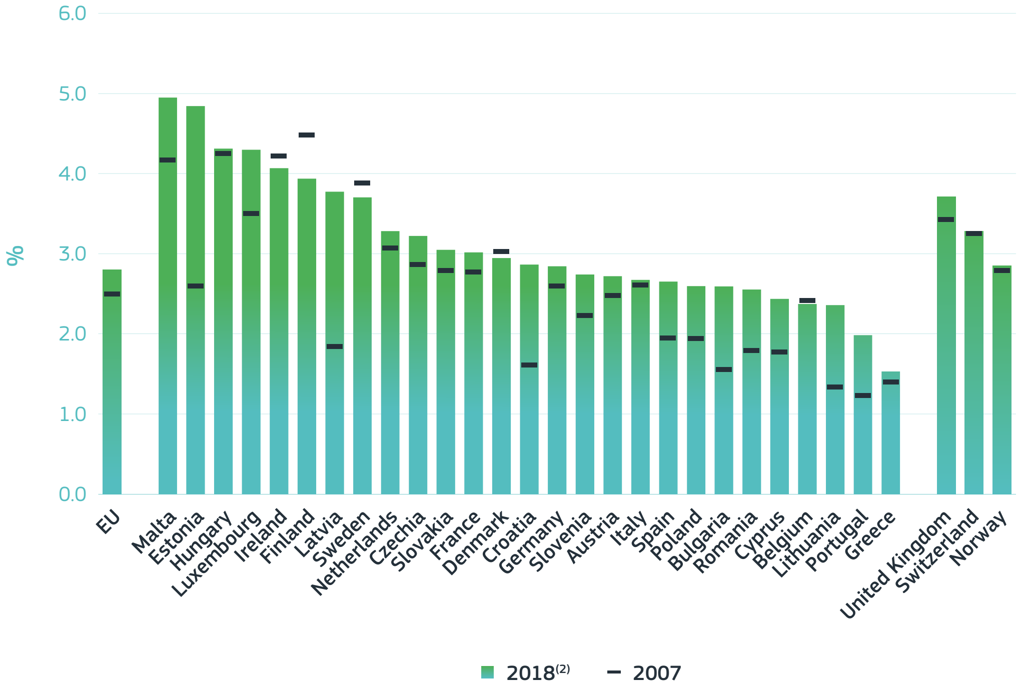
Employment in the ICT sector increased in most EU Member States between 2007 and 2018. Malta, Estonia, Hungary, Luxembourg and Ireland have the highest shares of ICT employment, at above 4% of total employment (Figure 5.4-7). On the other hand, in 2018, in Greece, Portugal, Lithuania and Belgium the role of the ICT sector in employment was the lowest, with less than 2.5% of employment. This is partly correlated with the economic structure, as previously noted that the size of the ICT sector in terms of value added in these economies was also smaller in relative terms. With the exception of Ireland, Finland, Sweden, Denmark and Belgium, all the other EU Member States maintained or even increased their employment shares in the ICT sector between 2007 and 2018.

Figure 5.4-7 Employment in ICT[(1)] as % of total employment, 2007 and 2018



Science, research and innovation performance of the EU 2020

Source: DESI report ICT Sector and its R&D Performance, PREDICT project

Notes: [(1)]The comprehensive definition of ICT, as defined in the PREDICT project, was used. [(2)]NO, CH: 2016.

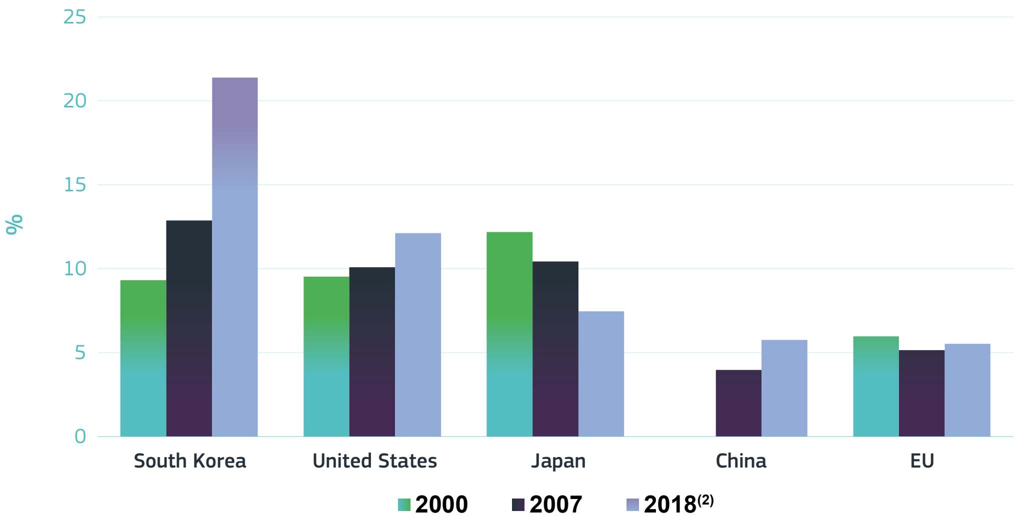
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter54/figure-54-7.xlsx

R&D intensity

The ICT sector is considerably less R&D intensive in the EU than among other international players, notably South Korea but also the United States and Japan. Figure 5.4-8 presents the evolution of business enterprise expenditure on R&D as a percentage of the value added of the ICT sector in 2000, 2007 and 2018 by major economy. The ICT sector is the most R&D intensive in South Korea where R&D intensity has been on the rise since 2000. The United States comes next, also showing slight increases in the R&D intensity of the ICT sector over time. In Japan, R&D intensity has been on the decline since 2000, although it was still above that of the EU in 2018.

In the EU, the R&D intensity of the ICT sector was the highest in Finland, Austria and Sweden. 'Innovation leaders', namely Finland, Sweden and Denmark, and 'strong innovators', such as Austria and France, rank highest in terms of their ICT industries' R&D intensity in 2018. At the lower end of the spectrum are Latvia, Luxembourg, Croatia, Lithuania and Romania (Figure 5.4-9). Norway stands out an H2020 associated country with a very high R&D intensity in the ICT sector (for which data are available), close to that of Finland.

Figure 5.4-8 Business R&D intensity of ICT(1), 2000, 2007, 2018



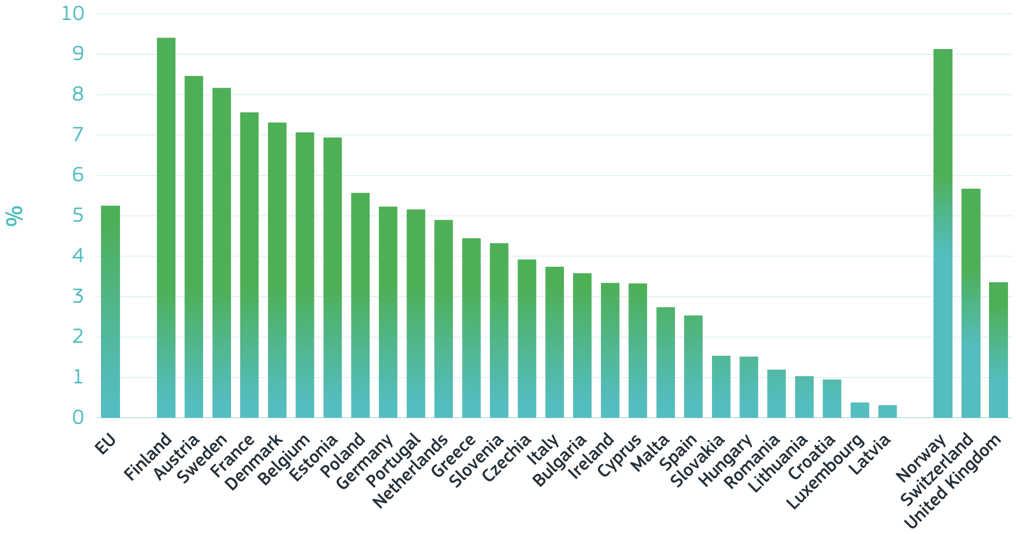
Science, research and innovation performance of the EU 2020

Source: DESI report ICT Sector and its R&D Performance, PREDICT project

Notes: [1]Business enterprise expenditure on R&D as % of value added. The operational definition of ICT, as defined in the PREDICT project, was used. The operational definition of ICT allows for international comparison with non-EU countries. [2]CN: 2016; JP: 2017.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter54/figure-54-8.xlsx

Figure 5.4-9 Business R&D intensity of ICT(1), 2018(2)



Science, research and innovation performance of the EU 2020

Source: DESI report ICT Sector and its R&D Performance, PREDICT project

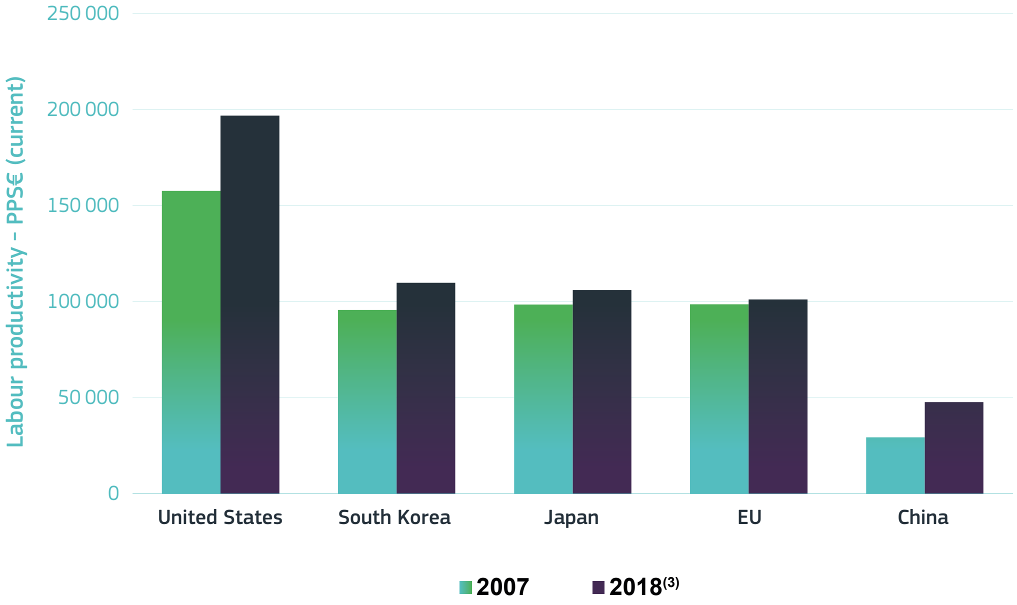
Notes: [1]Business enterprise expenditure on R&D as % of value added. The comprehensive definition of ICT, as defined in the PREDICT project, was used. [2]CH: 2015; IE: 2014; NO: 2016.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter54/figure-54-9.xlsx

Productivity

The ICT sector is more productive in the United States, South Korea and Japan than in the EU. Figure 5.4-10 compares the evolution of labour productivity in the ICT sector between 2007 and 2018 by major economy. Relative to 2007, all economies have increased productivity levels in this sector, except for the EU where it seems to have stabilised. In 2018, labour productivity was the highest in the United States, followed by South Korea, Japan, and the EU. China seems to have the least-productive ICT sector (from the economies presented in the graph) even though labour productivity has risen considerably in just over a decade.

Figure 5.4-10 Labour productivity (GDP per person employed)(1) in ICT(2), 2007 and 2018



Source: DESI report ICT Sector and its R&D Performance, PREDICT project

Notes: (1)GDP per person employed in current PPS€. (2)The operational definition of ICT, as defined in the PREDICT project, was used. The operational defintion of ICT allows for international comparison with non-EU countries. (3)CN: 2016; JP: 2017.

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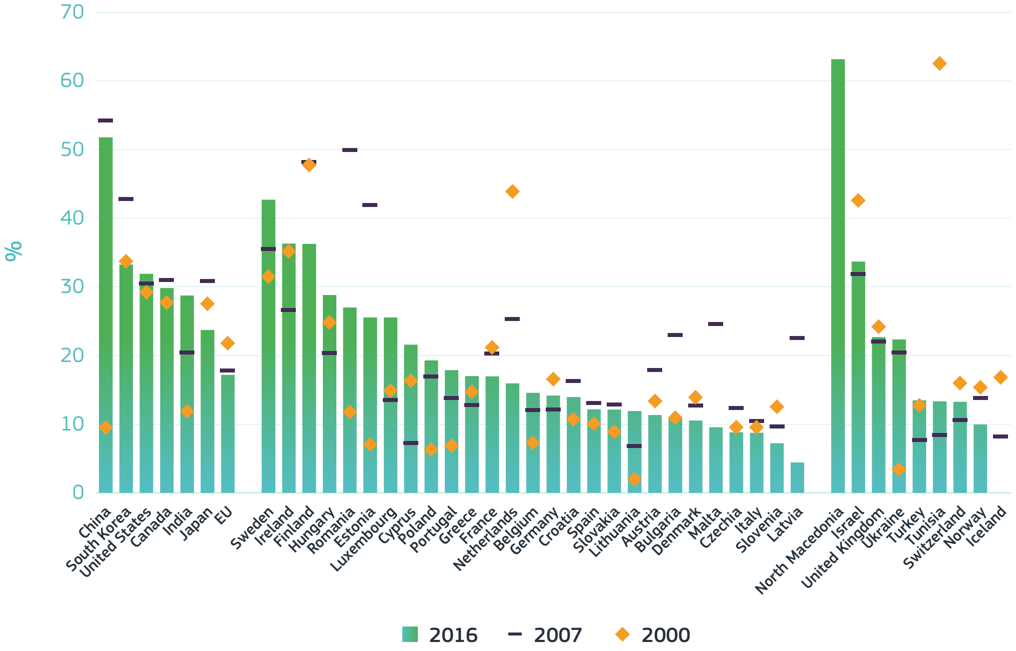
Patenting activity

The EU seems to trail behind other major economies when it comes to the relative innovativeness of the ICT sector. Figure 5.4-11 illustrates a means of representing the innovativeness of the ICT sector by looking into the evolution of the share of ICT-related patent applications, although there are certainly other ways. Major economies, such as China, South Korea, the United States, Canada, India and Japan, clearly outperform the EU in this respect. For example, 52 % of Chinese patents were ICT-related, compared to a much lower share of 17 % in the EU in 2016. Moreover, the share of ICT patents in the EU overall seems to have stabilised, while in China and India the share has been on the rise since 2000. In 2016, in the EU, the weight of ICT-related patents was the most pronounced in Sweden (43 %), Ireland (36 %) and Finland (36 %). Of course, the economic structure also plays an important role here, as we have seen before that these EU Member States also have high ICT value-added shares. Conversely, the share of ICT patents was the lowest in Latvia (4 %), Slovenia (7 %), Italy and Czechia (9 %).

Figure 5.4-11 ICT-related[1] PCT patent applications as % of total PCT patent applications[2], 2000, 2007 and 2016



Source: OECD (Patents by technology)

Notes: [1]Domains covered are: telecommunications, consumer electronics, computers, office machinery, and other ICT. [2]Patent applications filed under the PCT, at international phase, designating the European Patent Office (EPO). Patent counts are based on the priority data and the inventor's country of residence.

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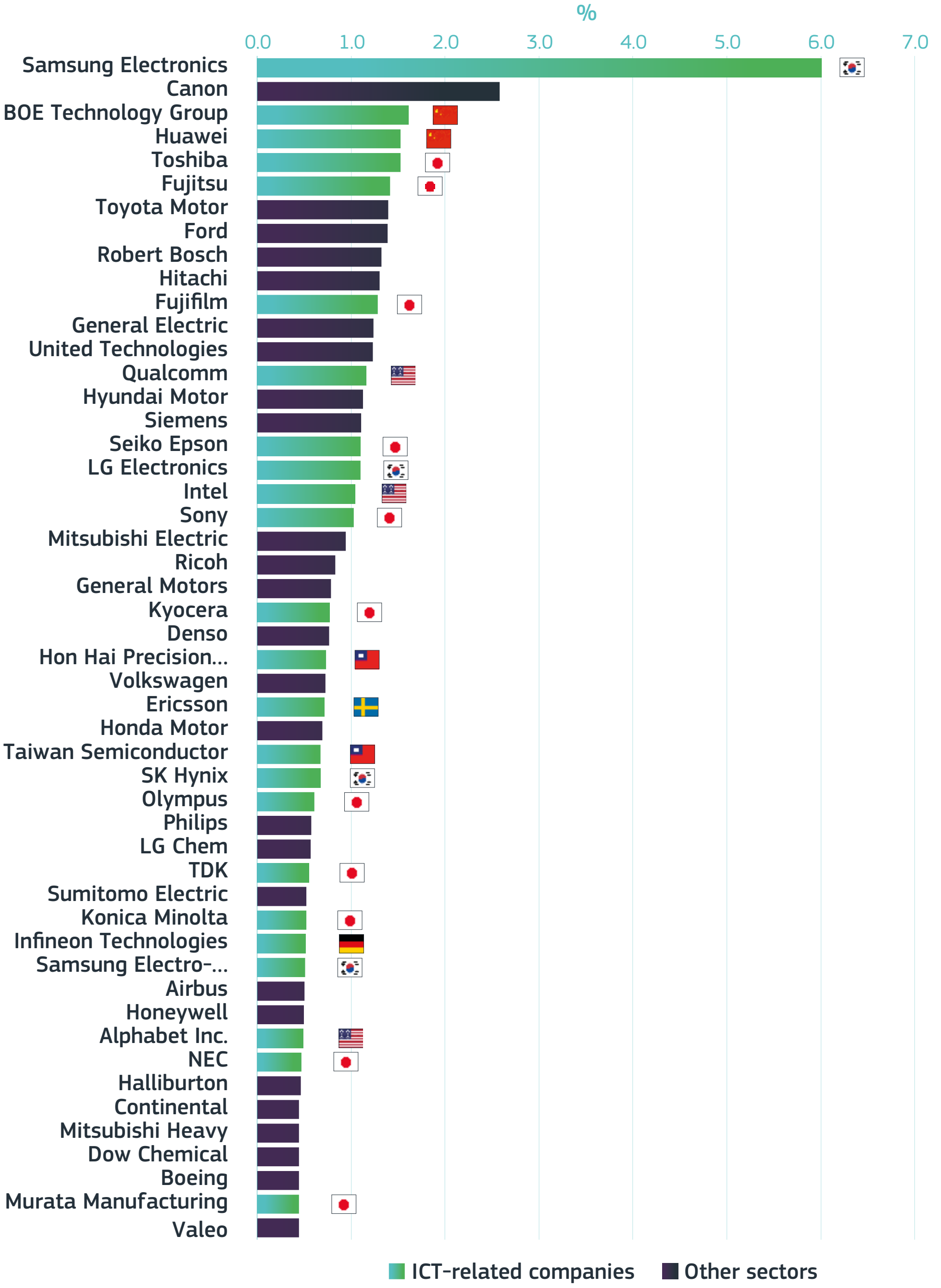
Almost half of the 'top 50 patenting companies' operate in the ICT sector and are mainly found in Asia, while the EU is represented by two companies. Figure 5.4-12 shows that within the most R&D-intensive investors active in patenting worldwide, ICT-related companies emerge as very active patenting companies, notably in computers and electronics. In particular, of the top 50 patenting companies, close to half are ICT-related. Asian companies (with headquarters in Japan, South Korea, China and Taiwan) are in the lead, while Ericsson (Sweden) and Infineon Technologies (Germany) represent Europe.

Figure 5.4-12 Share in patenting of the 'top 50 patenting companies' by sector and country for ICT-related companies, 2014-16



Source: OECD and Joint Research Centre-OECD, COR&DIP© database v.2., 2019

Note: Data concerns IP5 patent families.

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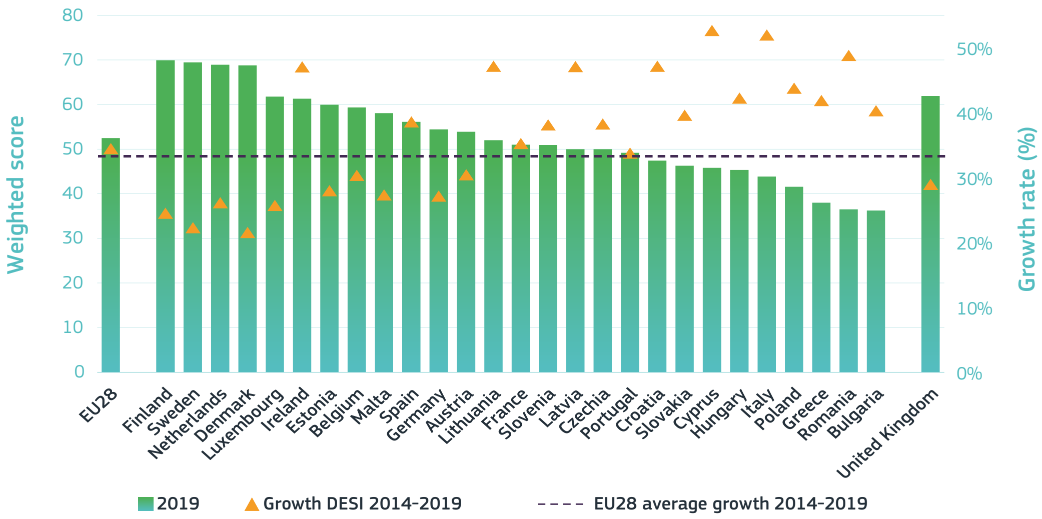
3. An EU digital divide remains, although there is some catching up

Digital competitiveness seems to be highest among the EU's 'innovation leaders' which demonstrates the import-ance of developing a country's digital capacity to innovate. At the same time, the digital divide between the most-advanced and least-digitally-advanced nations seems to be closing. Since 2014, the European Commission has issued the Digital Economy and Society Index (DESI) to monitor and benchmark the evolution of digital competitiveness in EU Member States across different digitalisation pillars. These include the dimensions of connectivity, human capital, use of internet, integration of digital technology, and digital public services.

The results of DESI 2019 show that the EU's 'digital leaders' are Finland, Sweden and the Netherlands (Figure 5.4-13). On the other hand, Bulgaria, Romania and Greece are the least-digitally-advanced Member States. Nevertheless, all EU Member States seem to have increased their digital performance between 2014 and 2019. More importantly, some catching-up from the laggards seems to have taken place, as shown by growth rates higher than the EU average. Hence, all EU Member States are improving their digital capacities and the digital divide has become less nuanced, although further efforts are needed to continue in this positive path towards digital convergence[2].

Figure 5.4-13 Digital Economy and Society Index (DESI)(1), 2019 and growth rate 2014-2019



Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on European Commission, DG CNECT (Digital Economy and Society Index 2019)

Note: (1)The Digital Economy and Society Index (DESI) is a composite index that tracks the evolution of digital competitiveness. The index is the average of the five main dimensions: connectivity, human capital, uses of internet, integration of digital technology, and digital public services.

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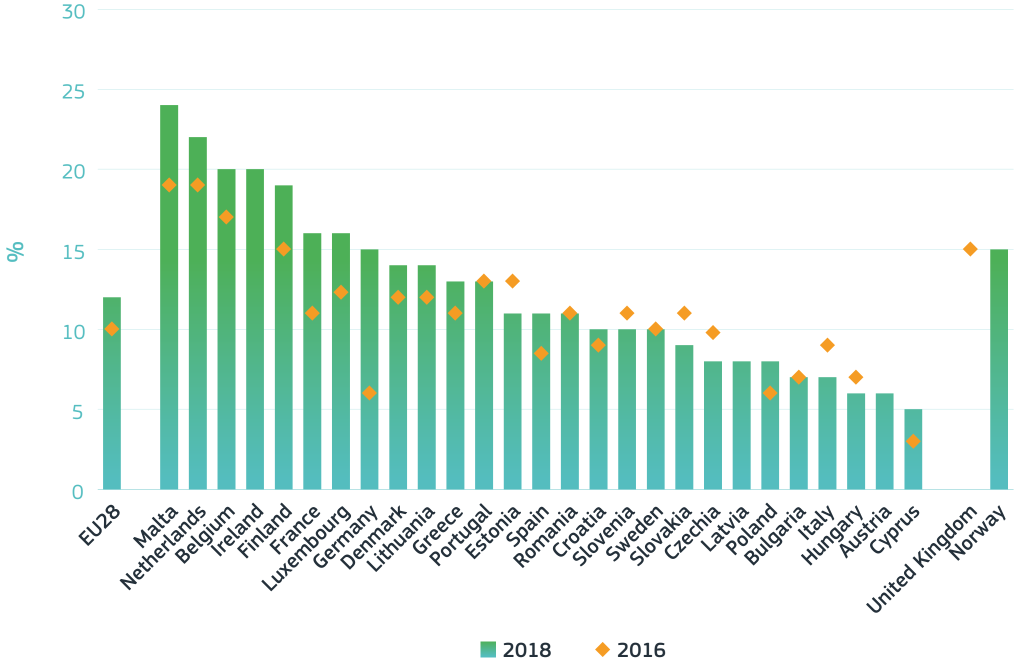
[2] Indeed, in absolute terms substantial differences remain especially between top and lower performers.

Slightly more than 1 in 10 enterprises in the EU performed big data analyses as part of their work. However, in some countries, the gap in the uptake of this practice by firm size is considerable. Due to the huge amounts of data created every day, companies often need to have the capacity to process all the information produced digitally. Big data is usually characterised by its '3 Vs' – namely, *volume*, *variety* and *velocity*. Overall, the percentage of enterprises performing big data analytics increased in most EU Member States between 2016 and 2018 (Figure 5.4-14). In Malta, the Netherlands, Belgium and Ireland, 20 % or more of all enterprises performed some sort of big data analysis, while in Cyprus, Austria and Hungary, less than 7 % of enterprises did so.

Figure 5.4-14 Share of enterprises analysing big data in total enterprises[(1)], 2016 and 2018



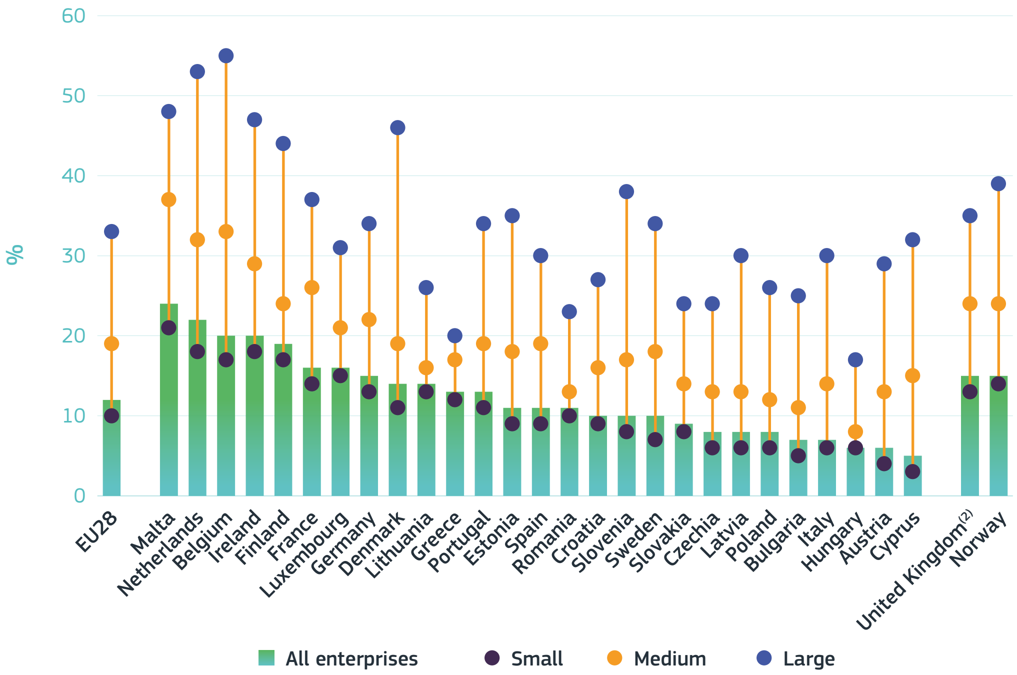
Source: Eurostat (online data code: isoc_eb_bd)

Note: (1)All enterprises, without the financial sector (10 or more people employed).

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter54/figure-54-14.xlsx

There are intra-EU differences in terms of big data uptake by firm size. Figure 5.4-15 depicts the difference by firm size in terms of the uptake of big data by country. While in Greece and Hungary there is not a very substantial difference in the use of big data by large, medium and small firms, in most Member States, big data practices seem less diffused across firms with large companies clearly making more use of big data analytics than medium-sized and, in particular, small firms. This is particularly true in countries such as Belgium and Denmark.

Figure 5.4-15 Share of enterprises[1] performing big data analysis by size, 2018



Science, research and innovation performance of the EU 2020

Source: OECD (2019) "Measuring the digital transformation" and Eurostat (online data code: isoc_eb_bd)

Notes: [1]Enterprises without financial sector. [2]UK: 2016.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter54/figure-54-15.xlsx

4. R&I essential to move towards 'green ICT'

ICTs can provide solutions to address climate change. At the same time, there is a need to reduce the global footprint of ICT which is being fostered by the digital transformation of the economy. In its 2009 Recommendation[3], the European Commission outlines a framework to 'mobilise ICTs to facilitate the transition to an energy-efficient, low-carbon economy', considering the potential of ICT to enhance energy efficiency. Indeed, ICTs can act as enablers of a low- (or even zero-) carbon economy. The Global e-Sustainability Initiative (2015) argues that ICT has the potential to cut global carbon emissions by approximately 15 % by promoting the efficiency of processes and energy use. As a result, ICTs can enable the 'smartification' of many aspects of our economies – i.e. smart cities, smart grids, smart mobility, smart governments, smart businesses, smart buildings, etc. – which reduce the environmental impact across sectors.

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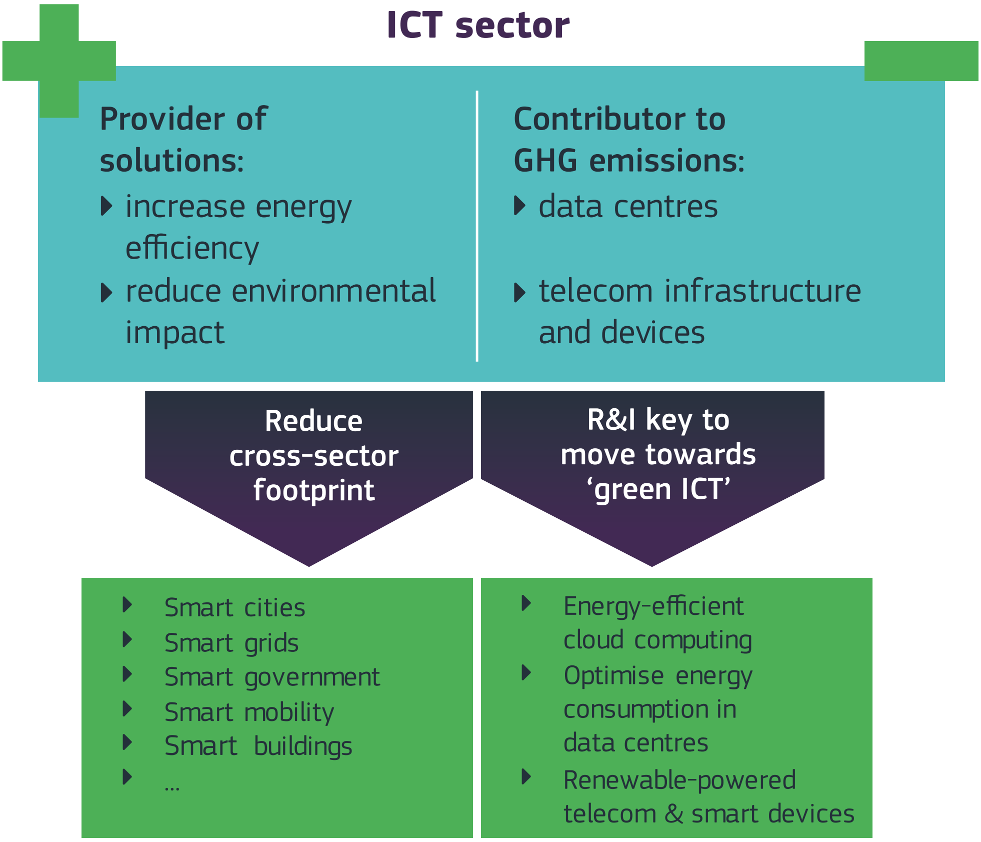
[3] https://ec.europa.eu/information_society/activities/sustainable_growth/index_en.html

However, with the exponential growth of data, more storage and computing capacity is needed. Moreover, the use of sophisticated telecoms equipment, infrastructure and mobile devices is also consuming increasing amounts of energy. The new EU Digital Strategy[4] explains that today the ICT sector accounts for 5-9% of electricity use and more than 2% of global greenhouse gas emissions (as much as all air traffic). If unchecked, the footprint could increase to 14% of global emissions by 2040. R&I can be fundamental in the move towards 'green ICT' – i.e. by exploring and creating new ways of making cloud computing and data centres energy efficient, telecom operations powered by renewables, and by generating smart devices. Figure 5.4-16 is a simplified representation of ICT's potential impact on greenhouse gas emissions. While ICT is an important enabler of green growth (left-hand side), there is also substantial energy consumption by using ICTs and the need to increase computing capacity. Nevertheless, R&I solutions could address some of the pitfalls of digital technologies in terms of environmental impact. This matter is further explored in Chapter 7 - R&I enabling artificial intelligence.

Figure 5.4-16 Visual representation of the impact of ICT on greenhouse gas emissions



Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on Global e-Sustainability Initiative (2015) and presentation by Richard Labelle (2014)
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter54/figure-54-16.xlsx

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[4] EU Digital Strategy: https://ec.europa.eu/commission/presscorner/detail/en/fs_20_281

5. Conclusions

Investments in ICT capital remain important within the range of intangible assets for economic growth, despite a decline in recent years in its contribution to GDP growth. The EU appears to underinvest in ICT compared to the United States, so boosting the levels of investment in ICT equipment and software in Europe seems fundamental to ride the next innovation wave.

When it comes to the ICT sector, our analysis shows that ICT services in the EU are clearly the largest component within the sector. Moreover, the role of the ICT sector has remained relatively stable over time in the EU, at around 4% of GDP. The share of employment in the EU's ICT sector has also risen over the last decade. However, the sector appears less R&D intensive, less productive and less active in ICT patenting than other major economies.

At the same time, this chapter shows that ICT diffusion is not happening at an appropriate rate. Some countries are still lagging behind in providing their workforces with the right digital skills, or in the uptake of digital technologies by companies of all sizes, and governments. **This calls for further accumulation and diffusion of ICT capital throughout Europe to ensure the adoption of digital technologies that will bring productivity gains across the economy**.

Another important consideration relates to securing network and information systems. In fact, securing ICT products and services may probably contribute to fostering their uptake by the market, society which, ultimately, could help the ICT sector in the EU. The EU Cybersecurity plan focuses on five priorities, including achieving cyber- resilience, drastically reducing cybercrime, developing cyberdefence policies and capabilities related to the Common Security and Defence Policy (CSDP), developing industrial and technological resources for cybersecurity, and establishing a coherent international cyberspace policy for the EU and promoting the EU's core values[5].

Finally, while on the one hand ICTs can provide solutions to address climate change by leading to smart grids, smart buildings and smart cities (to name but a few), **on the other hand, there is a need to reduce ICT's global footprint from the energy-intensive use** of data centres as well as infrastructure for telecommunications. In this context, **investing in R&I to generate solutions for energy-efficient cloud computing, or the optimisation of energy consumption in data centres, can lead to green ICT**.

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[5] https://ec.europa.eu/commission/presscorner/detail/en/IP_13_94

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CHAPTER
6.1

SCIENTIFIC PERFORMANCE

KEY FIGURES

21 %
EU's share of global scientific publications

21 %
EU's share of the top 1% highly cited scientific publications

60 000
EU publications contributing to or using machine-based learning activities

27 %
EU's share of highly cited scientific publications on food and bioeconomy

What can we learn?

- The **EU and China are the global leaders in terms of scientific output**, while the United States retains its lead in terms of scientific quality. **Output from Chinese researchers has risen exponentially** in the last two decades to almost match the EU.

- Within the EU, there is a **diversity of research intensities** and a **positive correlation between scientific quality and investments** in most countries.

- **Digitalisation is transforming science**. All areas of research are becoming data-intensive, increasingly relying upon and generating big data.

- **Science is key in addressing societal challenges**. The EU is leading in high-quality scientific publications in the food/bioeconomy and climate/environment sectors, while China is increasing exponentially across sectors, and the United States is losing its overall leadership.

What does it mean for policy?

- To remain a leading global scientific player, the EU and its Member States must **strengthen their efforts to increase the effectiveness and performance of their public research systems** through stronger R&I investments and policy reforms.

- To **exploit the full potential of science digitalisation**, policies must be adapted to reinforce researchers' digital skills, promote open science as well as to ensure the necessary investment in high-quality data infrastructures.

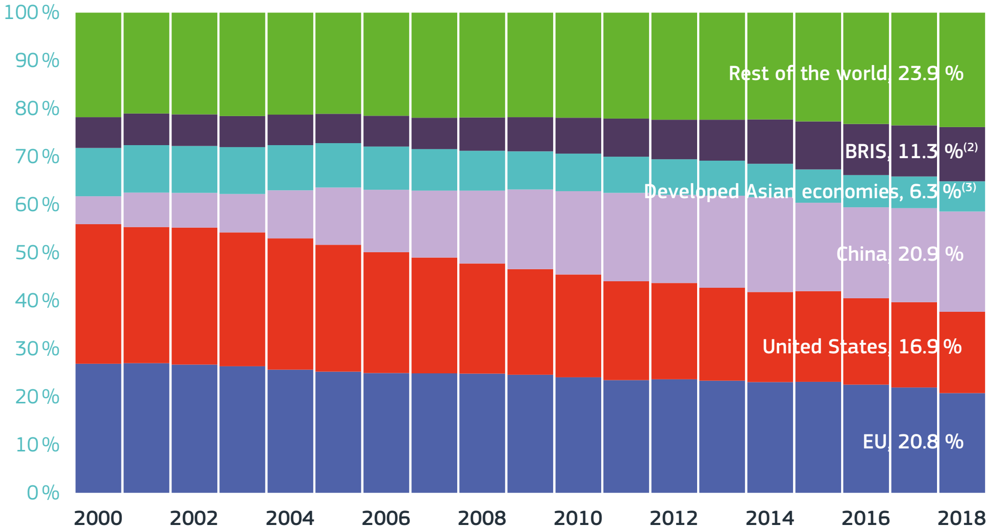
- As science is key in addressing societal challenges, the EU must not only ensure scientific leadership in key areas but must also **foster interdisciplinarity research** that is necessary to successfully deliver on the SDGs.

1. The EU and China are global leaders in terms of scientific output, while the United States retains the lead in scientific quality

Jointly with China, the EU remains in the leading position in terms of the share of scientific output worldwide, while the US' share has continued to shrink. With 7% of the world population, the EU is responsible for 20% of global R&D expenditure and 21% of scientific publications worldwide. However, with the United Kingdom leaving the EU, the EU's share declined from 30 % in 2000 to 21 % in 2018 (see Figure 6.1-1)[1].

China has established itself as a major scientific player and a competitor in high-tech sectors. The country's world share of scientific publications rose exponentially from 5.8 % in 2000 to 20.9% in 2018 (see Figure 6.1.2), showing China's leadership in the global ranking, jointly with the EU (without the UK). Moreover, China's share of world R&D expenditure has increased from 5% in 2000 to more than 20% today, which means that its R&D intensity has already overtaken that of the EU (European Commission, 2019a: 59).

Figure 6.1-1 World share of scientific publications(1), 2000 and 2018



Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit

Notes: (1)Data produced by Science-Metrix based on Scopus database. Fractional counting method used. (2)BRIS includes Brazil, Russian Federation, India and South Africa. (3)Developed Asia economies includes Japan and South Korea. (4)Figures correspond to the latest year, 2018.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter61/figure-61-1.xlsx

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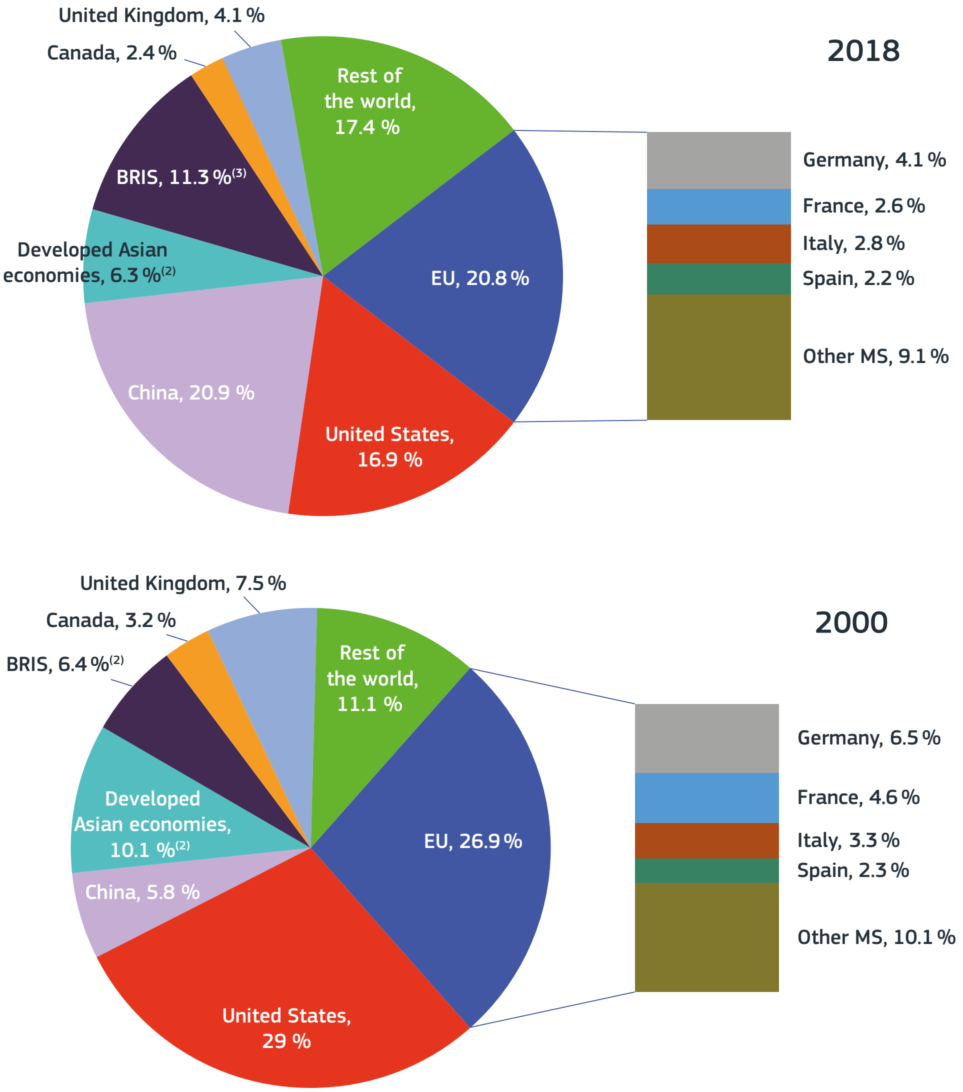
[1] One way to analyse the scientific performance of countries and regions is to look at the number of scientific publications published by the researchers based there. However, the rise of international collaboration over the last 20 years needs to be taken into account as a high proportion of scientific publications now have authors in more than one country.

Figure 6.1-2 World share of scientific publications[1] %, 2000 and 2018



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Notes: (1)Data produced by Science-Metrix based on Scopus database. Fractional counting method used. (2)Developed Asia economies includes Japan and South Korea. (3)BRIS includes Brazil, Russian Federation, India and South Africa.

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Simultaneously, the US' world share of scientific publications fell from 29 % in 2000 to 16.9% in 2018. This decline positions the US behind the EU, whose share fell from 26.9% in 2000 to 20.8 % in 2018 (both figures calculated without the UK). During the same period, BRIS countries[2] were able to increase their share from 6.4% to 11.3%.

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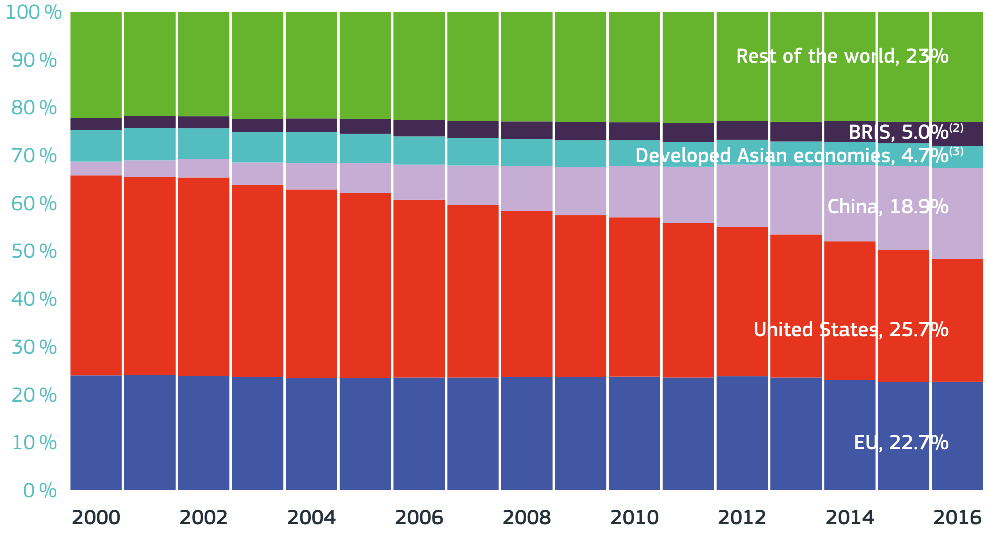
2 Brazil, Russia, India and South Africa.

Within the EU, all of the countries with the highest number of scientific publications have seen their world share shrink. From 2000 to 2018, Germany dropped from 6.5 % to 4.1 %, France from 4.6 % to 2.6 %, Italy from 3.3 % to 2.8 %, and Spain from 2.3 % to 2.2 %. The UK's share dropped from 7.5 % to 4.1 %.

The United States maintains its global leadership in terms of highly cited scientific publications, although it has seen a dramatic decline in its share. Europe remains in second place, while China continues its sharp rise. At 22.7 %, the EU has also maintained its high global share in terms of the top 10 % highly cited publications[3] (Figure 6.1-3). However, the respective output from the Chinese science system has grown exponentially – from 2.9 % in 2000 to 18.9 % in 2016 – and is coming closer to the output from the EU and US systems. In the latter, the share of the top 10 % highly cited publications fell dramatically from 41.8 % in 2000 to 25.7 % in 2016, significantly closing the gap between the United States and the EU. Moreover, the average quality of China's publications is improving (European Commission, 2019a: 60).

Figure 6.1-3 World share of top 10 % highly cited scientific publications(1), 2000 (citation window: 2000-2002) and 2016 (citation window: 2016-2018)



Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit

Note: (1)Data produced by Science-Metrix based on Scopus database. Scientific publications within the 10 % most-cited scientific publications worldwide as % of total scientific publications of the country; fractional counting method. (2)BRIS includes Brazil, Russian Federation, India and South Africa. (3)Developed Asia economies includes Japan and South Korea. (4)Figures correspond to the latest year, 2018.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter61/figure-61-3.xlsx

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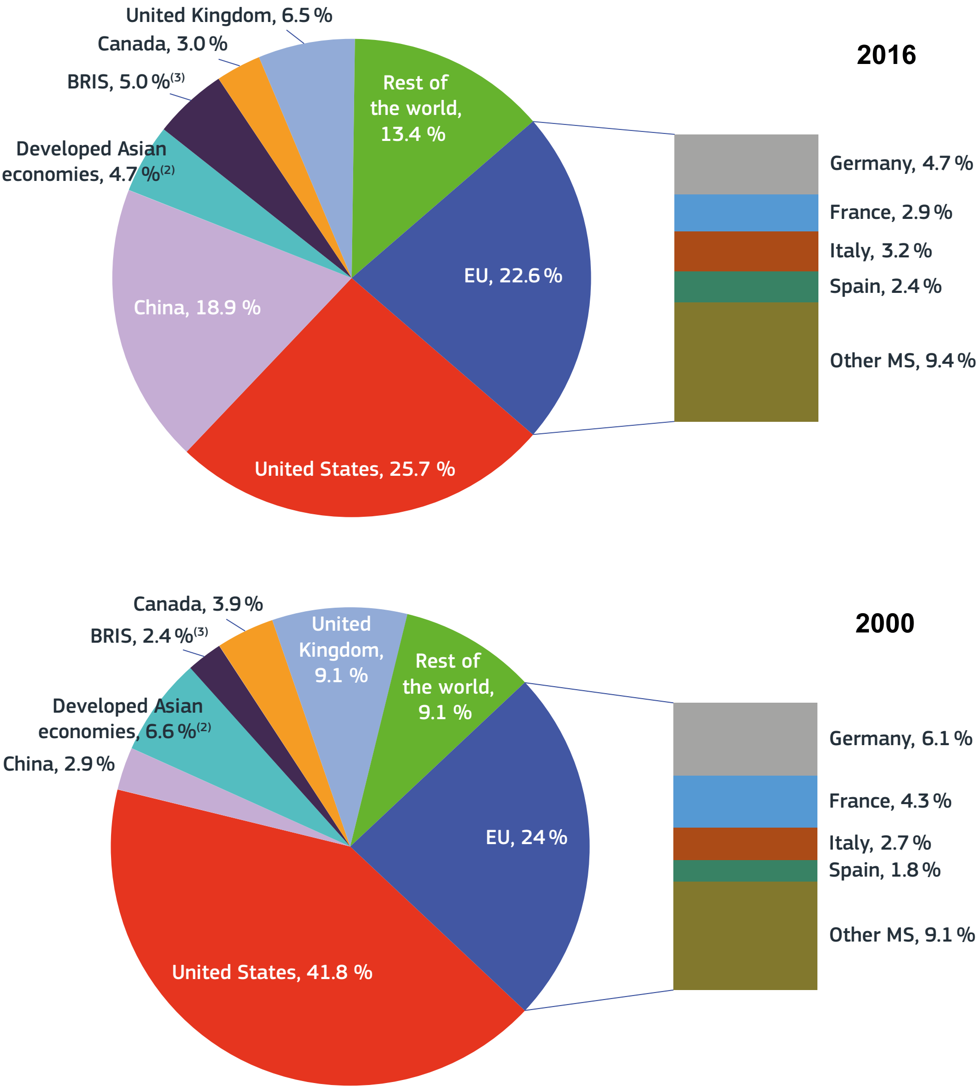
[3] In terms of quality, the number of times a publication is cited by other publications is seen as a useful proxy for the impact of that publication. The number of citations publications receive leans very heavily towards the most important or interesting findings. The top 1 % of highly cited papers receive around 25 % of all citations while a significant proportion of papers are not cited at all. International co-publications also tend to be more highly cited.

While the world share of 10 % highly cited scientific publications dropped in most EU countries between 2000 and 2016, Spain saw an increase from 1.8 % to 2.4 % (Figure 6.1-4).

Figure 6.1-4 World share of top 10 % highly cited scientific publications(1), 2000 (citation window: 2000-2002) and 2016 (citation window: 2016-2018)



Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit

Notes: (1)Data produced by Science-Metrix based on Scopus database. Scientific publications within the 10 % most-cited scientific publications worldwide as % of total scientific publications of the country; fractional counting method. (2)Developed Asia economies includes Japan and South Korea. (3)BRIS includes Brazil, Russian Federation, India and South Africa.

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With 21.2 % in 2000 and 20.9 % in 2016, the EU is maintaining its world share of the top 1 % highly cited scientific publications at an almost constant rate. Once again, as with the other indicators, China's increase in this category is exponential, rising from 1.9 % in 2000 to 17.5 % in 2016. On the other hand, while still the leading country, the US's share is in decline, falling from 48.8 % in 2000 to 31.3 % in 2016. During this period, there was no significant change in the share of BRIS countries and developed Asian economies.

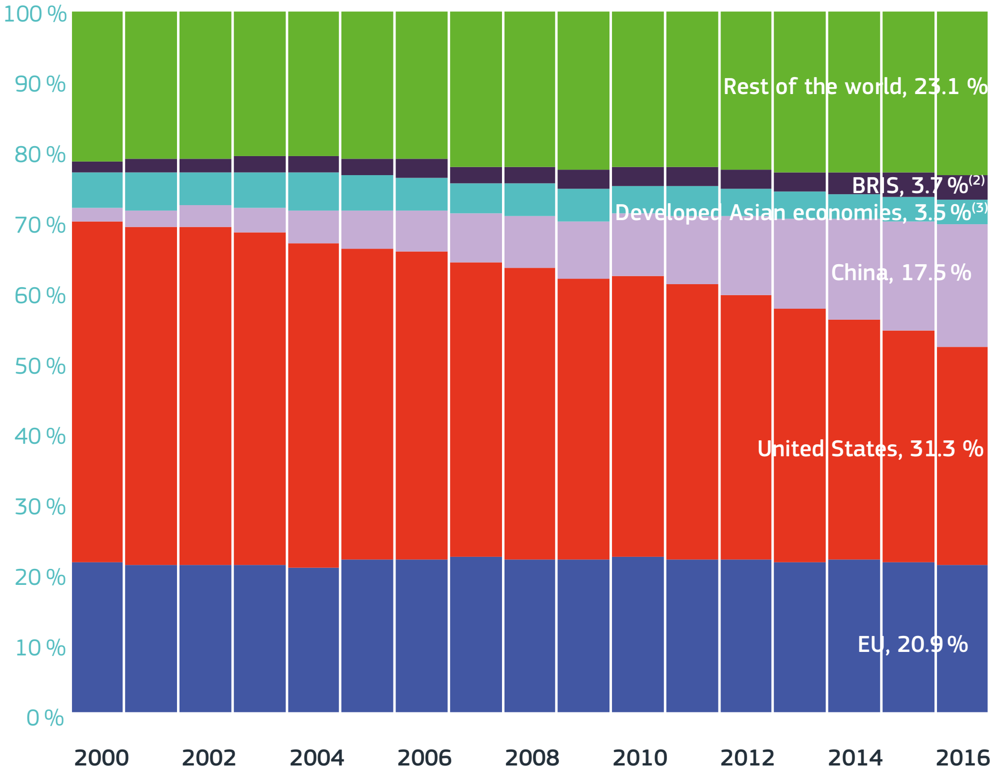
BOX 6.1-1 The European Research Council – facts and figures

The European Research Council (ERC) – the first pan-European funding body for frontier research – was set up in 2007 under the EU's Seventh Framework Programme for Research (FP7, 2007-2013). The total budget allocated to the ERC for the period 2014-2020 is EUR 13.1 billion.

- The ERC represents **17 % of the overall Horizon 2020 budget** (EUR 13.1 billion of EUR 77 billion).
- Since 2007, some **9 000 projects** have been selected for funding from more than **65 000 applications**.
- ERC grantees have won prestigious prizes, including **six Nobel Prizes**, four Fields Medals, and five Wolf Prizes.
- At the end of 2015, there were over **40 000 articles** acknowledging ERC support in international, peer-reviewed journals.
- Each ERC grantee employs on average **six team members**, thereby contributing to train **a new generation of excellent researchers**. Currently, over 50 000 postdocs, PhD students and other staff are working in their research teams.
- More than 70 % of projects assessed by an independent study made **scientific breakthroughs or major advances**, whilst around 25 % of them made incremental contributions.

Source: https://erc.europa.eu/projects-figures/facts-and-figures, accessed: 30 October 2019

Figure 6.1-5 World share of top 1% highly cited scientific publications[(1)], 2000 (citation window: 2000-2002) and 2016 (citation window: 2016-2018)



Science, research and innovation performance of the EU 2020

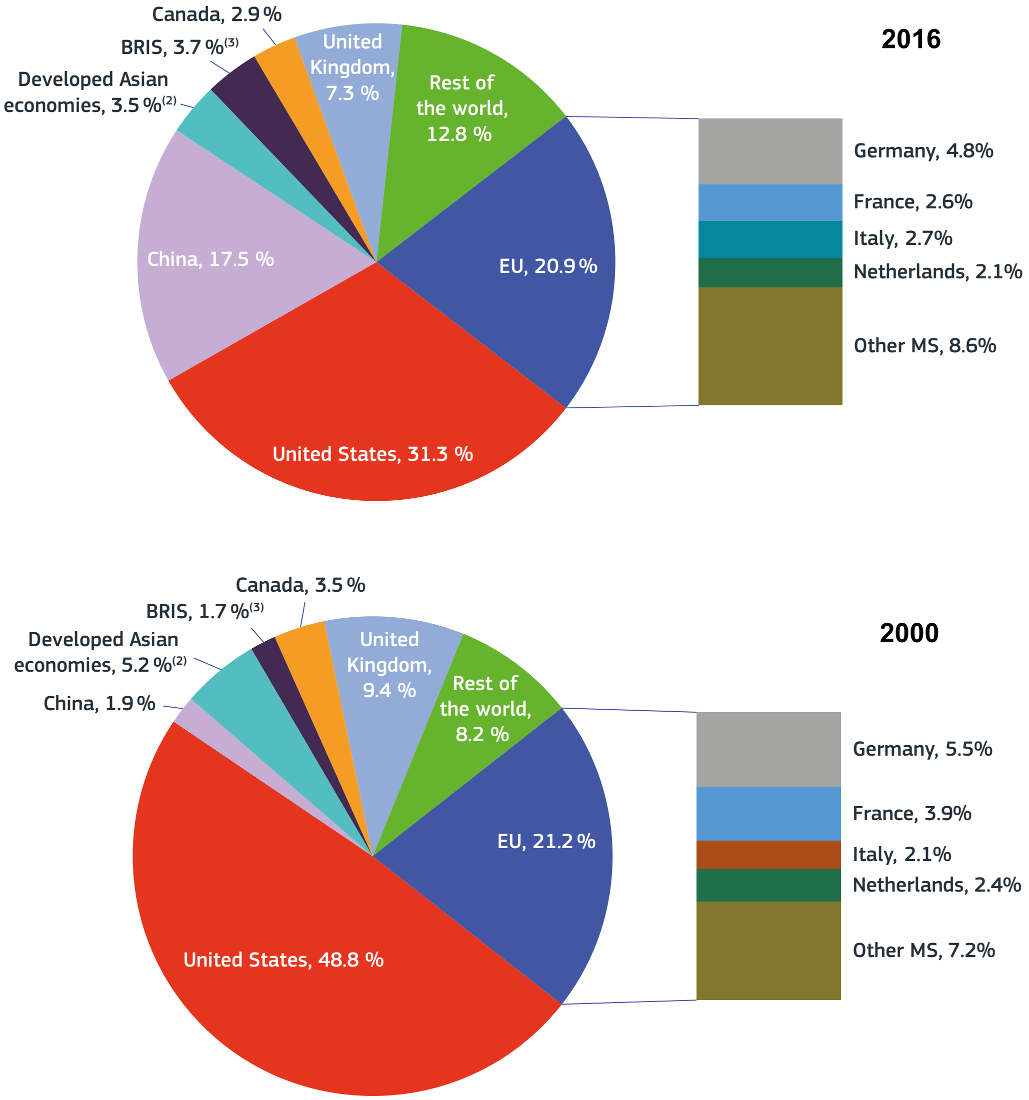
Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit

Note: (1)Data produced by Science-Metrix based on Scopus database. Scientific publications within the 1 % most-cited scientific publications worldwide as % of total scientific publications of the country; fractional counting method. (2)BRIS includes Brazil, Russian Federation, India and South Africa. (3)Developed Asia economies includes Japan and South Korea. (4)Figures correspond to the latest year, 2018.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter61/figure-61-5.xlsx

Whilst the world share of the 1 % of highly cited scientific publications dropped in most EU countries between 2000 and 2016, Spain saw an increase from 1.4 % to 2.0 %, as did Italy from 2.1 % to 2.7 %.

Figure 6.1-6 World share of top 1% highly cited scientific publications(1), 2000 (citation window: 2000-2002) and 2016 (citation window: 2016-2018)



Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit

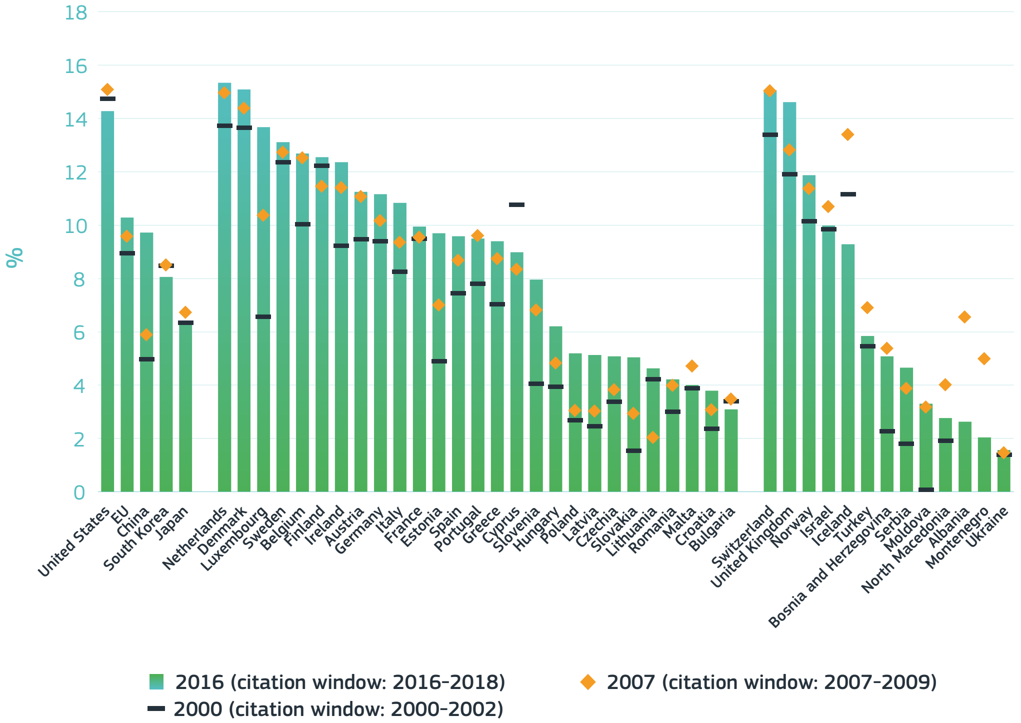
Notes: (1)Data produced by Science-Metrix based on Scopus database. Scientific publications within the 1 % most-cited scientific publications worldwide as % of total scientific publications of the country; fractional counting method. (2)Developed Asia economies includes Japan and South Korea. (3)BRIS includes Brazil, Russian Federation, India and South Africa.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter61/figure-61-6.xlsx

In terms of the share of the top 10% and top 1% most-cited publications as a percentage of the total scientific publications, Europe has stabilised its position behind the United States, while China is quickly catching up. Although Europe has made some progress in raising the quality of its science, differences across Member States persist. Despite a slight fall in the share of total publications among the 10% most-cited worldwide since 2000 (Figure 6.1-7), the United States still outperforms the EU. In other words, the EU has more publications than the United States but with a lower impact in terms of citations. China is quickly bridging the gap with the EU as its top 10% most-cited publications have almost doubled since 2000.

Strong differences persist between European countries' performances. Switzerland confirms its leading global position, followed by numerous western European and Scandinavian countries, which have continued to raise their scientific performance since 2000 (e.g. Belgium, Ireland, Germany, Austria and Luxembourg). While several Mediterranean and eastern European countries like Estonia, Greece, Hungary, Italy, Slovenia and Spain have managed to raise their scientific output compared to 2000, a decline has been noted for Iceland, Israel, Malta and Turkey since 2007.

Figure 6.1-7 Top 10% highly cited scientific publications(1), 2000, 2007 and 2016



Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit

Notes: (1)Data produced by Science-Metrix based on Scopus database. Scientific publications within the 10 % most-cited scientific publications worldwide as % of total scientific publications of the country; fractional counting method. (2)AL: 2008. ME: 2005.

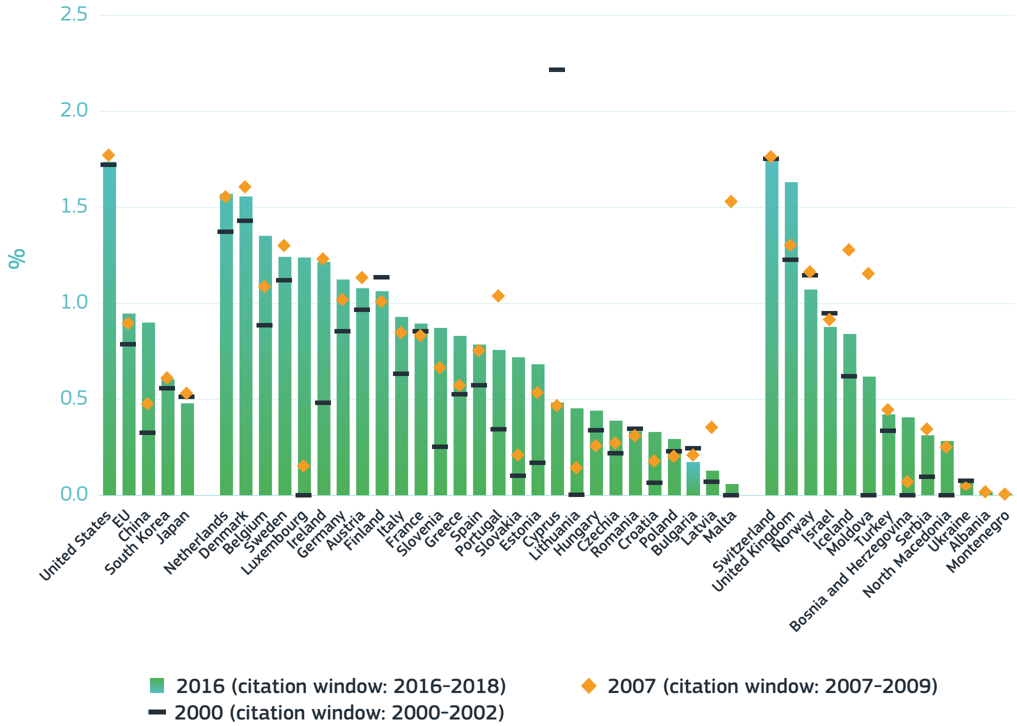
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter61/figure-61-7.xlsx

The share of the top 1 % of highly cited scientific publications as a percentage of the total scientific publications (Figure 6.1-8) **is often used as a proxy for scientific excellence**. On this measure, the EU has remained at the same level since 2007. This trend is similar for the United States, South Korea and Japan, while China's performance continues to increase steadily.

Within Europe, although differences between the Member States persist, the majority of EU13 countries have managed to increase the proportion of their publications in the top 1 % highly cited. Switzerland is the world's top performer in science as regards the top 1 % articles, ahead of the United States and followed by the UK, the Netherlands, Denmark, Belgium, Sweden, Luxembourg, Ireland, Germany, Austria and Finland, all of which score above the EU average.

The citation impact of scientific publications demonstrates the importance of international science collaboration to reach high scientific quality. This is confirmed by the fact that the citation impact of international co-publications for all countries is greater than that of single-country publications for all countries (Figure 6.1-9). China's scientific quality benefits most as a result of international scientific collaboration.

Figure 6.1-8 Top 1% highly cited scientific publications(1), 2000, 2007 and 2016

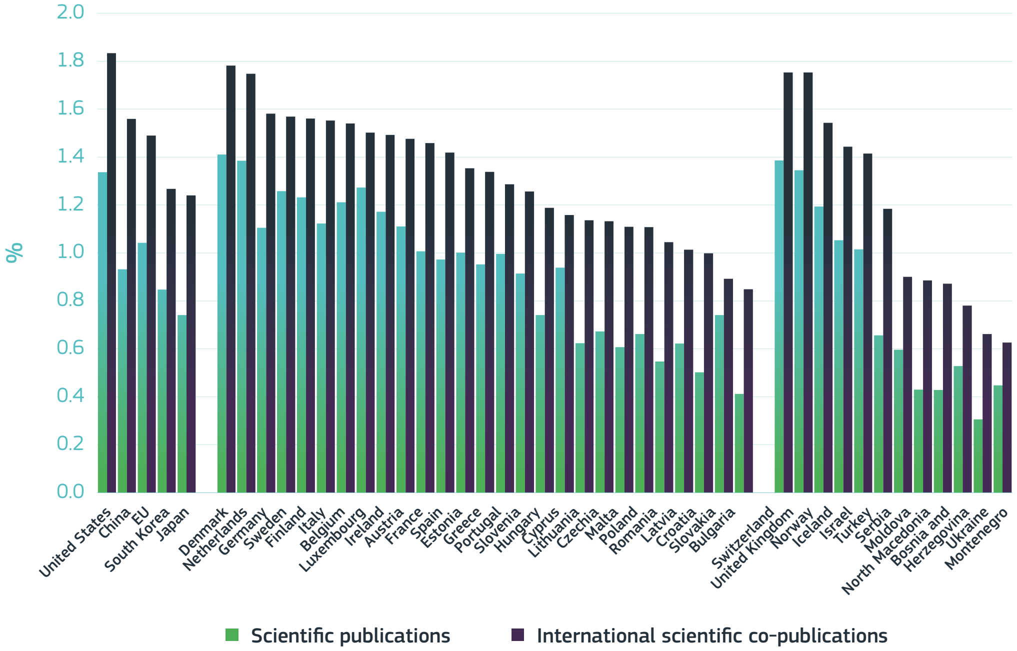


Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit

Notes: (1)Data produced by Science-Metrix based on Scopus database. Scientific publications within the 1 % most-cited scientific publications worldwide as % of total scientific publications of the country; fractional counting method. (2)AL: 2008. ME: 2005.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter61/figure-61-8.xlsx

Figure 6.1-9 Citation impact[1] of scientific publications, 2016 (citation window: 2016-2018)



Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit

Note: [1]Data produced by Science-Metrix based on Scopus database. Citation impact normalised by field and publication year (ratio of the average number of citations received by the papers considered and the average number of citations received by all papers in the main field, or 'expected' number of citations), citation window publication year plus two years.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter61/figure-61-9.xlsx

Within the EU, this positive correlation is stronger for most of the countries exhibiting lower scientific performance.

The international rankings (the Shanghai and Leiden Rankings[4]) position the EU as a leader in 'world-class' universities among the top 500 institutions, while the United States still heads the top 100.

Although all innovation leader countries[5] outperform the United States, some have seen their position deteriorate over the last decade. According to the Academic Ranking of World Universities (ARWU)[6], the EU has more universities (179) among the top 500 institutions than the United States (139), while the United States still leads in the top 100 (46, compared to 27 in the EU). The same holds true for the

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[4] Global international higher education rankings are perceived as a measure of quality, although the approaches vary according to the different rankings.

[5] As defined by the European Innovation Scoreboard 2019, these are Sweden, Finland, Denmark and the Netherlands (see https://ec.europa.eu/growth/industry/innovation/facts-figures/scoreboards_en, accessed: 30 October 2019).

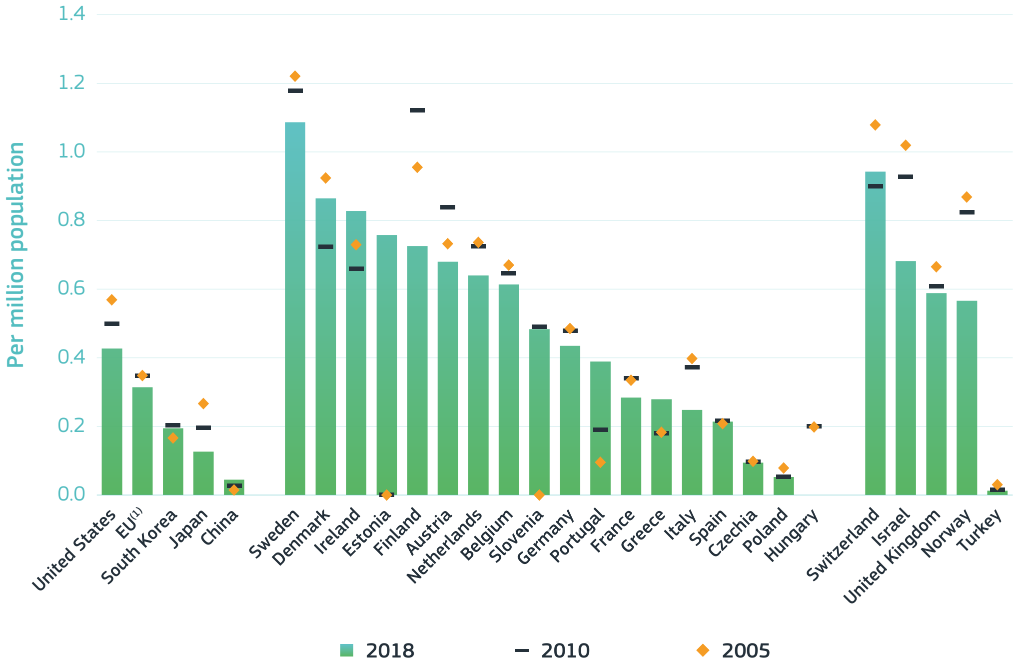
[6] Also called Shanghai Ranking, which is based on six indicators mainly related to an institution's scientific output (number of Nobel Prizes and Fields Medals, highly cited researchers, papers published).

Leiden Ranking[7], which shows a total of 211 EU universities and 146 US universities in the top 500 list of institutions, and 33 EU universities and 52 US universities in the top 100 list[8].

Overall, the United States still slightly outperforms the EU in terms of the number of top 500 universities per million population. However, all EU countries classed as 'innovation leaders' and 'strong innovators' outperform the United States on this indicator when using the Shanghai Ranking. The EU also outperforms South Korea, Japan and China[9] in terms of top institutions per million population (see Figure 6.1-10).

According to the Leiden Ranking, some of the best-performing countries in terms of the number of top 500 universities per million population (Sweden, Belgium, Finland and Switzerland) have seen their position drop since 2011. Yet, countries such as Ireland, Austria, Denmark and Norway have experienced a strong improvement in their performance compared to 2011 (Figure 6.1-11).

Figure 6.1-10 Number of top 500 universities in the Shanghai Ranking per million population, 2005, 2010 and 2018



Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on Shanghai ranking (http://www.shanghairanking.com/)

Note: (1)EU was estimated by DG Research and Innovation based on the data available for the Member States.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter61/figure-61-10.xlsx

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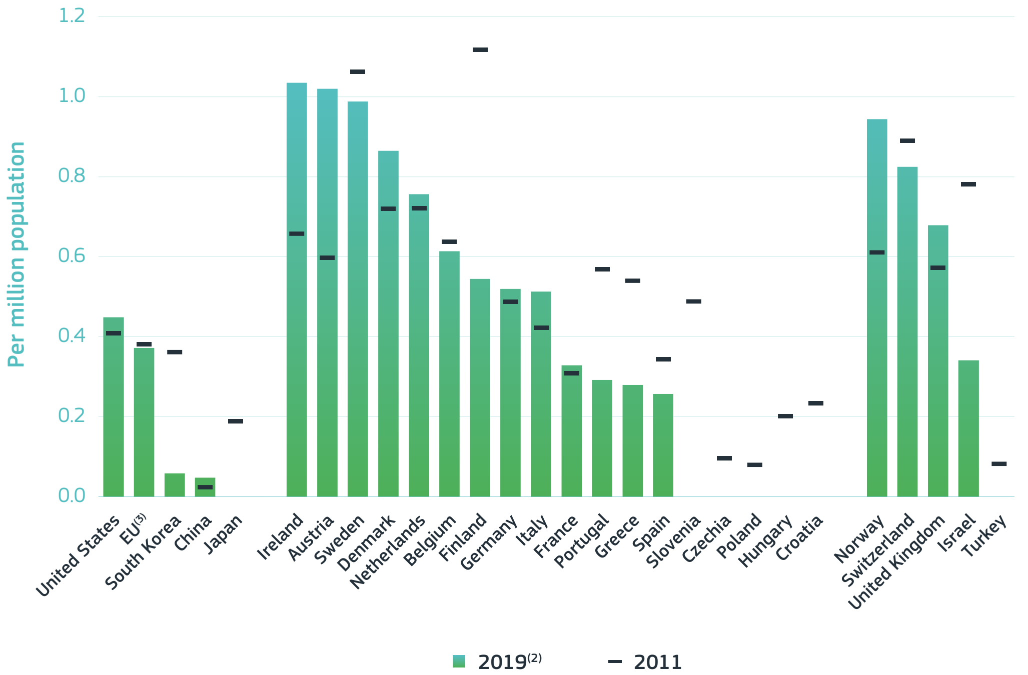
[7] The Leiden Ranking 2019 is based on a set of bibliometric indicators that provide statistics at the level of universities on scientific impact, collaboration, open access publishing, and gender diversity (for further details see https://www.leidenranking.com/information/indicators, accessed: 30 October 2019.

[8] Please note that university rankings do not take into account research efforts made by publicly funded research performing organisations.

[9] In the ARWU, this includes Hong Kong, Macao and Taiwan.

Figure 6.1-11 Number of top 500 universities in the Leiden Ranking per million population[1], 2011 and 2019



Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on Leiden ranking (http://www.leidenranking.com/)

Notes: [1]All publications included. Fractional counting used. Universities ranked by proportion of top 10 % publications. [2]Population refers to 2018 for all countries except US, JP, CN, and KR in respect of which population refers to 2017. [3]EU was estimated by DG Research and Innovation based on the data available for the Member States.

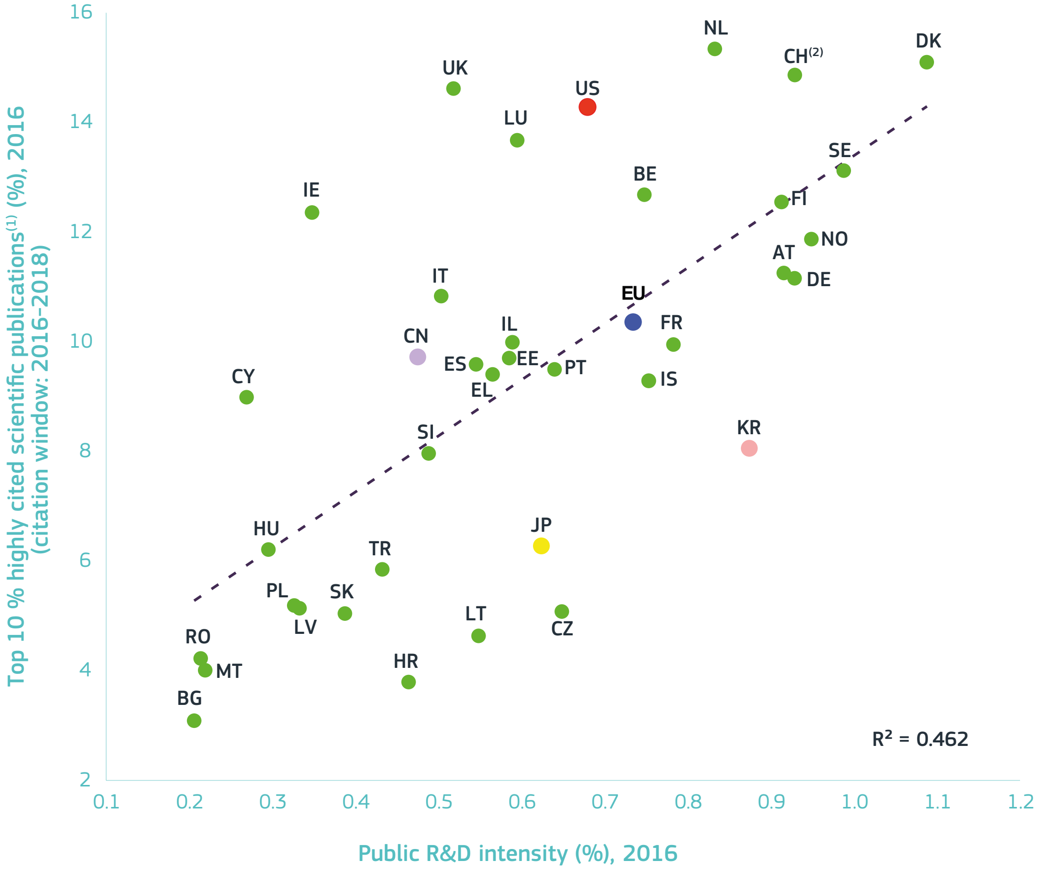
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter61/figure-61-11.xlsx

2. Within the EU, there is a diversity of research intensities and a positive correlation between scientific quality and investments

In Europe, a positive correlation between R&D intensity and scientific quality is evident in most countries. The Netherlands, Switzerland, Denmark, Sweden, Belgium, Finland, Austria, Norway and Germany enjoy higher levels of public investment in R&D than the EU average, as well as better scientific results (Figure 6.1-12). All Mediterranean (except Italy) and central and eastern European countries show below-EU-average R&D investment levels matched with below-EU-average levels of scientific excellence.

At the global level, the United States has a higher scientific impact than the EU despite lower public R&D intensity. Japan and South Korea show lower levels of scientific quality in relation to public investments. At the same time, China's scientific quality is approaching the EU level, despite a slightly lower R&D-intensity (Figure 6.1-12).

Figure 6.1-12 Public R&D intensity, 2016 and top 10 % highly cited scientific publications[(1)] 2016 (citation window: 2016-2018)



Science, research and innovation performance of the EU 2020

Source: Eurostat (online data code: rd_e_gerdtot), OECD and Science-Metrix using data from the Scopus database

Notes: (1)Scientific publications within the 10 % most-cited scientific publications worldwide as % of total scientific publications of the country; fractional counting method. (2)CH: 2015.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter61/figure-61-12.xlsx

Although several EU Member States are making numerous efforts to increase the effectiveness and performance of their public-sector research systems, further efforts are needed to introduce the necessary policy reforms. Between 2013 and 2016, research excellence in the EU28 increased at an annual growth rate of 3.2 %[10]. However, further efforts are needed to ensure well-functioning, efficient and impactful national R&I systems. The European Research Area (ERA) Priority 1 recognises this by calling for more effective national research systems and richer R&I policy mixes geared towards making a stronger impact by science and innovation in society.

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[10] Headline indicator composed of: share of top 10 % most highly cited publications per total publications (data source: CWTS); PCT patent applications per population (OECD); European Research Council (ERC) grants per public R&D (DG RTD, Eurostat, OECD); and participation in Marie Skłodowska-Curie fellowships (DG EAC); see European Commission (2019c: 11).

The European Semester 2019 also shows that further progress must be made, and it has demanded, for the first time, that all EU Member States make greater investments in R&I. A number of countries received additional country-specific recommendations (CSRs) for policy action to promote the quality and efficiency of their national R&I systems (quality of R&I policies and systems, stronger science-business links, support for breakthrough innovations and scale-up of high-growth firms, and sound framework conditions for business R&D).

The European Structural and Investment Funds (ESIF) and smart specialisation strategies are also prioritising investments in R&I in support of these reforms. Other reform-supporting tools include the Structural Support Reform Programme and the Horizon 2020 Policy Support Facility (PSF), which give advice to those Member States willing to improve the design, implementation or evaluation of their national R&I policies.

To ensure the effective use of public R&I funds, competitive funding is widely applied in EU Member States. However, the 2018 ERA Progress Report found that 'the balance between competitive funding and block funding still varies greatly between countries. In some countries with less-developed R&I systems, less competitive research-performing organisations rely mainly on block funding; this often affects their ability to attract the best talent and to develop and maintain research infrastructures' (European Commission, 2019b: 3). The Horizon 2020 PSF Mutual Learning Exercise on Performance-Based Funding[11] recommended Member States to carefully consider the proportion of institutional funding governed by performance-based criteria as a means of enhancing the effectiveness and performance of their public-sector research systems.

3. Digitalisation is transforming science. All areas of research are becoming data-intensive, increasingly relying upon and generating big data

Digitalisation has the potential to increase the productivity of science, enable novel forms of discovery and enhance reproducibility. Deep learning has become an increasingly popular method in most scientific disciplines. Digitalisation is a game-changer for science. The development and use of big data, for example, and the application of artificial intelligence (AI) is becoming increasingly relevant across all scientific domains (see Chapter 7 - R&I enabling artificial intelligence).

Digitalisation has the potential to promote collaboration as well as improve the efficiency of scientific research (OECD, 2019b: 57). The most noted potential – one that applies across all disciplines, including the humanities – concerns exploiting data and machine-learning techniques to support the research process (OECD, 2019c: 69ff).

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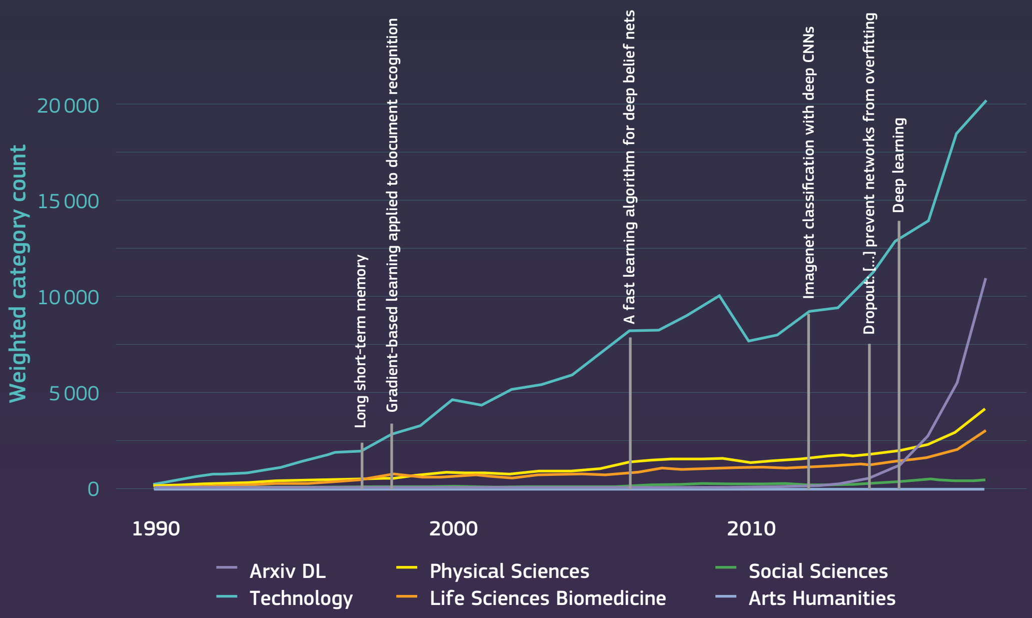
[11] See https://rio.jrc.ec.europa.eu/en/policy-support-facility/mle-performance-based-funding-systems, accessed 22 October 2019.

BOX 6.1-2 The rise of deep learning and its impact on global science[12]

Based on a contribution by Stefano Bianchini, Moritz Muller and Pierre Pelletier, BETA – University of Strasbourg

Much of the recent success of AI has been spurred by impressive achievements within a broader family of machine-learning methods, commonly referred to as deep learning. Deep learning enables computational models to learn representations of data with multiple levels of abstraction. Deep learning can be viewed as an 'invention in the methods of invention' – i.e. A technology that transforms the process of knowledge creation and improves the potential for discoveries in combinatorial-type research problems.

Figure 6.1-13 Publication activity related to deep learning



Science, research and innovation performance of the EU 2020

Source: Stefano Bianchini, Moritz Muller and Pierre Pelletier, BETA – Université de Strasbourg

Note: This figure represents the annual trends in deep-learning documents divided into five WoS subject categories. It also shows the yearly trend in deep-learning research published in arXiv, an open archive of academic preprints widely used by the computer-science community. The vertical grey lines indicate important methodological achievements in the field of deep learning. These breakthroughs (especially those in recent years) precede a strong upward trend in the application of the technology in various domains.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter61/figure-61-13.xlsx

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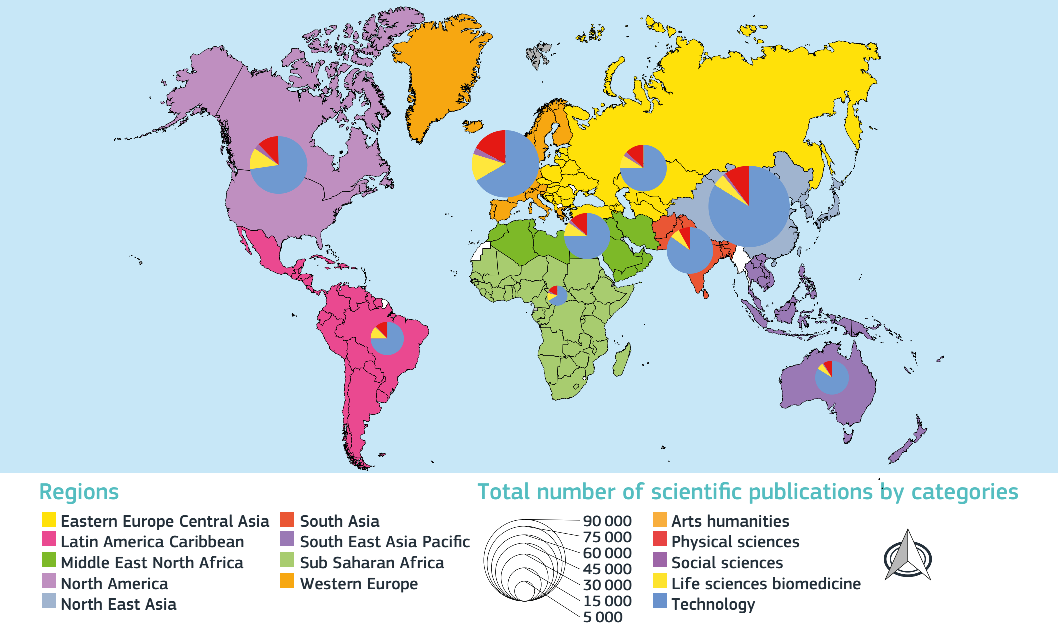
[12] Methodology: Web of Science (WoS) publication statistics are used to document how deep learning is being spread in science. Natural language processing techniques are used on text corpus (i.e. abstracts of scientific documents) for the identification of deep-learning-related terms (e.g. deep neural networks). Then a selected list of terms is used to identify those WoS documents that involve deep learning. These documents can either contribute methodologically to deep learning or use deep-learning-based tools to address disparate research questions. The WoS subject categories assigned to each document and authors' affiliations are used to map the diffusion of deep learning across the scientific system.

Figure 6.1-14 presents the geography of deep-learning activity by regions. The map shows a high level of activity in a small number of regions ranked as follows: north-east Asia, western Europe and North America. The map also documents a substantial variation in the applications across regions. Regions such as north-east Asia and eastern Europe seem to deploy deep learning mainly in the field of technology, while western Europe and North America show a significantly larger proportion of applications in life sciences and biomedicine.

The evidence suggests that **deep learning is spreading rapidly in many areas in the scientific system**. However, the important geographical dimension inherent in the process of creating and disseminating deep-learning-related knowledge suggests that countries are likely to exhibit heterogeneous patterns of specialisation. The performance of any deep-learning system relies heavily on good data. As such, science and technology policies should **improve access to high-quality data infrastructures through a well-designed data strategy**, which includes ethical and legal considerations. In addition, to achieve the full potential of deep learning, complementary resources are necessary. Among these assets, human resources (i.e. talented AI researchers) are the most important. **Deep learning also implies organisational changes in the scientific system**, such as team structure, public-private interaction, data sharing, etc.

Figure 6.1-14 **Geography of deep-learning activity**



Source: Stefano Bianchini, Moritz Muller and Pierre Pelletier, BETA – Université de Strasbourg

Note: This figure represents the geography of deep-learning activity by regions in the period 1990-2018. It also shows the share of WoS subject categories for each region.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter61/figure-61-14.xlsx

Moreover, the use of AI in science could enable novel forms of discovery and enhance reproducibility (OECD, 2018).

Avenues to promote the digitalisation of public research include strengthening researchers' digital skills, promoting open science (access to publications and data), ensuring appropriate investments in digital infrastructures for research, and creating incentives for interdisciplinary research. Promoting digitalisation of public research has become a priority for almost all EU Member States. In addition to open science[13], Member States are supporting various other measures, including strengthening researchers' digital skills by reinforcing interdisciplinarity (i.e. combining computer science with traditional disciplines) or offering specific trainings to master digital tools.

Moreover, Member States are investing in digital infrastructures that are critical for research (for example, platforms for sharing data and supercomputing facilities for AI). In 2018, the EU launched the European High-Performance Computing Joint Undertaking (EuroHPC JU) with a budget of around EUR 1 billion to develop top-of-the-range exascale supercomputers for processing big data, based on competitive European technology (see Chapter 7 - R&I enabling artificial intelligence)[14].

The digital transformation is also likely to change the accessibility of publications and data which has been limited to date[15]. While immediate open access is steadily increasing, the traditional subscription model remains the most prevalent, 'representing over 80% of the total number of articles published globally last year' (OECD, 2019a: 73). Access to data must consider legal and ethical constraints as well as normative attitudes and the availability of infrastructures (OECD, 2019a: 73).

4. Science is key in addressing societal challenges. The EU is a leader in high-quality scientific publications in the food/bioeconomy and climate/environment sectors

European Member States dominate the analysis targeting the UN SDGs. Figure 6.1-15 shows that Europe dominates the analysis targeted on the UN SDGs, indicating primarily the commitment of researchers to better understanding the goals, interactions between each of them, and potential trade-offs when addressing them. The figure is based on papers directly pertaining to SDGs, i.e. research articles with a title, abstract or keywords that explicitly contain the phrase 'sustainable development goal(s)'. North America and the Asia and Pacific region contribute less. Notably, the highest level of collaboration within the SDG papers surveyed was among European countries (see the 'dark purple cell'). Moreover, Europe

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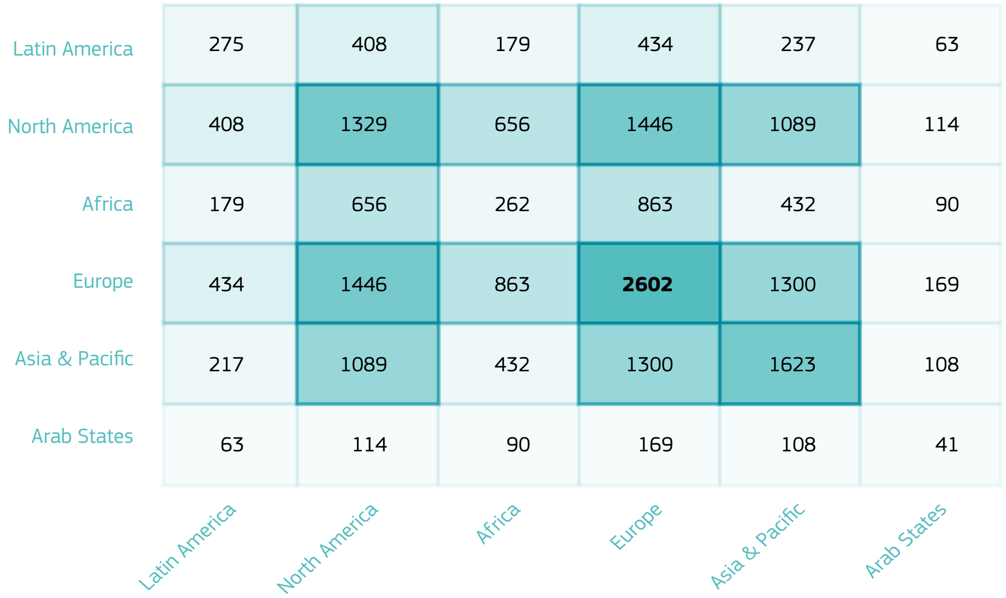
[13] See Chapter 6.2 - Knowledge flows.

[14] https://ec.europa.eu/digital-single-market/en/eurohpc-joint-undertaking#Budget, accessed 9 October 2019.

[15] See Chapter 6.2 - Knowledge flows.

Figure 6.1-15 Regional collaboration matrix for SDG core and citing papers(1)



	Latin America	North America	Africa	Europe	Asia & Pacific	Arab States
Latin America	275	408	179	434	237	63
North America	408	1329	656	1446	1089	114
Africa	179	656	262	863	432	90
Europe	434	1446	863	**2602**	1300	169
Asia & Pacific	217	1089	432	1300	1623	108
Arab States	63	114	90	169	108	41

Source: Institute for Scientific Information (2019: 10)
Note: (1)The figure is a pair-wise matrix showing the number of SDG papers authored by researchers in countries within each regional pair represented by the intersection of the row and column.
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter61/figure-61-15.xlsx

is the largest collaborator with North America (even larger than the intra-North American collaboration) and the largest collaborator with the Asia and Pacific region (while intra-Asia and Pacific region collaboration is slightly higher). Africa, the Arab States and Latin America have more frequent co-authorships with Europe than with North America.

The share of scientific publications remains the highest in 'health, demographic change and well-being' field. For all major science producers, the shares of scientific publications are highest for the societal challenge 'health, demographic change and well-being', although the EU saw a decrease from 64.4% to 56.3% between the periods of 2005-2009 and 2014-2018. Yet, for all other challenges, EU shares increased over the same periods. The same trend can be observed for China.

Scientific publications on 'food security, sustainable agriculture and forestry, marine, maritime and inland water research, and the bioeconomy' have the second highest share for all countries except China, for which both 'secure, clean and efficient energy' and 'climate action, environment, resource efficiency and raw materials' rank second (Figure 6.1-16).

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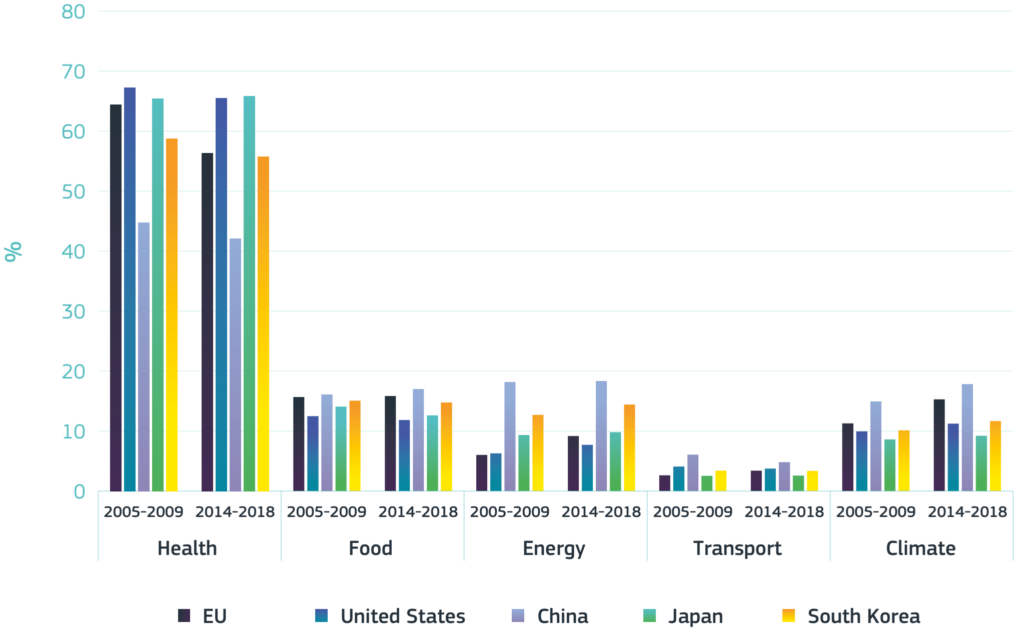
[16] Figure 6.1-15 is a pair-wise matrix showing the number of SDG papers authored by researchers in countries within each regional pair represented by the intersection of the row and column.

Figure 6.1-16 Share of scientific publications by societal challenge[(1)], 2005-2009 and 2014-2018)



Science, research and innovation performance of the EU 2020

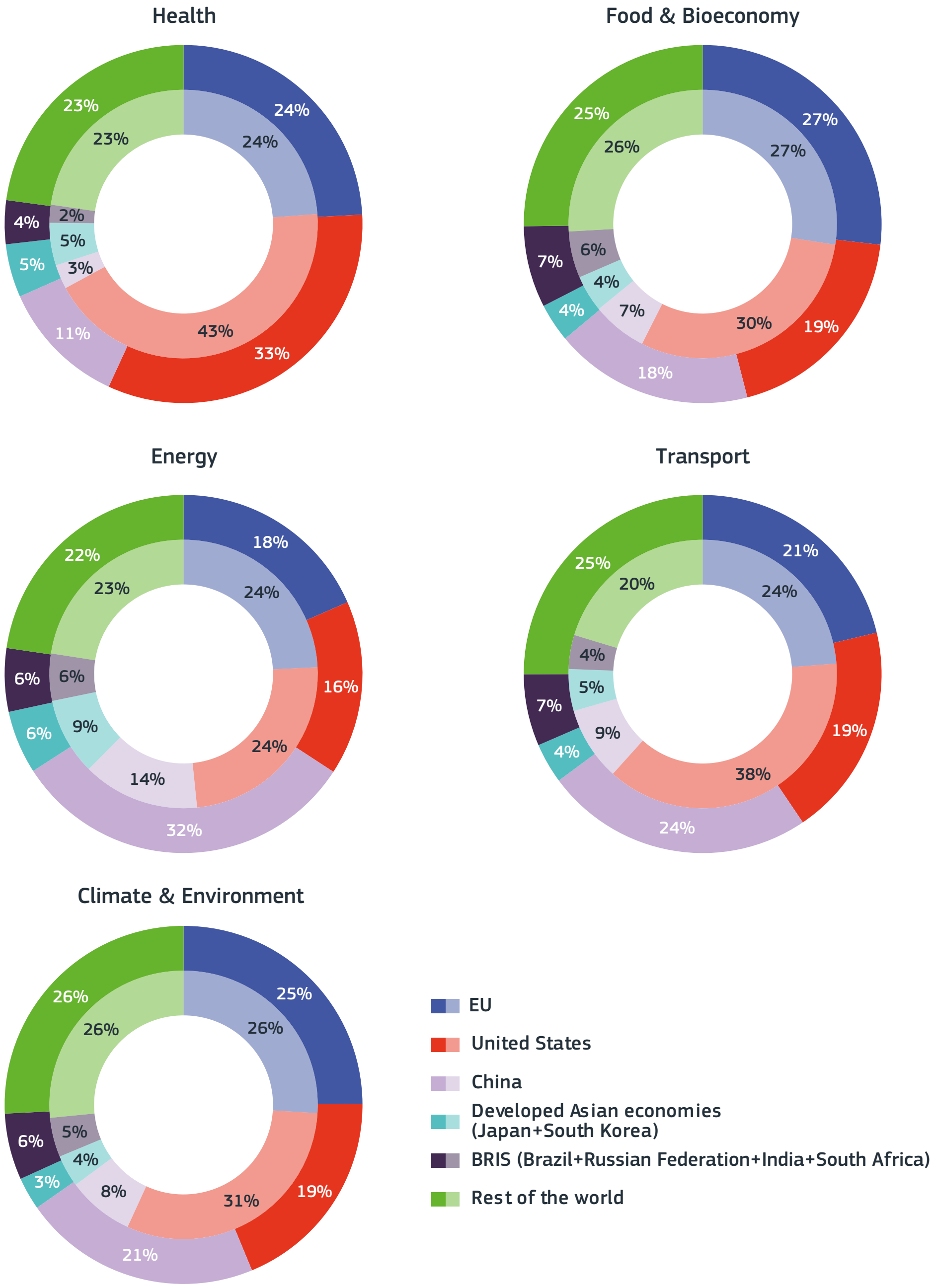
Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit

Note: [(1)]Data produced by Science-Metrix based on Scopus database. This presents the overall % of publications by area. The specialisation indices below are just dividing the % of EU by the % of other countries.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter61/figure-61-16.xlsx

The EU leads in high-quality scientific publications in the food and bioeconomy and climate and environment sectors when compared to its major competitors. While China increased its shares exponentially across all societal challenges, the United States lost its leadership in all of them. When comparing the EU to its major competitors (the US, China, and Japan), the EU leads in scientific publications related to food and bioeconomy and climate and environment (Figure 6.1-17). In all fields, the EU's share remained stable between 2006 and 2016, with the exception of energy where its share dropped from 24% to 18%. During the same period, China increased its shares exponentially across all societal challenges, taking top position in the areas of energy (from 14% in 2006 to 32% in 2016) and transport (from 9% in 2006 to 25% in 2016). At the same time, it reached second place in climate and environment (with 22% in 2016) behind the EU (with 25% in 2016). In contrast to the rise of China, the United States lost its leadership in all fields.

Figure 6.1-17 Shares (%) of top 10 % of scientific publications by Societal Grand Challenges, 2006 (interior) and 2016 (exterior)



Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit

Note: [1]Data produced by Science-Metrix based on Scopus database.

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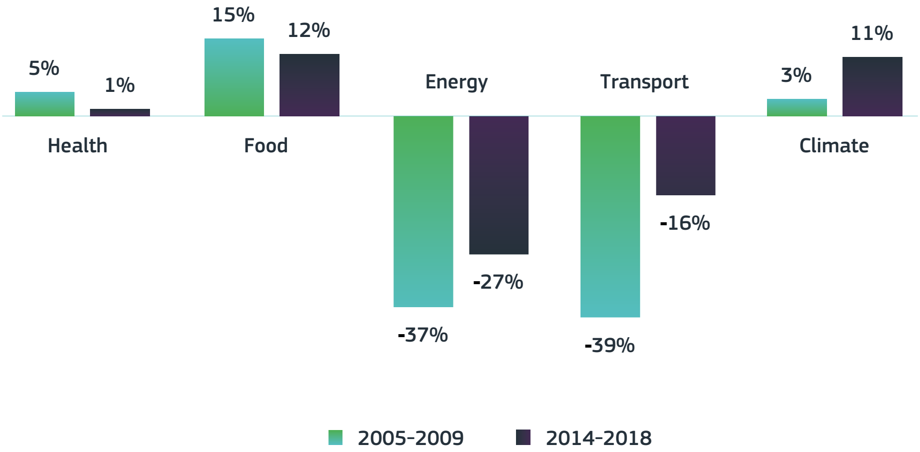
Compared to its main competitors, the EU is particularly specialised in food- and climate-related scientific publications. In comparison to its major competitors (the United States, China, Japan and South Korea), Europe shows a particular specialisation in food and climate change challenges (Figure 6.1-18). During the period 2014-2018, the share of EU publications in food-related challenge was 12% higher than for its competitors (falling from 15% during the period 2005-2009). In the climate-change challenge, it was 11% higher (increasing from 3% during the period 2005-2009). On the other hand, the EU lags behind in the energy and transport challenges.

Figure 6.1-18 Percentage difference in EU specialisation index (vs. US, China, Japan and South Korea), 2005-2009 and 2014-2018



Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit

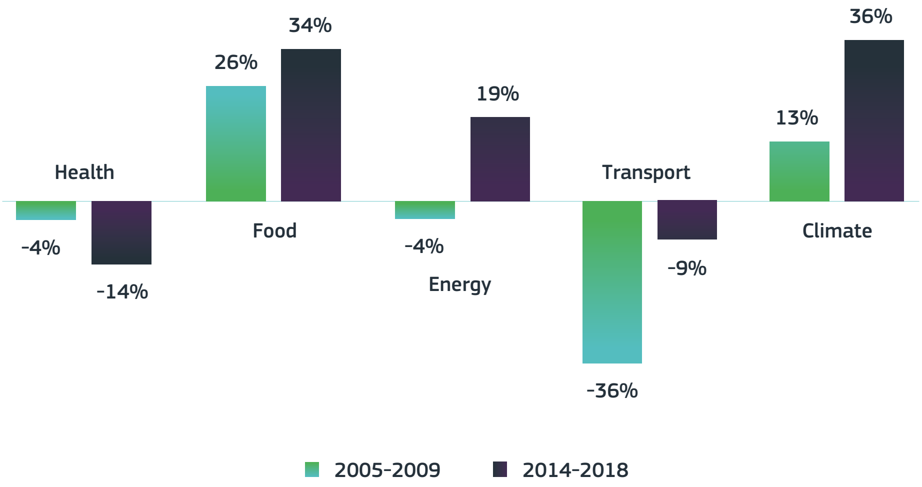
Note: [1]Data produced by Science-Metrix based on Scopus database. These figures compare the percentage of publications in the EU in one area (% of all EU publications) with the percentage of publications in the US, China, Japan and South Korea in the same area (% of all publications in these countries).

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter61/figure-61-18.xlsx

When compared only to the United States, the EU is stronger in the areas of food, energy and climate change, but lags behind it in health and transport-related publications. From 2005 to 2018, the EU increased its advance in the climate change area vis-à-vis the United States by almost three times (Figure 6.1-19).

Compared to China, the EU only appears stronger in health challenge, where its share of scientific publications is 34% higher (2014-2018). In all other areas, the EU appears weaker than China, especially in the energy challenge where the former produced 50% (2014-2018) fewer scientific publications than the latter (Figure 6.1-20).

Figure 6.1-19 Percentage difference in EU specialisation index (vs. US), 2005-2009 and 2014-2018



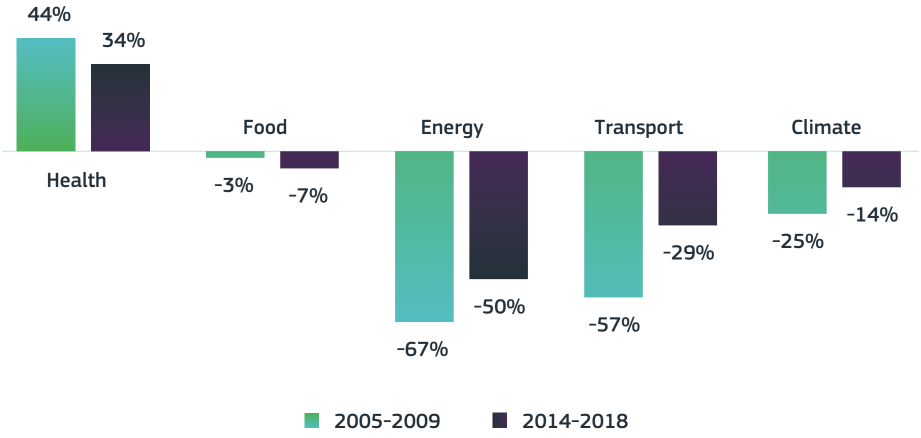
Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit

Note: [1]Data produced by Science-Metrix based on Scopus database. These figures compare the percentage of publications in the EU in one area (% of all EU publications) with the percentage of publications in the US in the same area (% of all publications in these countries).

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter61/figure-61-19.xlsx

Figure 6.1-20 Percentage difference in EU specialisation index (vs. China), 2005-2009 and 2014-2018



Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit

Note: [1]Data produced by Science-Metrix based on Scopus database. These figures compare the percentage of publications in the EU in one area (% of all EU publications) with the percentage of publications in China in the same area (% of all publications in these countries).

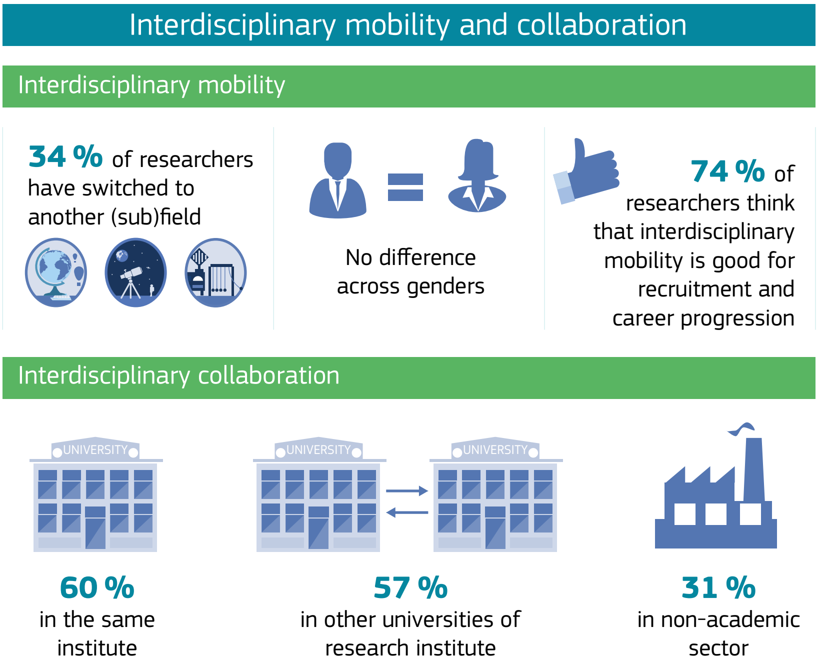
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter61/figure-61-20.xlsx

Research addressing SDGs requires interdisciplinarity. One third of all researchers in the EU have switched to another field or sub-field during their academic career. As all SDGs are interconnected, interdisciplinary and transdisciplinary research will be key to identifying positive complimentary interactions between the SDGs, as well as trade-offs that can constrain or stop progress on certain SDGs (International Council for Science, 2017).

A wide range of research approaches are needed to address the breadth and nature of the challenges reflected by the SDGs (SDSN Australia Pacific 2017). This goes beyond research between disciplines and demands the creation of new ones, such as 'sustainability science'. As a unique trans-, inter-, and multidisciplinary endeavour, sustainability science (Kates et al., 2001) aims to identify problems, opportunities and trade-offs between human, environmental and engineered systems. According to this concept, scientific, lay, practical and indigenous knowledge, as well as varying world views, are brought together (UN, 2019).

The MORE3 Final Report[17] provides evidence that one third of all researchers switch to another field or sub-field during their academic career. Below average shares of interdisciplinary collaboration are observed in the social sciences and humanities (Figure 6.1-21).

Figure 6.1-21 Interdisciplinary mobility and collaboration



Science, research and innovation performance of the EU 2020

Source: Based on MORE EU HE report

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter61/figure-61-21.xlsx

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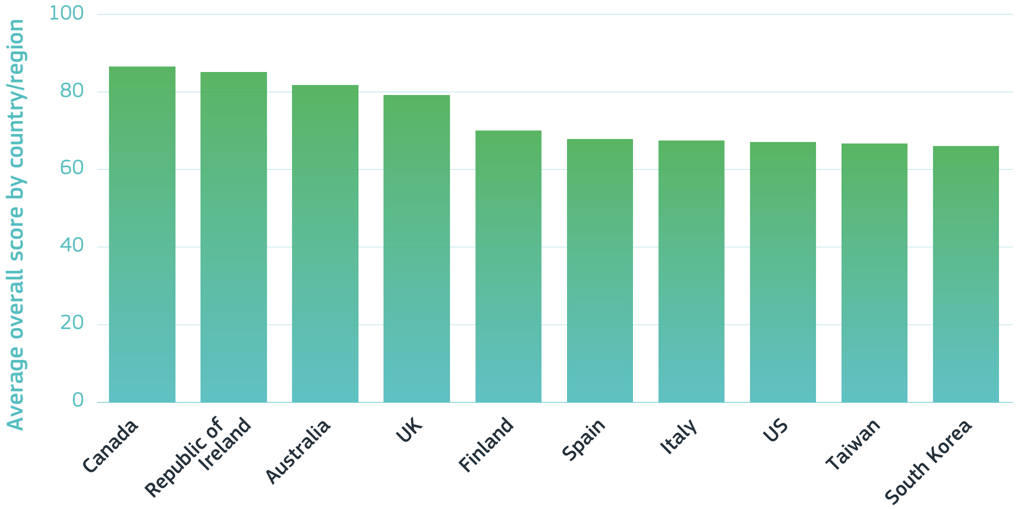
[17] See XXXX

Although interdisciplinarity may be well suited to addressing complex societal challenges while fostering academic excellence and innovation, the development of policies pursuing interdisciplinary careers is hampered by the absence of a clear-cut definition of interdisciplinarity.

Universities play a critical role in providing the necessary knowledge to support social, environmental and economic transitions. Canada, Ireland and Australia are the top countries where universities are leading the way in supporting just and responsible social change. The Times Higher Education University Impact Rankings 2019 is the first attempt to measure global universities' success in delivering the SDGs[18]. It uses calibrated indicators to provide comparisons across three broad areas: research, outreach, and stewardship. Metrics are based on 11 of the 17 UN SDGs.

Results from the first edition reveal a new hierarchy of global institutions compared to research-focused rankings, with New Zealand's Auckland and two Canadian institutions – McMaster University and the University of British Columbia – comprising the top three overall, alongside the UK's University of Manchester. On average, universities in Canada are the highest performing, with Ireland and Australia coming next[19] (Figure 6.1-22). When it comes to overall representation, Japan tops the list of the 76 countries represented with 41 ranked institutions, while the United States has 31 and Russia 30. Twenty-six EU universities feature among the top 100 performing universities, followed by 17 from the UK.

Figure 6.1-22 Average overall score by country/region in the Times Higher Education University Impact Rankings 2019



Source: THE Impact Rankings

Note: Excludes territories with fewer than five institutions in ranking.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter61/figure-61-22.xlsx

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[18] For the ranking, see: https://www.timeshighereducation.com/rankings/impact/2019/overall#!/page/0/length/25/ sort_by/rank/sort_order/asc/cols/undefined; for the methodology, see: https://www.timeshighereducation.com/ world-university-rankings/ methodology-impact-rankings-2019, accessed 4 September 2019.

[19] https://www.timeshighereducation.com/news/university-impact-rankings-2019-canada-leads-way, accessed 16 October 2019.

Figure 6.1-23 Global performance of EU universities against UN SDGs in the Times Higher Education University Impact Rankings 2019

Global performance of EU universities against UN SDGs (Top 100)		
Position in THE ranking	**Name**	**Country**
6	University of Gothenburg	Sweden
7	KTH Royal Institute of Technology	Sweden
9	University of Bologna	Italy
15	University of Helsinki	Finland
16	University of Padua	Italy
16	Vrije Universiteit Amsterdam	The Netherlands
19	Aalto University	Finland
21	University College Cork	Ireland
28	Trinity College Dublin	Ireland
29	Pompeu Fabra University	Spain
34	Autonomous University of Barcelona	Spain
35	University of Limerick	Ireland
43	Aix-Marseille University	France
58	University College Dublin	Ireland
60	University of Hamburg	Germany
65	University of Amsterdam	The Netherlands
75	University of Eastern Finland	Finland
76	Comenius University in Bratislava	Slovakia
78	University of L'Aquila	Italy
83	University of Minho	Portugal
86	Comillas Pontifical University	Spain
92	University of Latvia	Latvia
94	University of Girona	Spain
97	Aalborg University	Denmark
98	Dublin City University	Ireland

Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on Times Higher Education ranking (https://www.timeshighereducation.com/rankings/impact/2019)

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter61/figure-61-23.xlsx

5. Conclusions

The EU's scientific performance is framed by several grave developments, including the UK's exit from the EU, the rise of China, digitalisation, and a new focus on the SDGs. This chapter has shown that the **EU and China are the global leaders in terms of scientific output, while the United States retains the lead in scientific quality**. Notably, output by Chinese researchers has risen exponentially over the last two decades to nearly match the EU.

Within the EU, there is a diversity of research intensities among the Member States and a positive correlation between scientific quality and R&I investments in most countries. Although several EU Member States are making numerous efforts to enhance the effectiveness and performance of their public-sector research systems, further efforts are needed to introduce the necessary policy reforms.

Digitalisation has the potential to increase science productivity, enable novel forms of discovery and enhance reproducibility. It is transforming science. This chapter has illustrated that all areas of research are becoming data-intensive, increasingly relying upon and generating big data.

Last but not least, this chapter points out that science is key in addressing societal challenges. The EU leads high-quality scientific publications in the food/bioeconomy and climate/environment sectors, while China's output is increasing exponentially across sectors and the United States has lost its overall leadership.

These findings trigger certain policy implications. First, to remain a leading global scientific player, the EU and its Member States must **strengthen their efforts to enhance the effectiveness and performance of their public research systems through stronger R&I investments and policy reforms**. Second, to exploit the full potential science digitalisation, policies must be adapted to reinforce researcher's digital skills, promote open science as well as ensure the necessary investments in high-quality data infrastructures. And third, as science is key to addressing societal challenges, the **EU must not only ensure scientific leadership in key areas but must also foster interdisciplinarity research which is necessary to successfully deliver on the SDGs**.

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CHAPTER
6.2

KNOWLEDGE FLOWS

KEY FIGURES

13 %
EU researchers currently employed in another country with large differences between MS

3rd
place for EU in public-private co-publications after USA and South Korea

11 %
of EU patents are filed with foreign co-inventors while USA ranks first with 13 %

60 %
of publications in open access for Croatia, the Netherlands and Luxembourg

What can we learn?

- **Researchers' mobility remains key to knowledge diffusion**, yet stark disparities remain between countries in international and intersectoral mobility patterns in the EU. In general, countries with a higher R&I performance tend to have a greater inflow and outflow of researchers.

- **In terms of public-private co-publications, the EU is catching up with South Korea and the United States**. Private financing of public research is stagnating at the global level. A few large innovative companies are making the most of international and inter-sectoral cooperation.

- **The US and EU are leading in international technological cooperation**, whilst China and Japan are falling behind. In some EU countries, knowledge diffusion and technological transformation continues to be stimulated through foreign direct investment and foreign business research investment.

- **The EU continues to lead on open science policy and international scientific collaboration**, with its EU Framework Programme playing an important role.

What does it mean for policy?

- Divergence between the EU Member States on researcher's mobility patterns calls for a **better understanding of drivers of and barriers to international and intersectoral mobility** as well as the implementation of **policies to foster brain circulation**.

- There is a need to **strengthen the capacity of small firms to engage in R&I collaborations**, including with academia. Despite digitalisation, the geographical proximity of academia is still paramount for innovative activities in industry.

- **International technological cooperation policies need to be put into a wider perspective of changing global approaches** to trade and technological sovereignty.

- While the open access policy in the EU is well advanced, **efforts in implementing its ambitious European open data policy and mainstreaming open science policies and practices must be stepped up**.

Knowledge flows are paramount in creating solutions to the challenges that Europe and the world are currently facing (i.e. from carbon neutrality through sustainable food systems to smart mobility) and in ensuring the competitiveness of European companies. The diffusion of knowledge and technology across companies, regions and countries helps to address differences in productivity growth and the take-up of digital technologies, and is a pre-requisite to cope with the growing complexity of innovation processes. Free circulation of knowledge has been at the heart of the European Research Area initiative.

1. Researchers' mobility remains key to knowledge diffusion, yet stark disparities remain between countries in international and intersectoral mobility patterns in the EU

Researchers – progressively mobile between sectors, disciplines and countries – provide an important channel for knowledge diffusion between research organisations, business, non-profit organisations and public administrations. Mobility enables faster absorption and valorisation of knowledge, fosters lasting cooperation and, at the same time, increases researchers' career prospects. Yet, mobility patterns diverge between Member States in terms of mobile human resources in science and technology (HRST), international mobility of researchers as well as intersectoral mobility[1]. Greater asymmetric mobility of high-skilled professionals and academics may exacerbate existing inequalities, thereby further weakening the economy of post-industrial and/or peripheral regions and countries (Iammarino et al., 2019). It may also undermine efforts to raise the quality and efficiency of all European national R&I systems. This calls for a strengthened role of place-based innovation based on the partnership of enterprises, universities and government, as well as a better understanding of drivers of and barriers to international and intersectoral mobility.

While mobile human resources in science and technology have increased only slightly at the EU level in the last 10 years, they remain a small share of the total R&I workers, with differences between the Member States. Between 2007 and 2018, the mobility of human resources in science and technology (HRST) increased only slightly in the EU to reach 7.8 %, with the majority of countries oscillating between 10 % and 5 % of the mobile HRST workforce. However, the overall trend remains disappointing and shows a very mixed pattern, as can be seen in Figure 6.2-1. A decline in mobility occurs both in northern countries (Denmark, Finland, Sweden, Iceland and Norway), which were characterised by higher mobility, and eastern and southern countries (Spain, Italy, Latvia, Bulgaria and Romania) that showed lower mobility. Conversely, mobility increased most significantly in Lithuania, Luxembourg, Malta, France, Germany and Switzerland.

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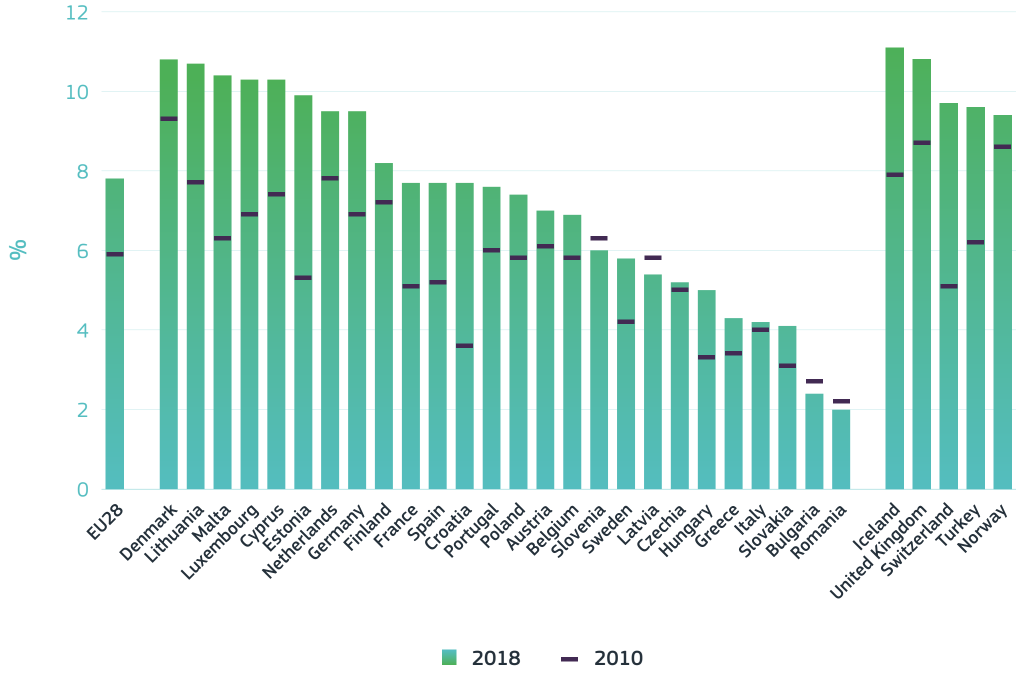
[1] The (physical) mobility of researchers from one sector (academia) to another (e.g. industry).

Figure 6.2-1 Job-to-job mobility(1) of human resources in science and technology (HRST)(2) as % of total HRST, 2010 and 2018



Science, research and innovation performance of the EU 2020

Source: Eurostat (online data code: hrst_fl_mobsex)

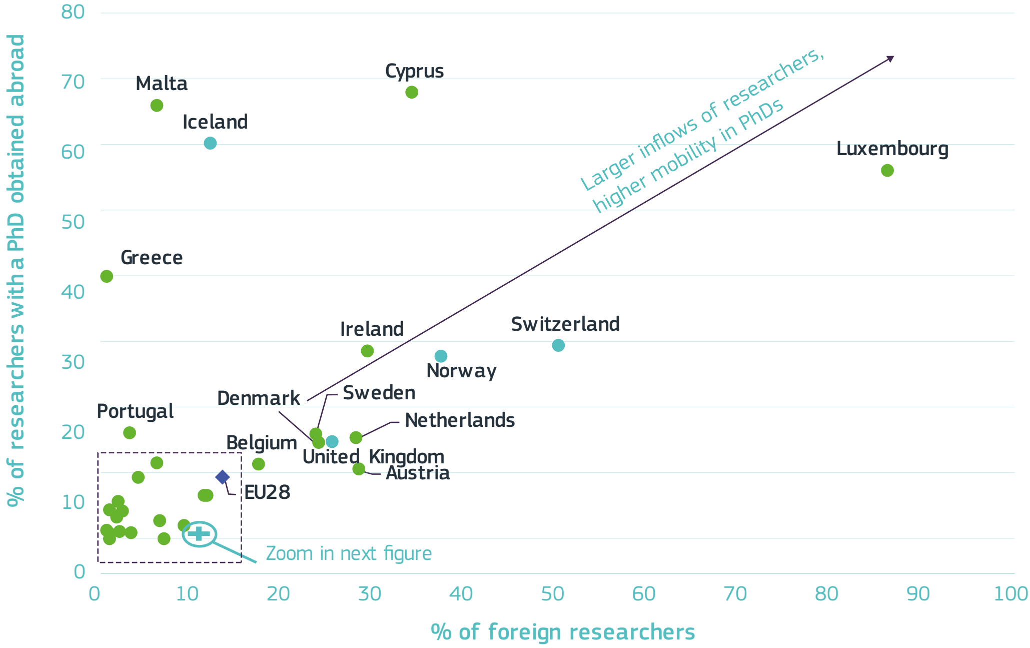
Notes: (1)Shows the movement of individuals between one job and another from one year to the next. It does not include inflows into the labour market from a situation of unemployment or inactivity. (2)HRST: People with tertiary education and/or employed in science and technology.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter62/figure-62-1.xlsx

As regards the international mobility of researchers, there are vast differences between countries with a higher share of inflow of researchers observed in higher-performing countries and an overall higher mobility of researchers from smaller R&I systems. Brain circulation across countries and regions continues to be unbalanced. Malta, Greece and Iceland have the highest share of researchers who have obtained PhDs outside of their country of origin, as well as lower inflows of foreign researchers. At the same time, the Nordic countries, Austria, Switzerland and the UK, have the highest share of inflows of researchers. Luxembourg, Ireland and Cyprus – albeit to a lesser extent – present both high inflows of researchers and high mobility during PhD programmes (Figure 6.2-2).

In general, countries with higher R&I performances tend to have a higher share of researchers who have obtained their PhD in another country and higher researcher inflows. Yet, France, Germany, Spain, Italy and Finland report degrees of mobility that are lower than the EU average. The size of the national research system also has an impact on researchers' mobility. In the case of Cyprus, Malta and Luxembourg, this has resulted in mobility which is higher than EU average, while Germany and France show the opposite trend (Figures 6.2-2 and 6.2-3).

Figure 6.2-2 International mobility of researchers



Science, research and innovation performance of the EU 2020

Source: European Commission, MORE3 study (2016)

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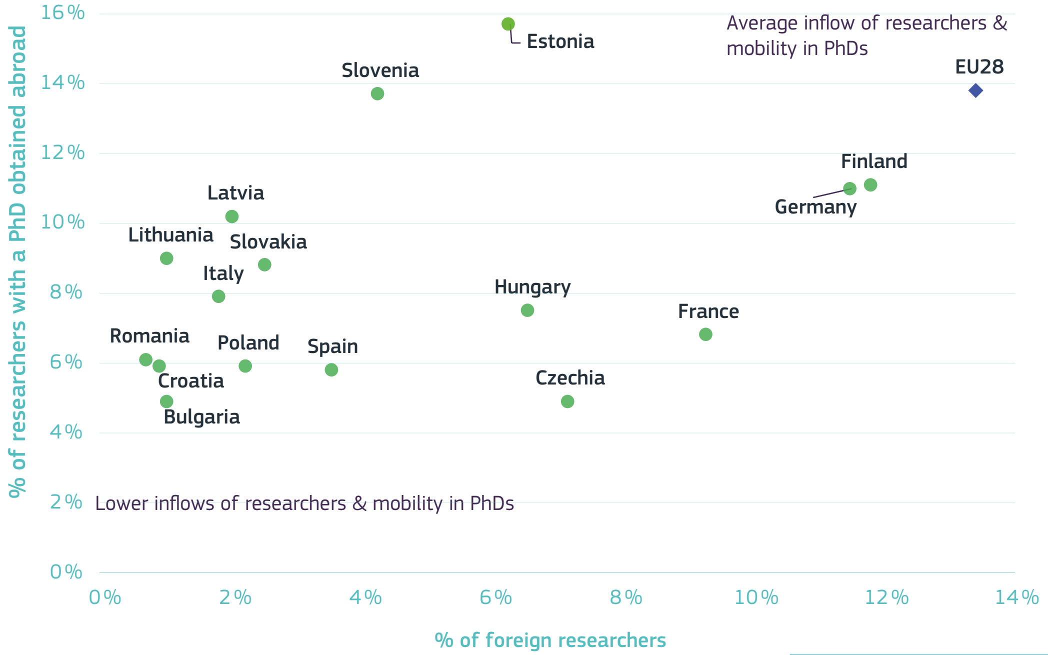
Figure 6.2-3 International mobility of researchers - zoom from the previous figure



Science, research and innovation performance of the EU 2020

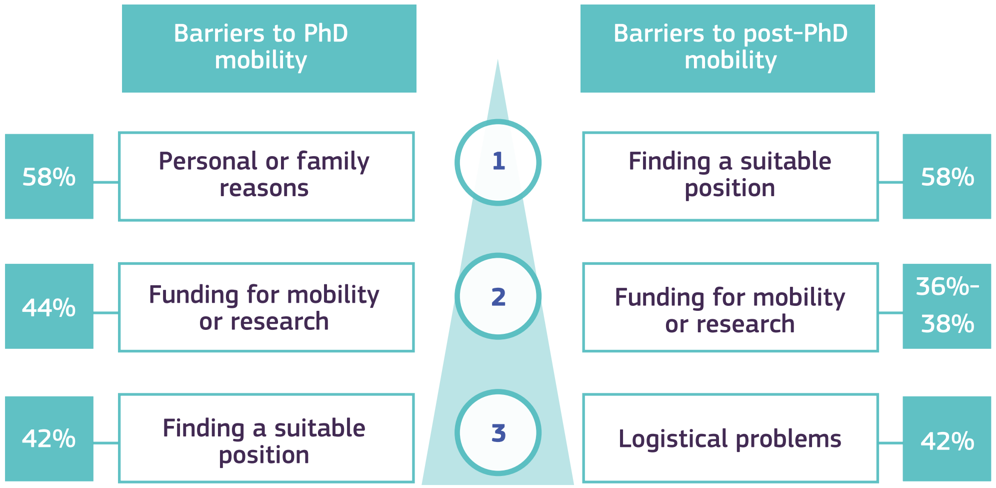
Source: European Commission, MORE3 study (2016)

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter62/figure-62-3.xlsx

The asymmetry in mobility flows, while highly beneficial for hosting countries, may prove detrimental to lower-performing research systems if mobility is one directional (Veugelers, 2017). This calls for an active strategy of enticing international researchers while providing attractive opportunities for returning researchers. There is ample evidence that returning researchers are more productive and maintain collaborative links with their previous institutions (Jonkers and Cruz-Castro, 2013). Wagner et al. (2018) point to the correlation between a country's internationalisation in terms of international co-authorship of scientific articles and the mobility of researchers and the high impact of scientific work.

Dedicated studies[2] report various factors that act as barriers to researchers' international mobility, such as personal or family reasons, funding, and finding a suitable position. The MORE3 study[3] also notes that 16 % of mobile researchers have experienced 'forced mobility' – i.e. the extent to which researchers feel forced to move to another country due to the lack of career options in their home country or the requirements of the system. At the EU level, 16 % of the researchers report international mobility during their PhD and 13 % are currently employed in a country other than their country of citizenship.

Figure 6.2-4 **Top three barriers to mobility of researchers (%)**



Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on MORE3 study
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter62/figure-62-4.xlsx

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[2] The MORE3 study, funded by the EC, collects detailed information and data on the mobility patterns and career paths of EU researchers.

[3] https://cdn1.euraxess.org/sites/default/files/policy_library/final_report_2.pdf

Intersectoral mobility of researchers increased by 6 percentage points compared to 2010. In 2017 51 % of EU researchers worked in the private sector, only 20% of those researchers were female. Intersectoral mobility, understood as the mobility of researchers from academia to industry (and vice versa), is an important mechanism for fostering knowledge transfer and valorisation (in addition to graduates working in industry, collaborative and contract R&D, and (informal) consulting).

Based on Eurostat data[4], 51% of EU researchers worked in the private sector in 2017 (not including not-for-profit organisations) compared to 45% in 2010. In terms of gender, only one fifth (20%) of researchers in the private sector are female (She Figures 2018). More specifically, women researchers were under-represented in 35 of the 39 countries examined by the report. In the majority of European countries, women researchers are more likely to work in the higher education sector or in government. However, between 2008 and 2015, in the business enterprise sector, the annual growth rate among women researchers was higher than that of men (6.5% for women and 5.6% for men in the EU28). The proportion of women researchers was within the 40% to 60% range in only four countries (North Macedonia, Bosnia and Herzegovina, Croatia and Latvia), while all the other countries failed to reach the 40% threshold.

Figure 6.2-5 presents the intersectoral mobility of researchers currently working for a higher education institution and shows the share of researchers moving to another sector at some point in their research careers. The highest levels of mobility are observed in the eastern and southern Member States, with Poland, Bulgaria, Greece, Czechia and Latvia, while the lowest levels of mobility are seen in the northern and western Member States. Therefore, there is a clear pattern of higher intersectoral mobility in the lower-performing countries that may be due to poorer prospects for the exclusively academic path. Interestingly, Norway, Croatia and Romania are all outliers to this trend. More granular data from the MORE3 study show that later-career-stage researchers are more inclined to take positions in government organisations, postdoctoral researchers tend to move to private industry and, in particular, to small and medium-sized enterprises (SMEs) and start-ups, while established researchers are more likely to move to the not-for-profit sector.

The EU Framework Programme's Marie Skłodowska-Curie Actions (MSCA) support intersectoral mobility via co-funding of doctoral programmes and the MSCA Research and Innovation Staff Exchange (RISE), which are based on flexible intersector (within Europe) and international (with third countries) exchanges of highly skilled R&I staff.

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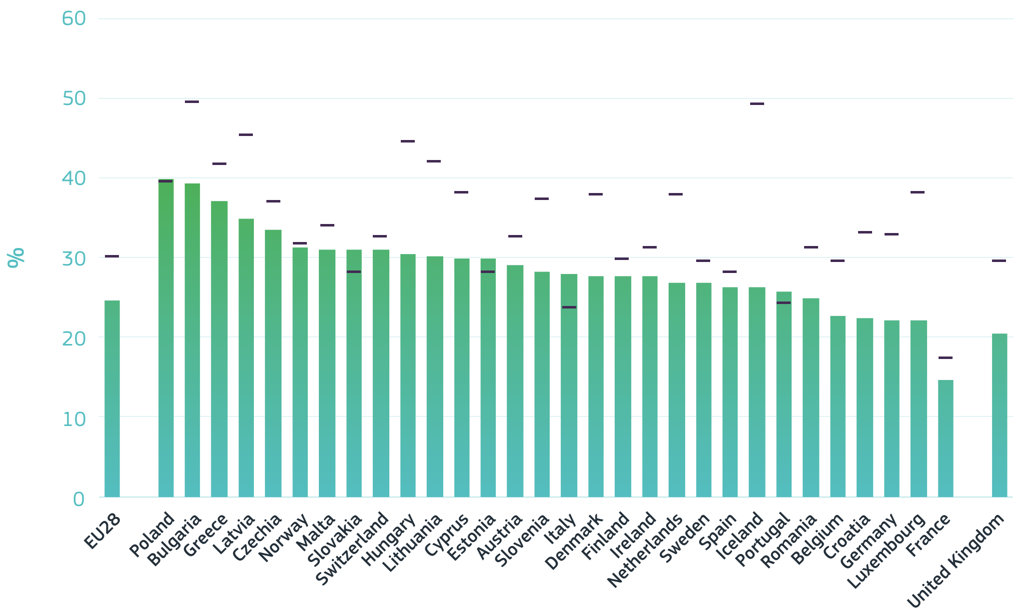
[4] Based on Eurostat, total R&D personnel (researchers) by sectors of performance, occupation and sex (rd_p_persocc); cf. indicator 1.6 in the MORE3 Indicator report on researchers.

Figure 6.2-5 Evolution of intersectoral mobility, 2012 and 2016



Science, research and innovation performance of the EU 2020

Source: European Commission (2017), MORE3 study

Note: Data from MORE3 EU HE survey (2016) and MORE2 EU HE survey (2012).

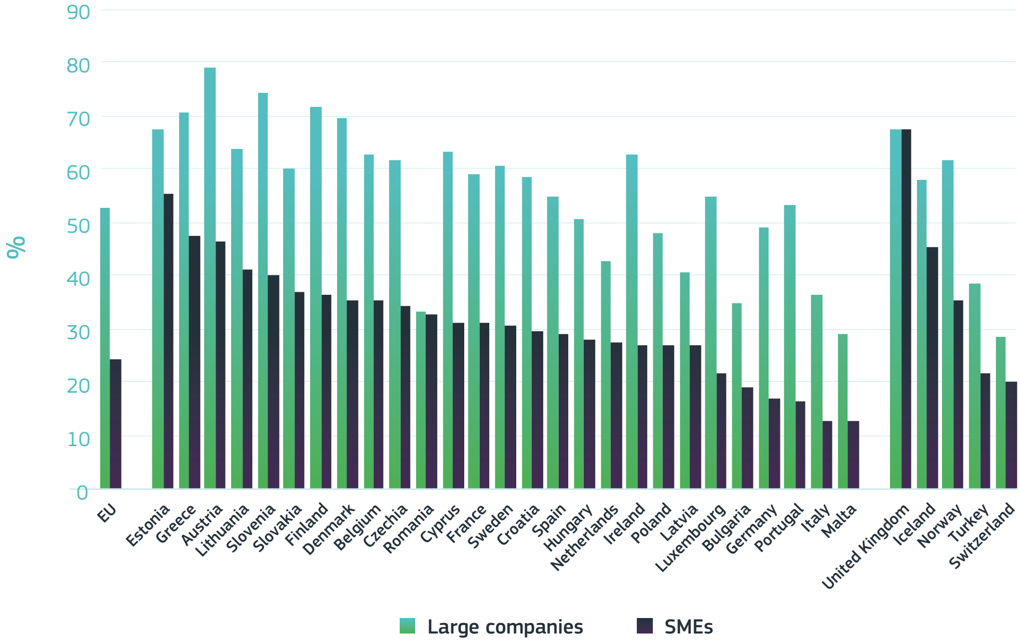
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter62/figure-62-5.xlsx

2. In academia-industry co-publications, the EU is catching up with South Korea and the United States while privately financed public research is stagnating at the global level

Collaboration between enterprises and with public research-performing organisations enables faster knowledge diffusion and valorisation; it is a strong driver of innovation. Companies can benefit from highly qualified human resources, access – often tacit – knowledge and technology, as well as from using research infrastructures. Higher education institutions can gain additional revenue streams from consultancy work, licensing or patenting, equip their researchers with new skills and gain insights into the innovation process (Rybnicek and Königsgruber, 2018). In a globalised world, this collaboration is enabled and further stimulated by digitalisation and is becoming increasingly international. This type of intersectoral, interdisciplinary and international collaboration will be crucial to achieve the UN's Sustainable Development Goals (SDGs)[5], given the need for the participation of private companies, non-profit organisations, citizens and public administrations to achieve systemic transitions for sustainable growth.

All EU countries have a higher share of large innovative companies engaging in cooperation than innovative SMEs, although the differences between the Member States are stark for both types of enterprises. Figure 6.2-6 depicts the degree of business cooperation with other enterprises or organisations divided between large and small and medium-sized enterprises (SMEs). More than half of the innovative large companies engage in cooperation activities with third parties across the EU, compared to one in three innovative SMEs. All countries are characterised by higher shares of collaboration among large enterprises (with the exception of the UK where the shares are almost equal between large companies and SMEs). The highest participation of SMEs is noted in Estonia, Greece and Austria as well as in the UK and Iceland, while Austria, Slovenia, Finland, Denmark, Ireland and Norway display the highest shares of participation by large companies.

Figure 6.2-6 Share of innovative enterprises(1) involved in any type of cooperation (%), 2016



Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on Eurostat (online data code: inn_cis10_coop)

Note: (1)Product- and/or process- innovative enterprises, regardless of organisational or marketing innovation (including enterprises with abandoned/suspended or ongoing innovation activities).

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter62/figure-62-6.xlsx

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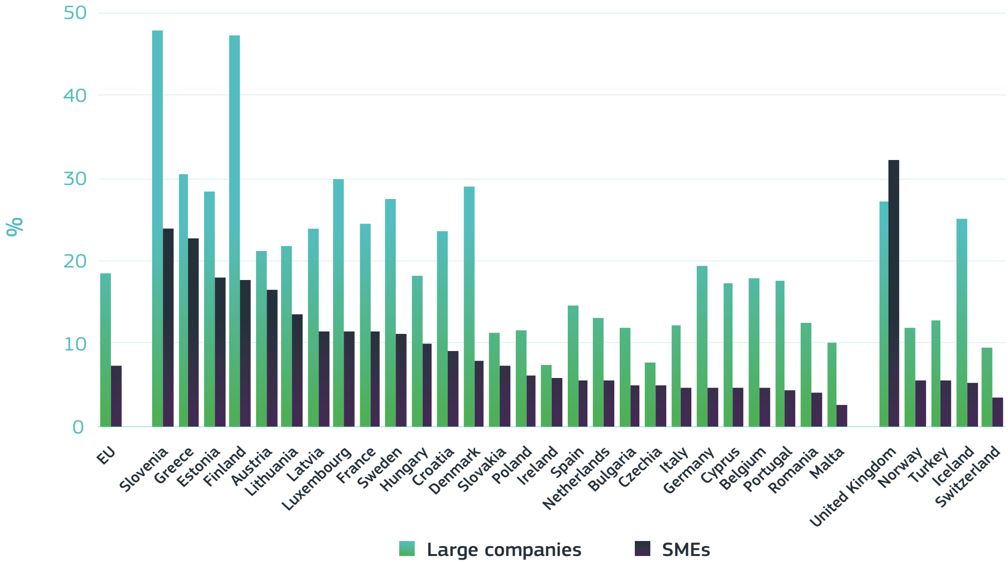
[5] https://sustainabledevelopment.un.org/?menu=1300

When looking at the innovative companies involved in collaboration with competitors or other enterprises in the same economic sector, in all countries except the UK, where the shares are equal, large companies tend to be more collaborative within their economic sectors than SMEs. While in all countries except the UK, where the shares are almost equal at around 30%, large companies tend to be more collaborative within their sectors than SMEs in cooperation that is very often organised vertically around supply chains. However, the differences between countries are very important with almost 50% of large companies in Slovenia and Finland involved in cooperation, compared to only 7% in Czechia and Ireland. SMEs display a much lower tendency to collaborate in their sector, with two-digit figures only in Baltic countries, Greece, Slovenia, Austria, Luxembourg, France and Sweden and less than 5% in Czechia, Italy, Germany, Cyprus, Belgium, Portugal, Romania and Malta (Figure 6.2-7).

In all EU countries, the number of public-private co-publications continues to rise although the EU still lags behind the United States and South Korea. Japan and China occupy the fourth and fifth position, respectively. The EU's good standing has to be considered in the context of important differences between the Member States. A public-private co-publication involves R&D staff in businesses, or other private-sector organisations, co-authoring a research publication with partners in a public-sector organisation. In addition to inter-firm cooperation, this type of collaboration represents a successful channel for knowledge transfer ('knowledge spillover').

Figure 6.2-7 Share of innovative enterprises[(1)] cooperating with competitors or other enterprises in the same sector (%), 2016



Science, research and innovation performance of the EU 2020

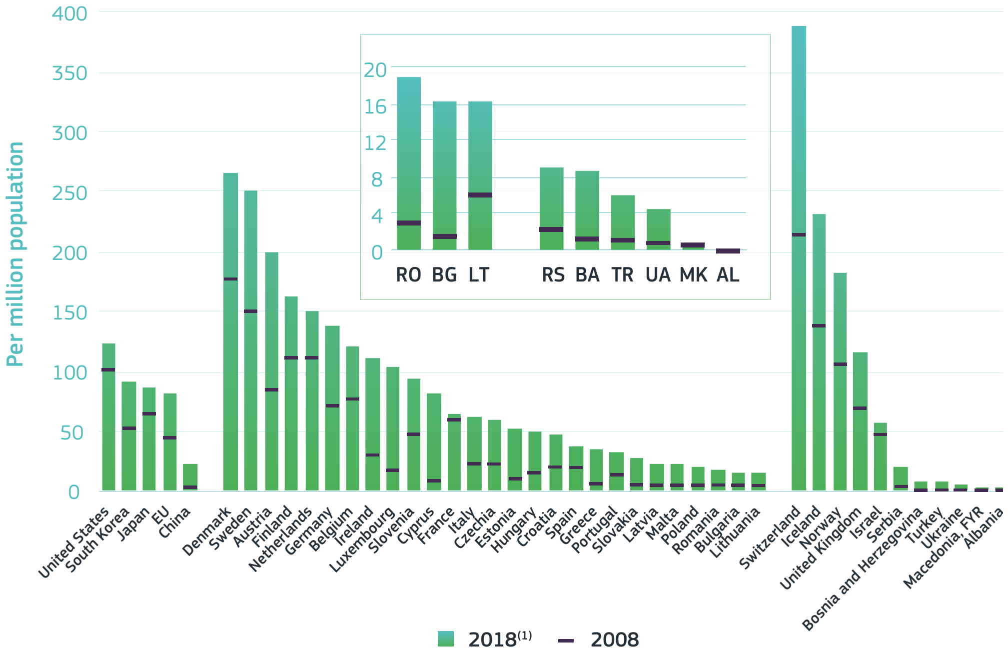
Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on Eurostat (online data code: inn_cis10_coop)

Note: [(1)]Product- and/or process- innovative enterprises, regardless of organisational or marketing innovation (including enterprises with abandoned/suspended or ongoing innovation activities).

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter62/figure-62-7.xlsx

Figure 6.2-8 shows that, while the EU improved its position in terms of growth and overtook Japan between 2008 and 2018 (from 47.1 to 86.4 with Japan rising from 65.7 to 86.1 per million population), the United States and South Korea continued to expand their public-private collaboration (from 105 to 122.7 and from 53.4 to 92.6, respectively). Although China also noted very important growth (from 4 to 22.5), it remains relatively far from other countries. There are major differences within the EU, with Denmark, Sweden and Austria featuring impressive rates of 267.1, 257 and 200.5 per million population. Eastern and southern European countries are mainly situated at the bottom of the ranking with Poland, Romania, Bulgaria and Lithuania registering the lowest rates at 20.9, 19.1, 16.5 and 16.4, respectively. The associated countries are also divided between high rankings, such as Switzerland, Iceland and Norway (388.5, 232.5 and 182.4, respectively) and very low rankings, such as Albania (0.7), North Macedonia (4.3) and Ukraine (5.8). These stark differences may be due to the quality of the science base, as well as the absorptive capacity of the private sector and its R&I intensity.

Figure 6.2-8 Public-private co-authored scientific publications per million population, 2008 and 2018



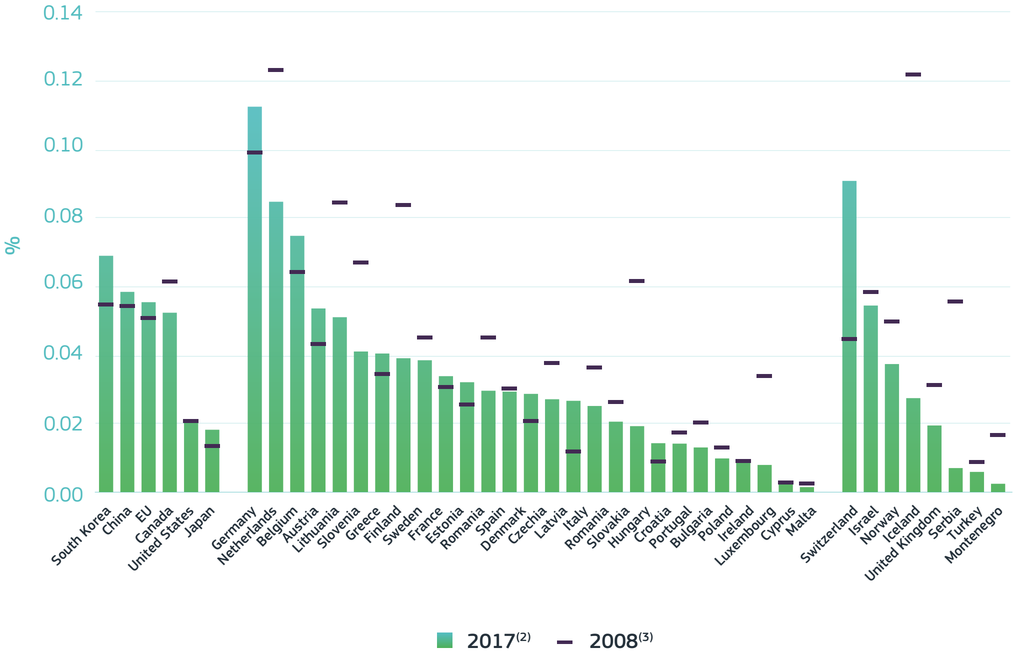
Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on Science-Metrix using data from the Scopus database, Eurostat and World Bank data

Note: (1)US, JP, CN, KR: 2017.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter62/figure-62-8.xlsx

In the EU, public expenditure on R&D financed by business enterprises has risen only slightly with important differences between the Member States, associated countries and third countries. Collaboration between business and academia is often measured by the share of public spending on R&D that is financed by private companies as a percentage of GDP. Figure 6.2-9 shows that while this type of collaboration has risen slightly in the EU over the last 10 years, several countries face a sharp decline in this value. The Netherlands, Finland, Lithuania, Slovenia and Hungary as well as Iceland and Serbia report significant declines, while Germany and Belgium as well as Switzerland and Bosnia and Herzegovina note relatively important increases. Among third countries, South Korea and China are the best performers, putting the EU average into third place while far outperforming both the United States and Japan. Although the international comparison confirms the EU's good position, the stark differences and decline in some Member States call for enhanced linkages between the public and private sectors.

Figure 6.2-9 Public expenditure on R&D financed by business enterprise(1) as % of GDP, 2008 and 2017



Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit
Data: Eurostat (online data code: rd_e_gerdfund), OECD
Notes: (1)Public expenditure on R&D financed by business enterprise does not include financing from abroad. (2)SI, UK, IS, IL: 2016. (3)DK, LU, NL, AT, SE, NO, RS: 2009; EL, ME: 2011. (4)US, JP, CN, CA, BE, FR, NL, RO, SI, IS, RS: breaks in series occur between 2008 and 2017.
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter62/figure-62-9.xlsx

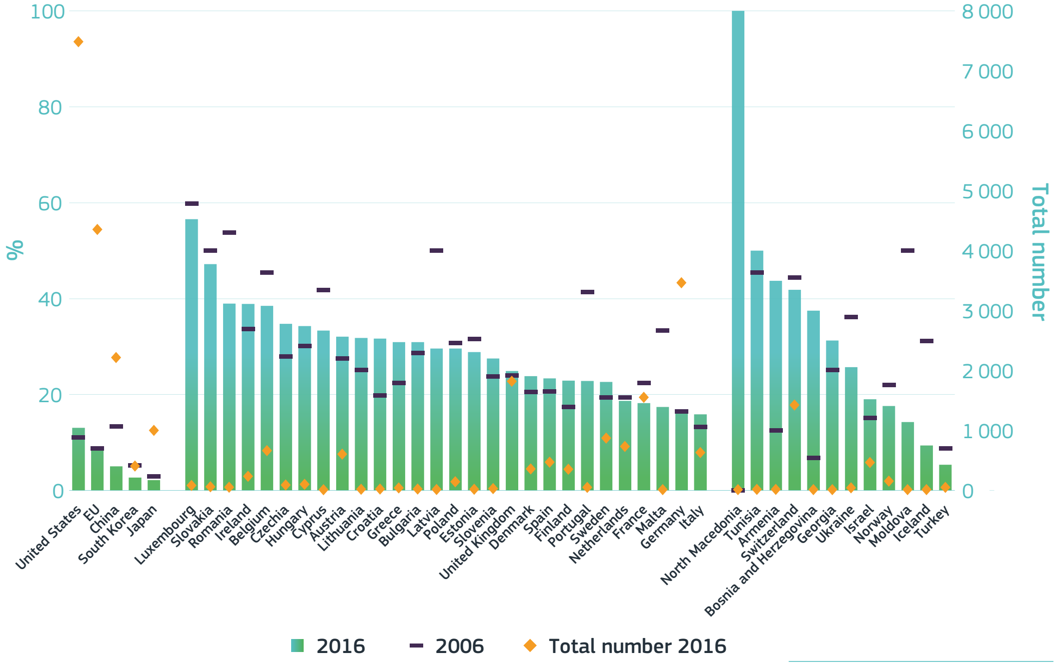
3. The US and EU are leading in international technological cooperation. In some EU countries, foreign direct investment and foreign business research investment still play an important role in knowledge diffusion

In some European Member States, as well as globally in catching-up economies, knowledge diffusion and technological transformation are driven by foreign business research investment and foreign direct investment (FDI).

The intensity of knowledge flows can be proxied by the share of foreign value added in exports (share of foreign value added in exports shows how much of a country's value added of inputs were imported in order to produce intermediate or final goods/services to be exported). A high share of added value shows a high amount of knowledge flowing into a given country. It can also be measured by the share of patents with foreign co-inventors in the total number of patents.

The United States and EU are leading in international technological cooperation, while China and Japan are falling behind, as shown by the share of patents with foreign co-inventors in the total number of patents. Figure 6.2-10 shows European countries' performance including extra and intra-European collaboration, while the EU performance refers only to collaboration with extra European inventors. As for other indicators of collaboration, large variations are observed between the Member States, with Luxembourg and the eastern European countries taking the lead. The smallest shares are reported by larger Member States with a strong industry base, such as Germany, Italy and France, as well as Malta which relies heavily on the - less patent-intensive - information and communications technology industry. For countries associated with the Framework Programme, this variation is important, although given the very low absolute values for many of them, the results are difficult to interpret (e.g. only two patents for North Macedonia).

Figure 6.2-10 Share (%) of PCT[1] patents with foreign co-inventor(s) in total number of patents[2], 2006 and 2016 and total number of patents with foreign co-inventor(s) in 2016



Science, research and innovation performance of the EU 2020

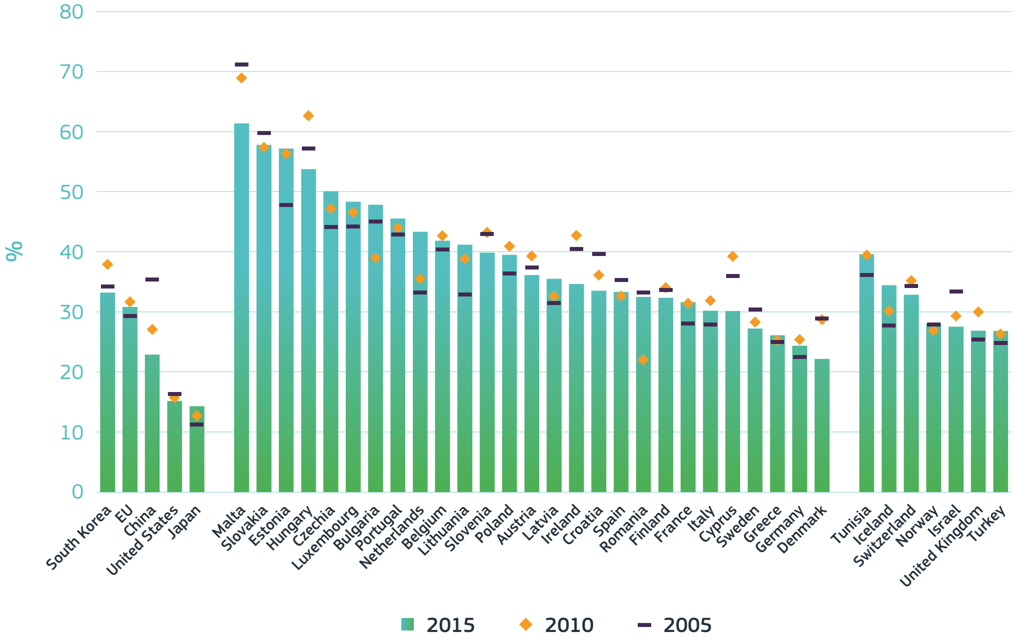
Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on OECD (International co-operation in patents) data

Notes: [1]Patent Cooperation Treaty (PCT) patents, at the international phase designating the European Patent Office. [2]Full counting method used.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter62/figure-62-10.xlsx

The foreign value-added share of gross exports in high-tech and medium-high-tech sectors is still very important in Europe, notably for southern and central eastern European countries. At the global level, it is still significant for South Korea and China, with China having an active policy in place to reduce its needs for foreign-based technology. In the EU, Slovakia, Estonia, Hungary, Czechia and Bulgaria, together with Malta and Luxembourg, exhibit the highest share of foreign value added at between 61 % and 48 %. Germany, Denmark, Greece and Sweden exhibit the lowest share (under 30 %, which is the EU average) in the EU. For Slovakia, Hungary and Czechia – with its strong manufacturing base – FDI is still a major source of external R&D financing. With their open economies, both Malta and Luxembourg attract foreign investment in specific tech sectors. At the global level, South Korea and China's shares are still significant albeit declining (in 2015, 33 % for South Korea and 23 % for China, a fall of 35 % over 10 years). The EU shares remain high at 31 %, while the United States and Japan rank lower (15 % and 14 %, respectively). The gradual decrease for China will most probably continue given the 'Made in China 2025 strategy' (2015) which seeks to steadily reduce the need for foreign-based technology by fostering domestic competitiveness and to further facilitate the access of Chinese companies to international markets (JRC 2019).

Figure 6.2-11 Foreign value added share (%) of gross exports in high-tech and medium-high-tech sectors, 2005, 2010 and 2015



Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on OECD (Trade in Value Added - TiVA) data

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter62/figure-62-11.xlsx

4. The EU continues to lead on open science policy and international scientific collaboration with its Framework Programme playing an important role

Advances in technology make science both an increasingly open and global enterprise. Technological advances, including digital infrastructures, strong open science bottom-up activism as well as funders and institutional policies, drive these changes in science practices.

The progress both in data production and its availability through open data standards is speeding up the research process, addressing the reproducibility crisis (e.g. Ioannidis and Khoury, 2011) **and increasing the efficiency of public investment in research**. Sharing publicly funded scientific results openly democratises the access to science across countries and widens it to companies and citizens. Open access[6] and transdisciplinary data reuse and interoperability (FAIR principles[7])

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[6] Immediate, online, free availability of research outputs without restrictions on use commonly imposed by publisher copyright agreements – OpenAIRE definition.

[7] The FAIR data principles define a minimal set of community-agreed 'aspirational' guidelines for the publication of digital resources such as datasets, code, workflows, and research objects, to achieve a state of 'FAIRness' (Wilkinson et al., 2018).

are vital for addressing the interconnected and pressing socio-economic and environmental challenges we are currently facing (UN SDGs). While open access policies are already mature within existing European, national and institutional policies, advances in data sharing face many obstacles, given the lack of data-sharing valorisation (journal impact factors and citations; Scheliga and Friesike, 2014). Changing the reward and incentive system for researchers is key to ensuring higher take-up and demands the involvement of major stakeholders (higher education institutions, funding agencies, ministries of science and higher education). The Commission has already made provisions for cost eligibility for open science activities in its next Framework Programme.

Several EU Member States and associated countries are ahead of the United States, leading the transition to the open access of research outputs, while China and South Korea are lagging behind. Research stakeholders are pursuing a global process of facilitating the transition to open science, which is most visible in mature policies of open data and open access to scientific publications. As shown in Figure 6.2-12, country performances regarding open access to scientific publications made available through online repositories (green access)[8] is very disparate with lower shares in lower-performing countries, while the performance on open access to scientific publications made available through publishers' websites (gold access)[9] oscillates at around 10% for most countries. The differences in performance in open access through online repositories may be due to differences in the availability of national and university research repositories and the existence of national and institutional policies.

As observed in Figure 6.2-12, Croatia, the Netherlands, Luxembourg, Sweden, Austria, the UK, Norway and Switzerland are ahead of the United States, while China and South Korea are lagging behind.

The European Commission co-designed and co-implemented an ambitious and holistic open science policy[10]. It introduced a strong open access and open data mandate in Horizon 2020 and has included potentially stricter requirements in Horizon Europe (research data open by default, mandatory data management plans, mainstreaming of FAIR principles, strengthened requirements on open access) as well as support for citizen involvement in research (citizen science). The European Commission's approach was endorsed by several funders and institutions and inspired international, national and regional policies (e.g. the Australian Research Data Commons[11] or the African Open Science Platform[12]). The Commission also supports the efforts of cOAlition S[13] to accelerate the full transition to open access to scientific

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[8] Research outputs that are not made open access from the publisher's website but from an open access repository, whether institutional or thematic. This is commonly referred to as green open access.

[9] Research outputs are made openly accessible on the journal website by the publisher. This is commonly referred to as gold open access.

[10] For example, laid out in the Commission Communication: European Cloud Initiative - Building a competitive data and knowledge economy in Europe: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52016DC0178&from=EN and Commission Recommendations on access to and preservation of scientific information: https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32018H0790&from=EN

[11] https://ardc.edu.au/about/

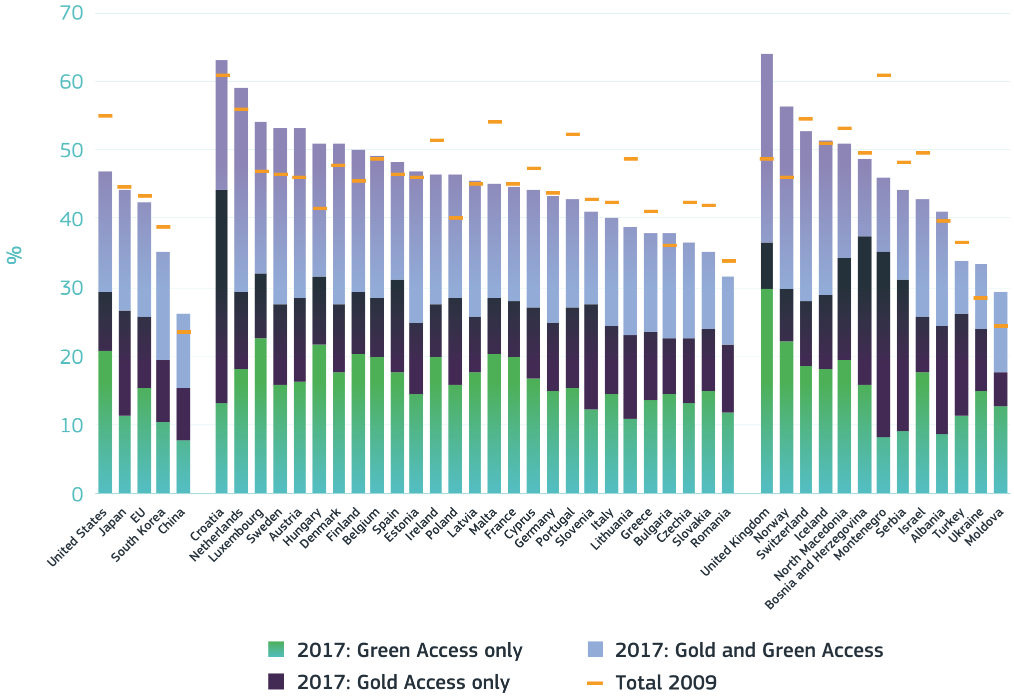
[12] http://africanopenscience.org.za/

[13] https://www.coalition-s.org/

publications. Open science principles and practices are an integral part of EU policy, including the new Directive on open data and the reuse of public-sector information[14], the revised Recommendation on access to and preservation of scientific information[15] and the General Data Protection Regulation[16]. National initiatives in the Netherlands, Finland and Italy show that Member States are taking up these policies and activities. Recent evidence finds that – as a direct result of directional policies by research funders – open science activities have structuring effects on both scientific outputs and knowledge flows, as well as on institutional research structures and practices, increasing research performance and economic performance (Tennant et al., 2016; Fell, 2019).

The work on open science principles and incentives is also spreading globally through the work of the G7, OECD and under the auspices of the Research Data Alliance (RDA)[17].

Figure 6.2-12 **Open access scientific publications(1) with digital object identifier (DOI) as % of total scientific publications with DOI, 2009 and 2017**



Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit
Note: (1)Data produced by Science-Metrix using data from Scopus and 1findr databases. The full counting method was used.
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter62/figure-62-12.xlsx

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[14] https://ec.europa.eu/digital-single-market/en/european-legislation-reuse-public-sector-information

[15] https://ec.europa.eu/digital-single-market/en/news/recommendation-access-and-preservation-scientific-information

[16] https://ec.europa.eu/info/law/law-topic/data-protection/data-protection-eu_en

[17] https://rd-alliance.org/

BOX 6.2-1 The European Open Science Cloud

Most of the underlying data of scientific work is not published and therefore not accessible to the research community or the public. If relevant data was findable, accessible and interoperable for scientists, these combinations would lead to (unforeseen) reuse and to faster developments in science. This is the aim of the European Open Science Cloud (EOSC).

The EOSC will enable data sharing and offer Europe a trusted and open environment for the scientific community, provide seamless access to data and interoperable services addressing the whole research data life cycle. The development of the EOSC achieves EU policy objectives such as Open Science, FAIR data implementation and the Digital Single Market.

The EOSC will be a virtual commons (resources accessible to all researchers) **where science producers and science consumers come together for greater insights, new ideas and more innovation**. By federating research data and services, the EOSC adds value. The EOSC uses information technologies to change the way scientists conduct research, and how collective scientific knowledge is created across disciplines and borders. The EOSC will evolve into a system that is flexible by design and can adapt to the changing landscape and technological advances.

A minimal viable EOSC environment is planned for the end of 2020, including agreed rules of participation, supporting services for the EOSC federation, an initial set of data services for researchers, a persistent identifier policy, metrics for FAIR data and certified services, and strategic orientations for financing models, the legal set-up and governance of the EOSC after 2020.

The resulting EOSC environment will then be progressively extended and scaled up while building on the following **common values**:

- Focus on research and innovation needs
- Community-driven
- Inclusive and respectful of diversity
- Accessible to all from large equipment, large computers and 'big data' to 'small data' and long-tail research
- Open by default – closed where necessary
- Hands-on and participatory
- Transparent and trustworthy.

Two thirds of researchers in the EU have collaborated or worked in more than one discipline, which is key to addressing the economic, social and environmental transitions required for a more sustainable Europe. Interdisciplinary collaboration, understood as collaboration between researchers working in different disciplines, is key to fostering knowledge and technology circulation across Europe. In addition, interdisciplinary research is needed to address the SDGs, enhance the ability to understand the complex challenges the world currently faces (Eagan, Cook and Joeres, 2002) as well as bring diverse perspectives together to find solutions and establish and exploit synergies.

The MORE3 survey shows that 73.5% of researchers have collaborated with researchers in other fields. In the EU, 60% of researchers collaborate with other researchers working in other disciplines but within the same institute, and 57% in other universities or research institutes. However, only 31% have collaborated with the non-academic sector. This limited knowledge flow outside of academia is one of the key issues to tackle in order to strengthen the valorisation of knowledge in Europe. More efforts are needed to embed a 'valorisation culture' in publicly funded research. The same study shows that 34% of researchers working in the EU have switched to another (sub-)field of science during their research career. Overall, researchers tend to have a positive view on this type of mobility in spite of the debates on the caveats of interdisciplinarity – e.g. difficulties in publishing articles based on interdisciplinary approaches, limitations over the peer-review process and scientific standards.

Figure 6.2-13 Share of researchers who have collaborated with or worked in more than one field in their current position

	Of all researchers (n=9,412)			
	EU28 total	**Per career stage**	**Per FOS**	**Per gender**
2016	73.5%	R1: 66.2%	NAT: 74.4%	F: 74.0%
		R2: 73.7%	ENG: 75.5%	M: 73.2%
		R3: 73.2%	MED: 76.2%	
		R4: 77.5%	AGR: 84.7%	
			SOC: 67.7%	
			HUM: 71.6%	

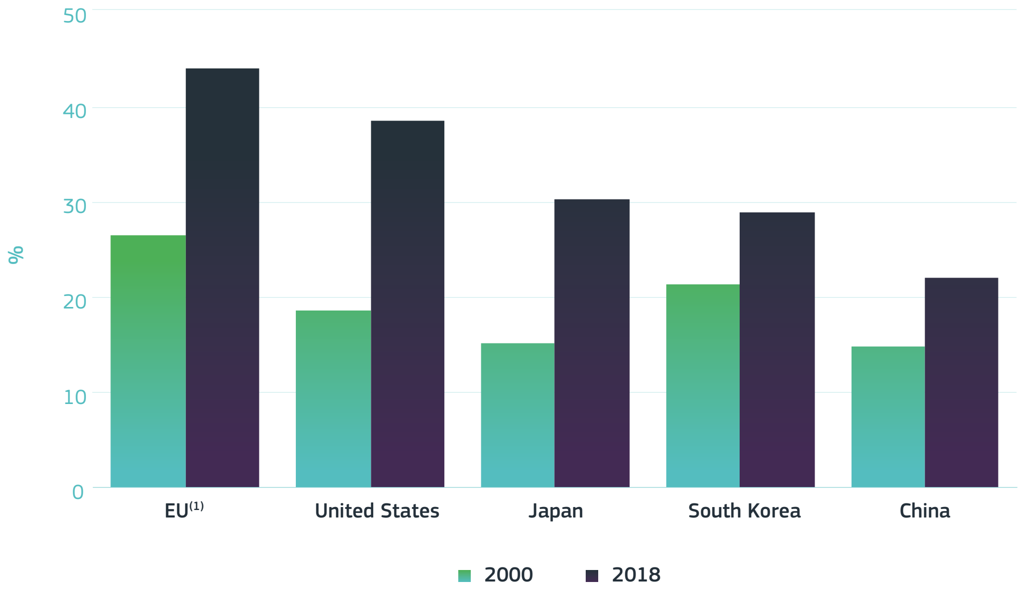
Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on MORE3 study

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter62/figure-62-13.xlsx

The EU has secured its leading position in international scientific collaboration, which has seen sharp increases both in the EU and in the United States and Japan. The EU28's share of international scientific co-publication almost doubled between 2000 and 2018 (from 24.6% to 43.7%, including intra-EU collaborations), with an even more significant rate of growth observed in the United States (from 18.7% to 38.3%) and Japan (from 15% to 30.3%). South Korea and China also increased their shares of international co-publications (from 21.2% to 28.9% and 14.8% to 22%, respectively). This trend leads to improved scientific quality since scientists achieve greater impact from their international collaborations. This is actively supported at the European level through specific Framework Programme funding and initiatives such as Marie-Curie Skłodowska Actions (MSCA). However, granular data on EU Member State collaboration shows that several eastern European countries (Romania, Bulgaria, Poland) still report lower levels of international exposure and collaboration (Figure 6.2-14).

Figure 6.2-14 International scientific co-publications as % of total scientific publications, 2000 and 2018[(1)]



Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit

Data: Science-Metrix based on Scopus database

Note: [(1)]EU average includes intra-EU collaborations.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter62/figure-62-14.xlsx

Horizon 2020 demonstrates broad international outreach attracting talent from around the world. Countries with strong R&I performances, such as Switzerland, Norway and Israel, are the most active associated countries in Horizon 2020, while almost one third of the participation from non-associated third countries comes from the United States. As per Figure 6.2-15, Switzerland is the most active associated country in terms of participation, with 2 808 – i.e. A share of 37 % of all associated countries. Norway, Israel and Turkey account for 23 %, 17 % and 9 %, respectively. The associated countries with the lowest participation (less than 1 % participation from associated countries) are Tunisia, Moldova, Georgia, Montenegro, Albania, Armenia and the Faroe Islands. Moreover, the networked analysis shows that Switzerland occupies a very central position in the collaboration network amongst participants in Horizon 2020, next to other EU28 countries such as Sweden, Greece and Austria[18].

With applicants from 163 non-associated third countries to date, Horizon 2020 demonstrates a broad international outreach. Currently, with over 1 100 participations, the US accounts for about 30 % of the participation from non-associated third countries (Figure 6.2-16). The United States

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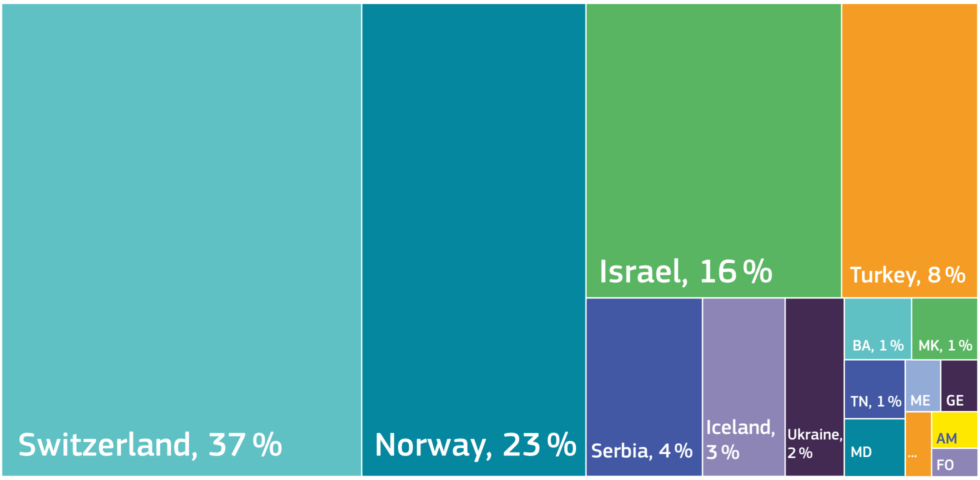
[18] https://ec.europa.eu/info/sites/info/files/research_and_innovation/knowledge_publications_tools_and_data/documents/h2020_monitoring_flash_022019.pdf

is followed by China (9 % of participations from non-associated third countries), Canada (6 %), Australia (5 %), South Africa (4 %) and Brazil (4 %). Overall, the top-20 participant non-associated third countries gather 81 % of these participations, with a lower level of participation from many developing economies.

Figure 6.2-15 Share of participations from associated countries in Horizon 2020 (% of all associated countries' participation)

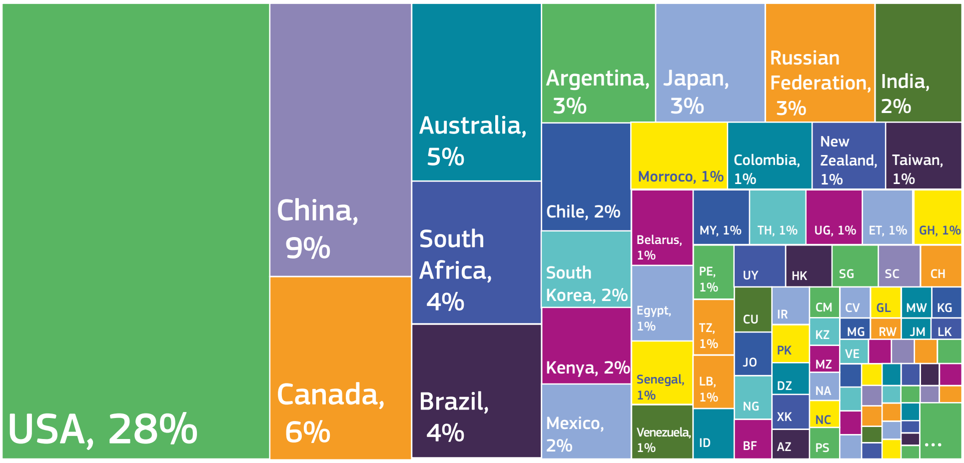


Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on CORDA data

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter62/figure-62-15.xlsx

Figure 6.2-16 Share of participations from non-associated third countries in Horizon 2020



Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on CORDA data

Note: Cut - off date - January 2020.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter62/figure-62-16.xlsx

Most of the collaborations are with countries with advanced R&I capabilities, in particular through researcher mobility schemes such as MSCA but also through specific projects and multilateral initiatives to support sustainable development and address global societal challenges. Countries with strong R&I performances, such as Switzerland, Norway and Israel, are the most active associated countries, while almost one third of participations from non-associated third countries come from the United States (partly due to its significant participation in MSCA schemes).

Interestingly, an analysis of the EU's R&I Framework Programme participation patterns shows specific preferences for cross-country collaborations. Geographical and cultural proximities among participants seem to play an important role in shaping the structure of collaboration networks, at least in the case of the EU Framework Programme (Balland et al., 2019).

5. Conclusions

Although researchers' mobility remains key to knowledge diffusion, stark disparities remain between countries in international and intersectoral mobility patterns in the EU. In general, countries with a higher R&I performance tend to have higher inflows and outflows of researchers and the size of the R&I system also plays an important role. Those divergences call for a better understanding of drivers of and barriers to international and intersectoral mobility as well as the implementation of policies to foster brain circulation.

The EU is catching up with South Korea and the United States in terms of public-private co-publications. However, private financing of public research remains stagnated at the global level, with large disparities between EU countries. Collaboration patterns show that a few large innovative companies are making the most of international and intersectoral cooperation. In order to raise the competitiveness of European SMEs, the capacity of small firms must be strengthened to enable them to engage in R&I collaborations. As the geographical proximity of academia is still paramount for industry's innovative activities – in spite of the importance of digitalisation policies – the interaction between industry and academia must continue to be facilitated and strengthened.

The United States and the EU are leading in international technological cooperation, while China and Japan have taken a step back. In some EU countries, as well as in globally catching-up economies, knowledge diffusion and technological transformation continues to be stimulated through foreign direct investment and foreign business research investment. International technological cooperation data points to an active policy in China which is trying to reduce its need for foreign-based technology through domestic competitiveness and to further facilitate Chinese companies' access to international markets. This places international technological cooperation policies in a wider perspective of changing global approaches to trade and technological sovereignty.

The EU continues to lead in open science policy. Among the global trend for intensification of international scientific collaboration, the EU has secured its leading position with its Framework Programme playing an important role by involving participants from third countries. While the EU's open access policy is well advanced, there is a need to step up efforts to implement Europe's ambitious open and FAIR data policy.

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CHAPTER
6.3

INNOVATION OUTPUT AND KNOWLEDGE VALORISATION[1]

KEY FIGURES

48 %
of EU companies were considered innovative

1 in 5
worldwide PCT patent applications come from the EU

9x better
performance on average for the top 10 EU economies in PCT patent applications

101.2
EU Innovation Output Indicator, below Japan and the United States

[1] Valorisation in the context of the EU Framework Programmes is referred to as exploitation.

What can we learn?

- The **EU is falling short in the Innovation Output Indicator compared to Japan and the United States**. **The economic impacts** seen as an outcome of innovation are not only related to innovation capacity but also **to the structure of the economy**, which explains the differences between countries.
- **Japan and China have increased** their share in PCT patent applications while **EU and US shares have dropped significantly** since 2000. In relative terms, the **EU lags behind South Korea, Japan and the United States**.
- **In PCT patent applications, there is still an innovation divide in the EU**, with north-western Europe performing well and south-eastern Europe performing poorly.
- The **EU is leading technological progress in the fields of energy, climate and environment and food and bioeconomy**.
- Nearly **half of the enterprises in the EU were considered innovative**, with higher shares for **product and/or process innovation**.

What does it mean for policy?

- The EU needs to **support European IP policy and culture, foster science-industry interaction** and **engage citizens, local communities and policymakers** in a **knowledge-valorisation policy** for societal, environmental and economic impact. In addition to improving innovation systems, the EU must **encourage structural reforms** that **upgrade Member States' technology profiles**.
- To tackle the current innovation divide, the EU needs to **support poorly performing countries** to improve their innovation systems, **facilitate knowledge circulation** among EU countries and **incentivise the creation** of innovation-intensive sectors in the economy.

1. Innovation output in Europe is lagging

According to the European Commission's Innovation Output Indicator (IOI), the EU lags behind Japan and the United States in terms of innovation output, mainly due to its poor performance in PCT patent applications, with very slow progress in recent years[2]. The composite indicator aggregates four components to measure innovation output (patents, employment in knowledge-intensive activities, trade in knowledge-based goods and services, and innovativeness of high-growth enterprises). These figures differ from the latest results from the European Innovation Scoreboard (EIS) in which the EU surpasses the United States for the first time. However, in addition to these four components, the EIS includes several other dimensions such as investments and framework conditions. Even though the EU is not performing well as a whole, some EU Member States, such as Sweden, the Netherlands and Denmark, show identical or better performances than international competitors in several innovation indexes. For instance, the top 10 in the latest Global Innovation Index[3] includes 5 EU Member States, with Sweden as the best EU performer. In the latest EIS, Sweden, followed by Finland, Denmark and the Netherlands, are the innovation leaders.

Within the EU, Ireland is the best performer, followed by Sweden, Luxembourg and Hungary. Conversely, with its performance worsening, Greece is at the bottom end of the Index, followed by Lithuania and Romania. To some extent, the Innovation Output Indicator confirms the innovation divide between north-western and south-eastern Europe (Figure 6.3-1). However, countries such as Hungary, Malta and Czechia, which show high shares of both medium and high-tech products in total exports and employment in fast-growing enterprises in innovative sectors, are remarkable exceptions. In terms of progress, innovation output has improved in most EU countries. Countries such as Malta and Portugal have improved considerably over time as a result of significant increases in patent applications and innovative high-growth enterprises, while innovation output has declined substantially in Greece due to deterioration in knowledge-intensive services exports and the innovativeness of high-growth enterprises. The mixed progress across the EU indicates that the innovation divide is not diminishing, even though the performance of some innovation leaders, such has Finland, Germany and Denmark, has also dropped.

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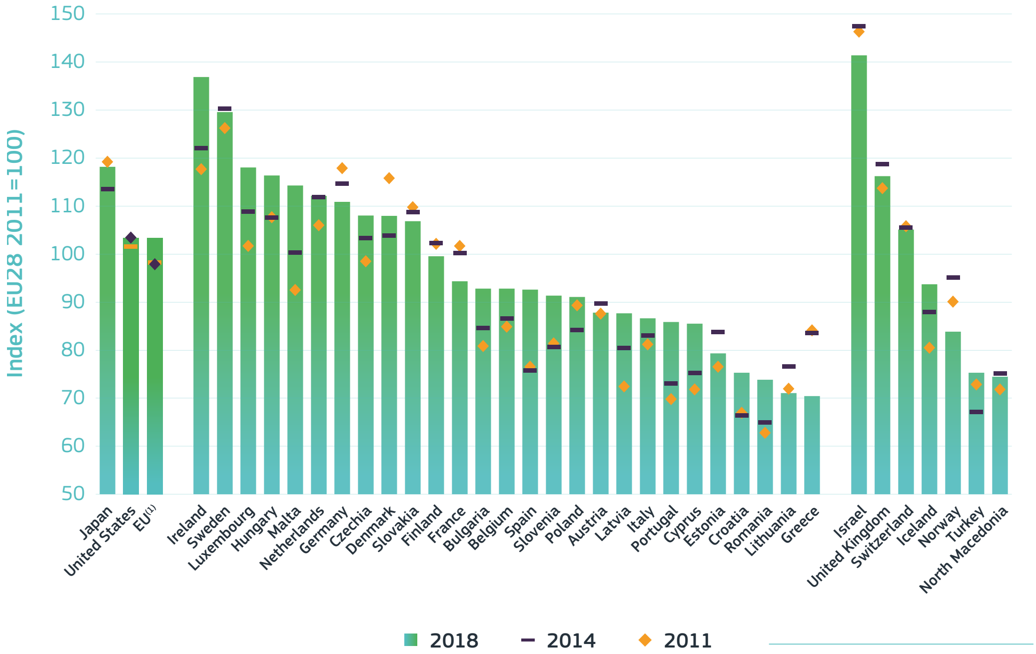
[2] For the last release of the Innovation Output Indicator see Vertesy and Damioli (2020).

[3] Cornell University, INSEAD, and WIPO (2019); The Global Innovation Index 2019.

Figure 6.3-1 Innovation output indicator (EU28, 2011 = 100), 2011, 2014 and 2018



Source: European Commission, DG Joint Research Centre (Vértesy and Damioli, 2020)

Note: (1)EU: Two sets of values are available: values for worldwide comparison and values for European comparison. The values for worldwide comparison are shown on the graph. The value for European comparison for 2018 is 101.7.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter63/figure-63-1.xlsx

2. Intellectual property in Europe: a mixed picture

To a certain extent, technological innovation resulting from investment in R&I is reflected in the patenting activities of R&I actors. In 2017, the EU accounted for 20% of worldwide PCT[4] patent applications, a decline from its 30% share in 2000 (Figure 6.3-2). While the share of PCT patent applications has been growing quickly in East Asian countries, mainly in Japan and China, in Western countries, such as the United States, the EU and the United Kingdom, the share has been declining. In 2016, China, in particular, became a powerhouse in international patent applications, having caught up quickly by growing at an annual rate of roughly 22% between 2000 and 2017. Even though the United States remains the world leader in PCT patent applications, its share declined significantly from 40% in 2000 to 23.5% in 2017. When comparing these figures with research production in terms of scientific publications, it can be concluded that the EU is not capable of capturing the full value of its excellent science.

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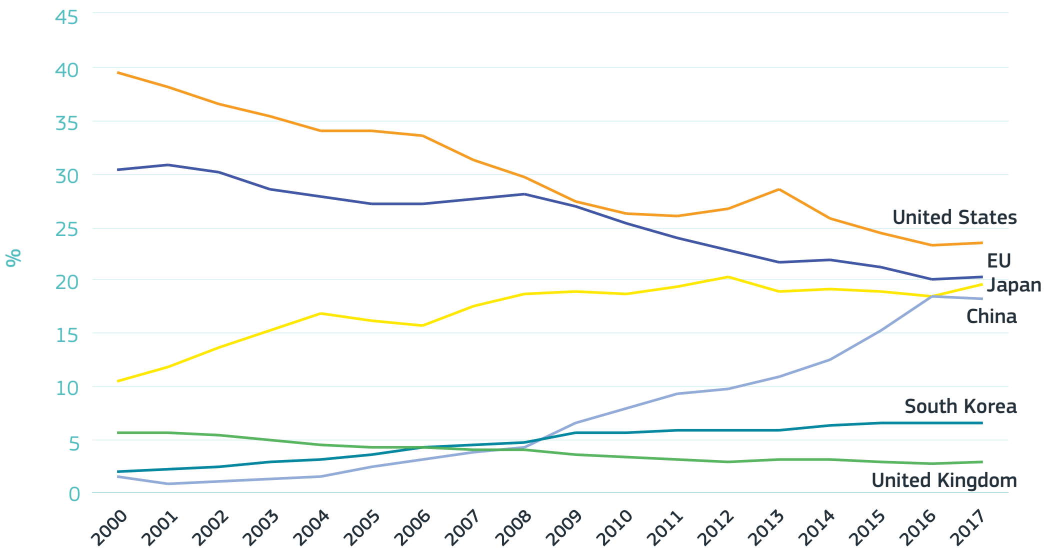
[4] Patent Cooperation Treaty.

Figure 6.3-2 World shares (%) of PCT patent applications[1], 2000-2017



Science, research and innovation performance of the EU 2020

Source: OECD (Patents by technology)

Note: [1]Patent applications filed under the PCT, at international phase, designating the European Patent Office (EPO). Patent counts are based on the priority date, the inventor's country of residence and fractional counts.

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In per capita terms, however, China's performance is well below that of the United States, the EU and advanced Asian economies. When normalised by population, PCT patent applications in Japan and South Korea improved remarkably over time (Figure 6.3-3). In 2000, while South Korea was behind the United States, Europe and Canada, in 2017 it was well ahead of those countries. In recent years, the EU's performance has been quite stable, with an increasing gap with Japan, South Korea and the United States, but remaining ahead of Canada.

Within the EU, performances vary considerably across Member States, reinforcing the persistent innovation divide. While north and western Europe mainly perform well, eastern and southern Europe's performance is poor. Nonetheless, it is important to highlight that several factors explain the differences in performance, i.e. patenting is linked, among other factors, to the share of manufacturing in value added (as manufacturing companies tend to patent more than service-sector companies[5]), to the high-tech orientation of the manufacturing sector, to the share of ICT and research-related services as against other types of services, to the enterprises' size distribution in a country (as larger enterprises tend to have higher patent propensity), and to the location of company's headquarters, as patenting tends to be carried out in countries with legislation which favours patent activity. Between 2000 and 2017, with the exception of Croatia and Finland, all the other EU countries have seen their performance improving. On the negative side, Finland stands out as its performance

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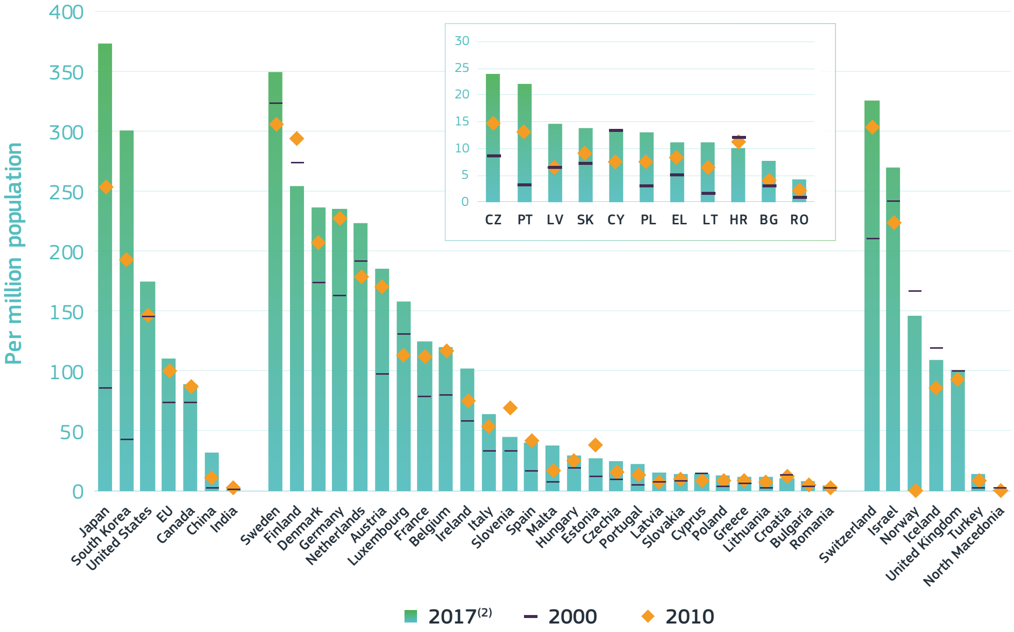
[5] EPO and EIPO (2019), IPR-intensive industries and economic performance in the European Union.

has worsened substantially. This might be associated with the weak performance of Nokia which is the most important patent applicant[6] in the country. On the other hand, countries like Portugal, Lithuania and Malta have seen two-digit compound growth rates over the same period. As possible explanations, in the case of Portugal, incentives for patent applications, such as the creation of a patent box in 2014, seemed to have boosted patent applications, mainly from the higher education sector[7,8]. Similarly, in the case of Lithuania, several measures to promote the protection of IP rights seemed to have boosted patent applications[9]. Other countries, such as Ireland and Austria, also show significant improvements.

Figure 6.3-3 **PCT patent applications⁽¹⁾ per million population, 2000, 2010 and 2017**



Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on OECD (Patents by technology), Eurostat and World Bank data

Notes: (1)Patent applications filed under the PCT, at the international phase, designating the European Patent Office (EPO). Patent counts are based on the priority date, the inventor's country of residence and fractional counts. (2)MK: 2016.

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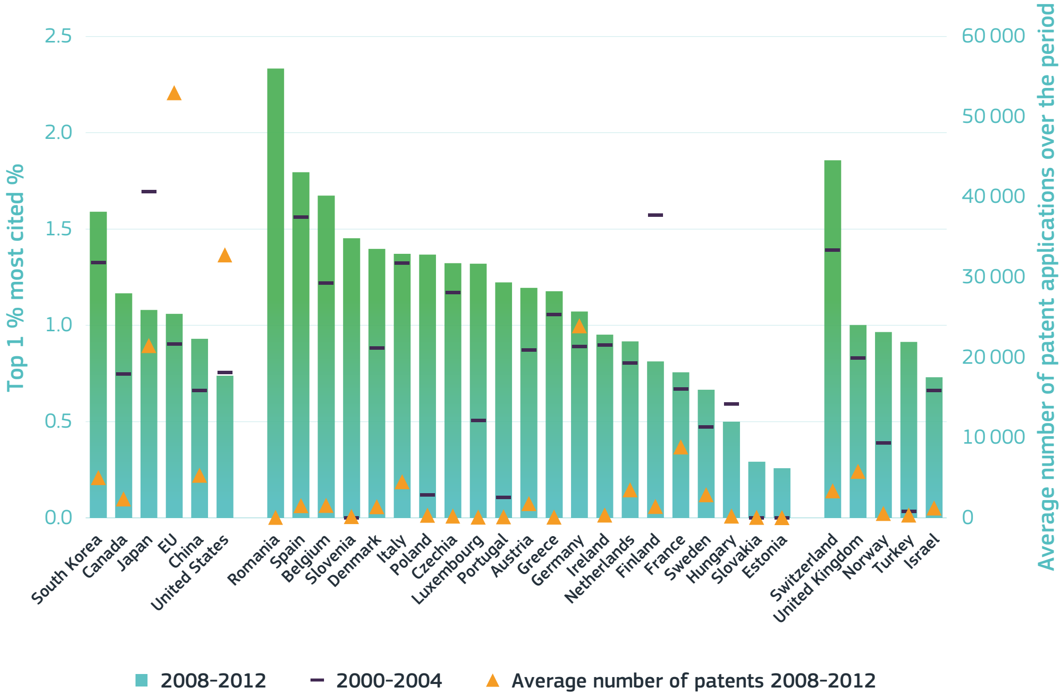
[6] ETLA - Research Institute of the Finnish Economy (2010), Nokia and Finland in a Sea of Change.

[7] European Commission (2015), RIO country report 2015: Portugal.

[8] European Commission (2014), a Study on R&D Tax Incentives.

[9] European Commission (2015), RIO country report 2015: Lithuania.

Figure 6.3-4 Top 1% most-cited patent applications filed with the EPO, average over 2000-2004 and 2008-2012, and average number of patent applications over 2008-2012



Science, research and innovation performance of the EU 2020

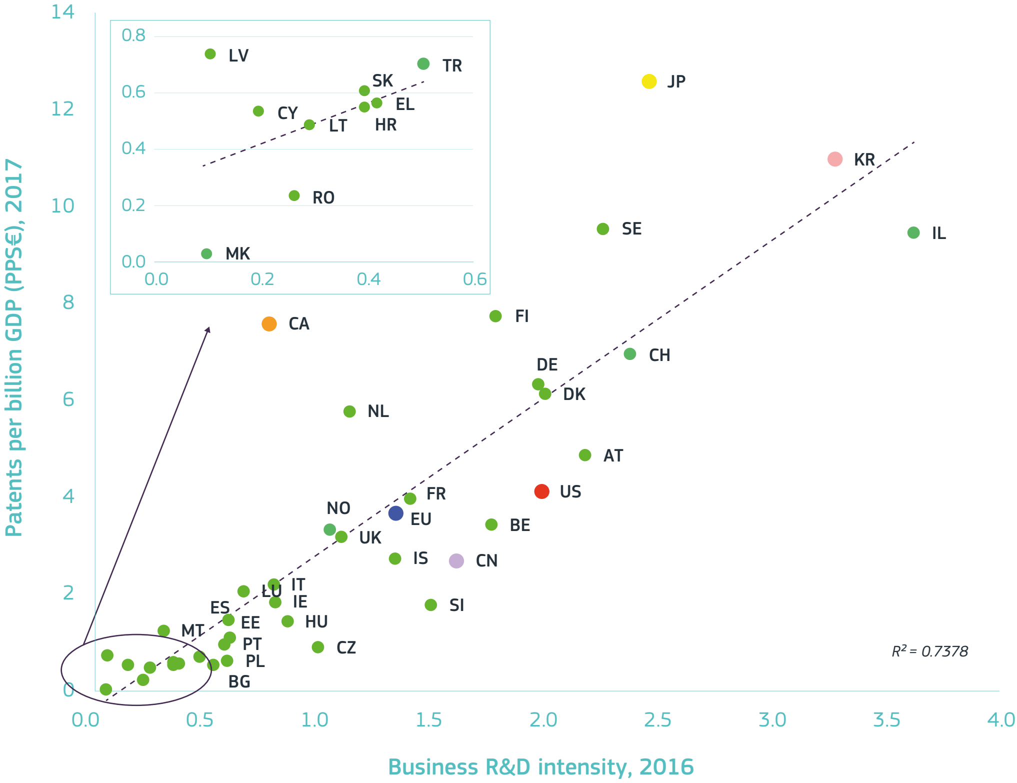
Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit

Notes: Data produced by Science-Metrix using data from EPO Patstat Spring 2019 database. A minimum of 30 patent applications for a given country and period are required to calculate a score. Fractional counting method was used. Five-year window used in the calculation. Data is calculated with five-year average to reduce volatility.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter63/figure-63-4.xlsx

As a measure of patent quality, the top 1% most-cited patent applications filed with the EPO shows South Korea, followed by Canada and Japan, ahead of the EU. On the other hand, the EU is ahead of China and the United States. Japan, which was the best performer at the beginning of the century, has declined significantly (Figure 6.3-4). Within the EU, Romania tops the ranking, followed by Spain and Belgium. At the bottom, Estonia, Slovakia and Hungary are the worst performers. Over time, only Finland has shown a decline, which is probably due to over reliance on Nokia, as mentioned above. Romania, Slovenia, Poland and Portugal have made the most improvements since the period 2000-2004. The results show a lack of innovation divide, with modest innovators such as Romania or Poland performing well, and lead innovators such has Sweden and Finland performing poorly. However, the absolute number of patents can have an impact on the results, with smaller amounts inflating the indicator and contributing to more volatility. For instance, during the period 2000-2004, Romania had fewer than 30 patents, which is the minimum necessary to calculate the score.

Figure 6.3-5 Patent applications[(1)] per billion GDP (PPS€), 2017[(2)] and business R&D intensity, 2016[(3)]



Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on OECD (Patents by technology), Eurostat and Unesco data

Notes: [(1)]Patent applications filed under the PCT, at the international phase, designating the European Patent Office (EPO). Patent counts are based on the priority date, the inventor's country of residence and fractional counts. [(2)]IL, MK: 2016. [(3)]CH: 2015.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter63/figure-63-5.xlsx

Japan and Canada are the most efficient in translating their business R&D investments into technological progress. They have high patent intensities when compared to their levels of business expenditure in R&D intensities, and are outperforming the EU, the United States and China. By assuming business investment in R&D as knowledge input and patents as knowledge output, patents can be considered as a return on investing in R&D[10]. In fact, as shown in Figure 6.3-5, there is a positive correlation between business R&D intensity and patent intensity. Compared to the United States, for a similar level of patent intensity, the EU uses less business investment in R&D. However, according to the latest Industrial R&D Investment Scoreboard[11], the top US R&D performers are companies in

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10 Maastricht University and UNU-MERIT (2019), R&D, innovation and productivity.

11 European Commission (2018), The 2019 EU Industrial R&D Investment Scoreboard.

the ICT sector, while in the EU, the top R&D performers are companies in the automotive and pharmaceutical sectors, which are more patent intensive. This might explain the differences between the United States and EU. Within the EU, according to the European Innovation Scoreboard, the most innovative economies, such as Sweden, Finland and the Netherlands, are also the countries with very high levels of patent intensity in relation to their levels of BERD intensity. On the other hand, Slovenia, Austria and Czechia, despite their relatively high levels of business expenditure in R&D, do not translate this into patent applications.

In order to assess how innovation is contributing to addressing sustainability and the challenges our society is currently facing, one can look at the evolution of patent activity in areas such as the bioeconomy and food security, climate and environment, energy, security, transport and health.

As regarding PCT patent applications by societal challenges[12], as defined under the Horizon 2020 Framework Programme, the total number of patent applications increased over time in all fields. However, not all of them follow the same path. After a significant increase up to 2012, the energy sector has shown a decline in recent years, albeit caused by a methodological issue[13]. Transport, which was the third most-patented field until 2010, overtook the food and bioeconomy sector with more than 22 000 patent applications in 2016, reducing the gap with health. Health remains the most-patented field over the period. Both sectors have a high patent propensity[14], reflecting their high number of patents compared to other fields. Even though the field of climate has a persistently low number of patents, this has more than doubled and, in 2016, accounted for almost 2 000 patents. Positive variations in the transport (+233 %), energy (+239 %), security (+209 %) and climate (+133 %) sectors show how fields like climate change, environment and resilience have moved significantly higher in the global political agenda (Figure 6.3-6)[15].

When considering the geographical differences, both the EU and the United States have been losing ground in patent applications in the societal challenges field, while Japan, South Korea and China, in particular, have become more important. In fact, only in bioeconomy and health do the EU and United States combined still represent more than 50 % of patent applications. The United States is the leader in the health, bioeconomy and security sectors, while the EU leads in the fields of energy, climate and transport. Besides its growing importance in all fields, China has becoming particularly strong in energy and security, while Japan has remained strong in the bioeconomy and transport.

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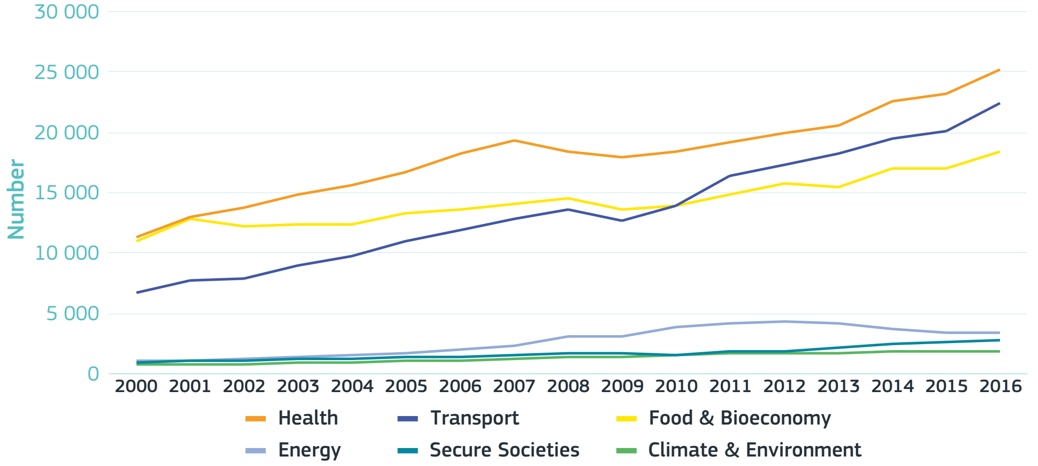
[12] https://ec.europa.eu/programmes/horizon2020/en/h2020-section/societal-challenges

[13] The decline is only due to the classification of the energy SGC, namely the Y-classification. A disadvantage of the Y-classification is that the CPC (Cooperative Patent Classification), on which it is based, is not provided for patents until the patents pending via the PCT process are transferred to the national phase. This is only the case 30 months after registration. The current margin in the figures is therefore even further back than in purely IPC-based patent searches. European Commission (2017), Final report on the collection of patents and business indicators by economic sector: Societal Grand Challenges and Key Enabling Technologies.

[14] EPO and EIPO (2019), IPR-intensive industries and economic performance in the European Union.

[15] European Commission (2019), Reflection Paper - Towards a Sustainable Europe by 2030.

Figure 6.3-6 Total number of PCT patent applications by Societal Challenge, 2000-2016



Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit

Note: Data produced by Science-Metrix using data from the European Patent Office Patstat Spring 2019 database.

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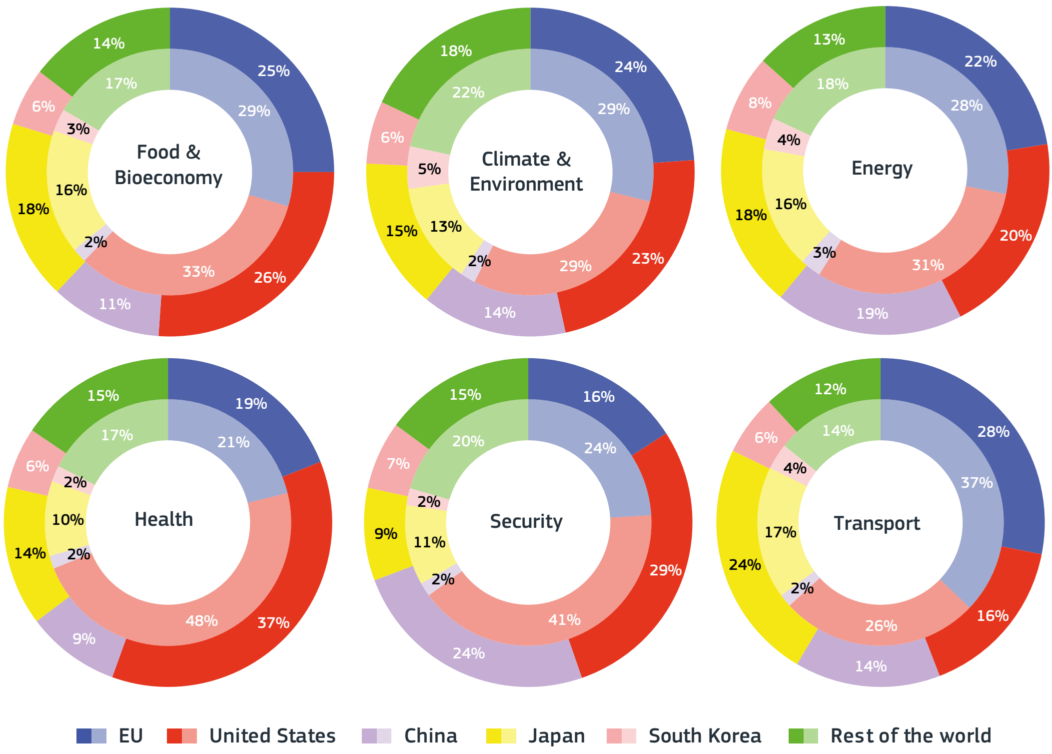
Figure 6.3-7 Share of PCT patent applications by Societal Challenges, 2016 (exterior) versus 2006 (interior)



Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit

Note: Data produced by Science-Metrix using data from the European Patent Office Patstat Spring 2019 database.

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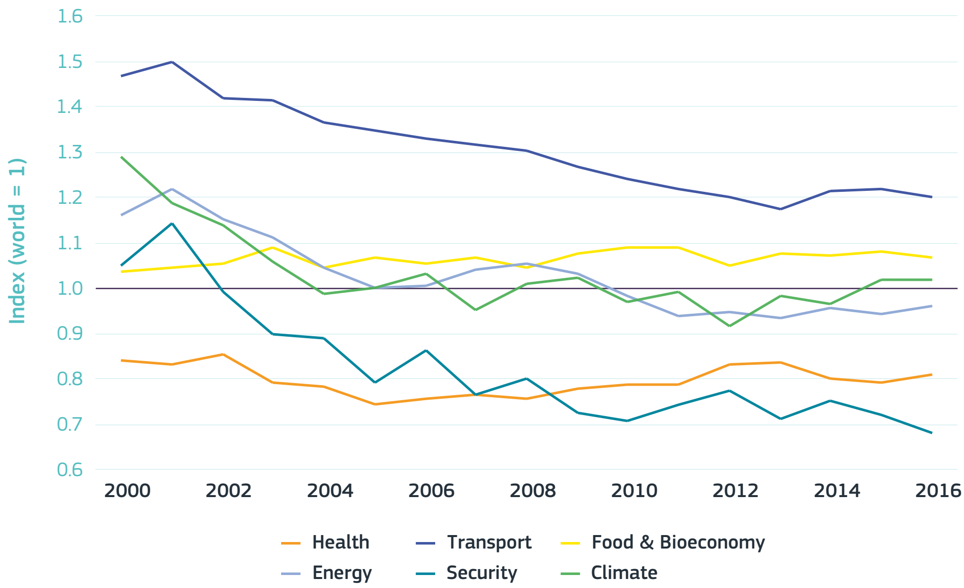
Compared to the rest of the world, the EU is more specialised in patenting in the fields of transport and food and bioeconomy, and less specialised in the health and security sectors. However, this can also be explained by the strong and patent-intensive automotive sector in some European countries. Over time, the EU has undergone significant changes (Figure 6.3-8). While in 2000, the EU was more specialised than the rest of the world in all fields except health, in 2016, only transport, food and the bioeconomy and climate, which have recovered slightly in recent years, were above the world average. In addition, the greatest negative variation was in the fields of security and climate. When comparing the performance with scientific publications, the EU is clearly stronger in the food and bioeconomy sector, with specialisation indexes above its main competitors in both scientific publications and patent applications.

Figure 6.3-8 EU Specialisation Index(1) by Societal Grand Challenge (vs. rest of the world), 2000-2016



Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit

Notes: Data produced Science-Metrix using data from the European Patent Office Patstat Spring 2019 database. [1]Specialisation refers to the Intensity in the EU for a given societal challenge relative to the intensity in the world for the same research area. Fractional counts and date of application used. [2]World average = 1.0.

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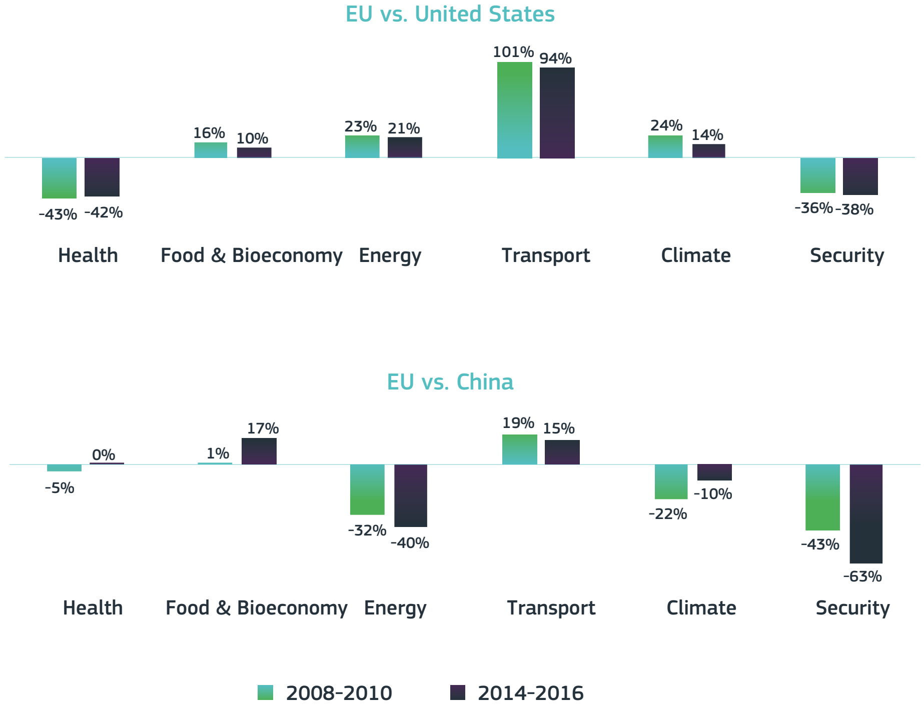
The EU is stronger in both transport and food and bioeconomy than the United States and China but weaker in security. Compared to the United States, the EU also patents more in the climate and energy fields (Figure 6.3-9). These results are also in line with the specialisation indexes in scientific publications in the same fields. In the health sector, however, the United States is significantly more specialised than the EU in both patenting and publishing. Compared to China, the EU has a very small advantage in the field of health, in addition to a very strong performance in terms of scientific publications. As regards the security and energy sectors, the EU not only shows lower specialisation than China, but its position has also deteriorated over time. In the field of climate, the EU has recovered in comparison with China, but worsened when compared to the United States.

Figure 6.3-9 EU Specialisation Index[1] by societal grand challenge (vs. United States and China), three-year average period



Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit

Note: Data produced by Science-Metrix using data from the European Patent Office Patstat Spring 2019 database. [1]Specialisation refers to the Intensity in EU for a given societal challenge, relative to the intensity of the United States and China for the same research area. Fractional counts and date of application used.

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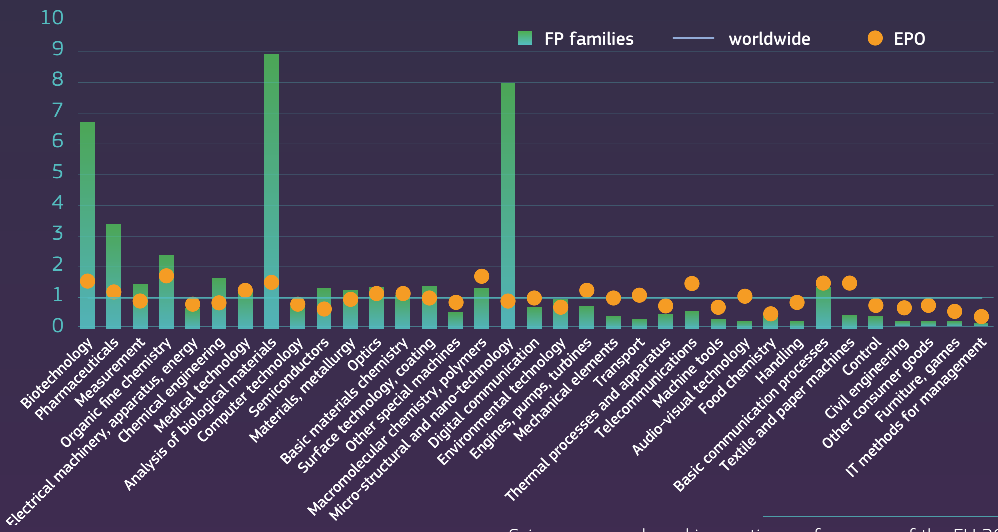
BOX 6.3-1 What type of inventions are self-reportedly patented as a result of the Framework Programme?

The majority of the FP self-reported inventions (patent families) are patented in health-related areas such as biotechnology, pharmaceuticals, organic chemistry or medical technology. Only a limited number of inventions relate to environmental technology.

The highest share of FP self-reported inventions (patent families) is related to biotechnology[16] 14% of all self-reported inventions). This is almost 6 times higher than the worldwide average (2.1% of world patents are in biotechnology). Pharmaceutical inventions follow with around 9% of FP inventions, almost 4 times more than the global average (2.7% of world patents are in this class) and 3 times more than inventions registered at the EPO in this class (3.4% of all EPO patents). Organic fine chemistry FP inventions are also visibly better represented than the overall world picture (a more than twofold increase from 6.1% of FP inventions to 2.6% in world patents) and in line with the percentage of EPO patents in the same class. Inventions in the analysis of biological materials class, as well as nanotechnology FP inventions seem to be over-represented in the FP compared to the percentage of patents in these classes worldwide. At the same time, the Framework Programmes produce proportionately fewer patents than what is observed worldwide in the electrical machinery and energy class, as well as in computer technology, digital communication, telecommunication, transport and environmental technology classes, among others.

Figure 6.3-10 Technological specialisation index of FP main patents, EPO published in 2009-2018 (worldwide=1)



Source: Upcoming Monitoring Flash #4 Patents in FP, DG R&I based on ORBIS Intellectual Property (IP), CORDA and own calculations. The analysis covers self-reported patents from more than 50,000 FP7 and Horizon 2020 projects funded until 2019.
Note: Values are normalised so that worldwide percentage of patents in each WIPO technology class equals 1. A value of 2 indicates a percentage (of FP or EPO patents) twice as high as the worldwide percentage of patents in that class.
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter63/figure-63-10.xlsx

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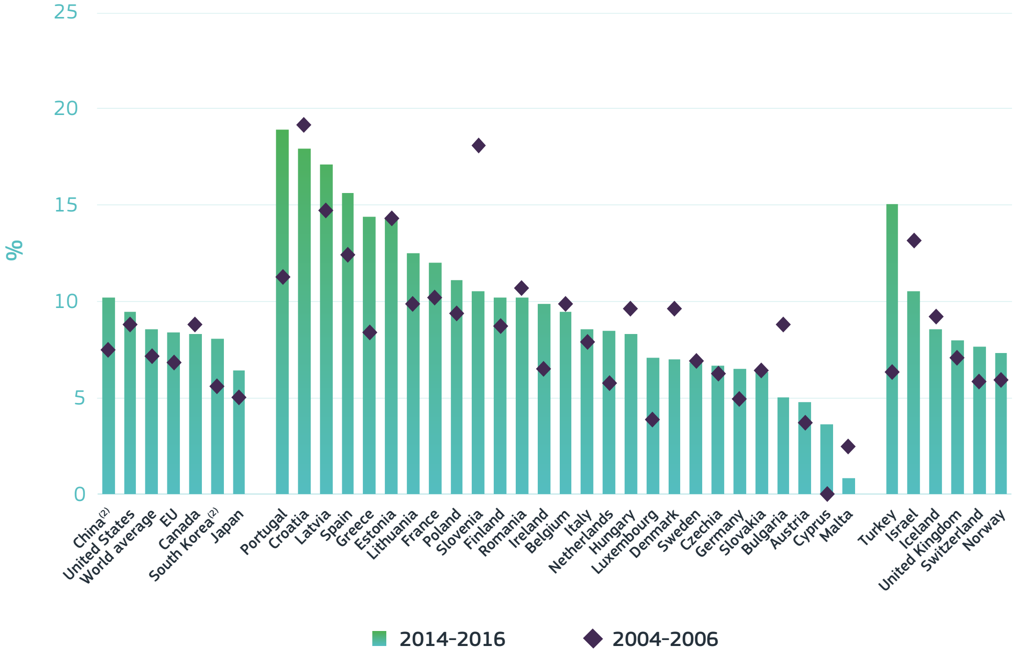
[16] Note that WIPO technology classes are counted only for the main patent of each FP foreground patent family, due to data constraints. Worldwide figures are, nevertheless, at patent-level, rather than patent family (invention) level. Given that the patents covering an invention are very similar, one can assume that they are registered in the same WIPO class.

China, followed by the United States, shows a slightly higher share of female applicants on patent applications than the EU. However, the EU performed marginally better than Canada, South Korea and Japan, and just below the world average with a share of 8.4 % during the period 2014-2016. Together with climate, environment and inequality, gender equality has become more relevant in the political agenda in recent years[17]. Therefore, it is important to analyse the contribution women have made to technological progress as patent applicants. Even though the share of female applicants in patent applications to the European Patent Office is small, performances vary significantly across Europe. Portugal then Croatia, Latvia and Spain display the highest shares, at over 15 %, while Malta then Cyprus and Austria display the lowest shares, at below 5 % for the period 2014-2016. Between the two periods presented, most countries have shown an improvement in the share of female applicants, with a particular emphasis on Portugal, Greece and Turkey. Conversely, Slovenia, Israel and Denmark saw a decline.

Figure 6.3-11 Share of female applicants on patent applications filed with the EPO by country (%), 2004-2006 and 2014-2016(1)



Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit

Note: Data produced by Science-Metrix using data from the European Patent Office Patstat Spring 2019 database. Gender was assigned to applicant names using the NamSor API. (1)Due to high volatily over time, an average of three-year period was used. The fractional counting method was used. (2)Data for China and South Korea has a high margin of error, thus results should be interpreted with caution.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter63/figure-63-11.xlsx

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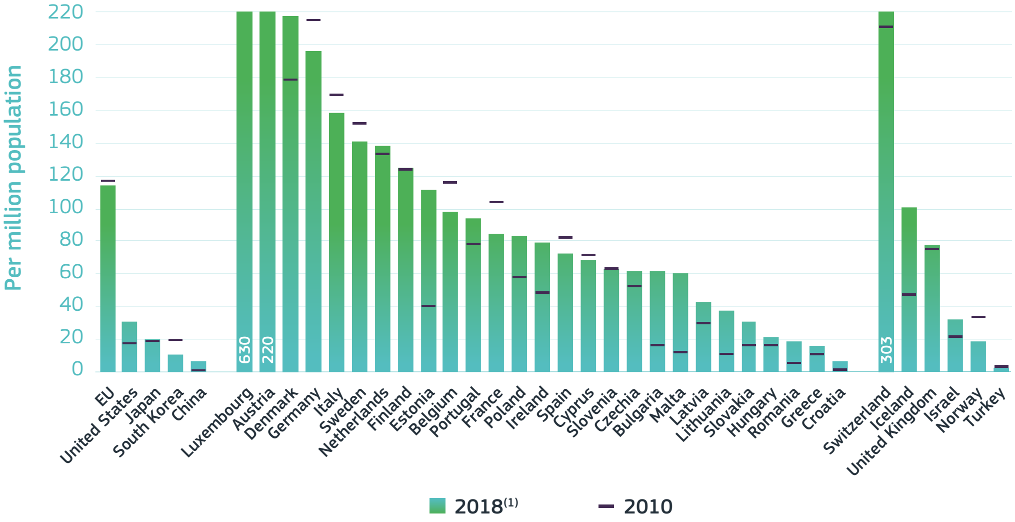
[17] Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: A Union of Equality: Gender Equality Strategy 2020-2025.

Over time, the EU has shown significant improvements in the case of trademarks, while achieving a stable performance in community designs. By looking at per capita community designs and trademarks[18] as a proxy for assessing patterns of innovation outside of the traditional exploitation of R&I results (Figures 6.3-12 and 6.3-13), the EU extensively outperforms the United States, Japan, South Korea and China.

Within Europe, the innovation divide is less striking in trademarks and community design applications than in patent applications. Countries like Cyprus and Estonia, which perform poorly in patent applications, rank particularly high in these types of IP applications. In addition, countries such as Lithuania and Bulgaria have shown significant improvements in recent years. These patterns might be the result of initial reforms in incentive systems and framework conditions. However, good performances in small countries like Luxembourg and Malta might be the result of legislation, easy procedures and attractive taxation systems rather than investment in innovation or more innovative companies. Despite the good performance of some less-innovative economies, countries performing traditionally well in innovation, like Denmark or Sweden, not only lead patent applications but also other types of IP applications. On the other hand, countries like Romania or Greece with less-attractive innovation systems perform poorly in both types of intellectual property rights.

Figure 6.3-12 Community design applications to the EU Intellectual Property Office (EUIPO) per million population, 2010 and 2018



Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on data produced by Science-Metrix using data from the EUIPO database, Eurostat and World Bank data

Note: (1)US, KR, JP, CN: 2017.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter63/figure-63-12.xlsx

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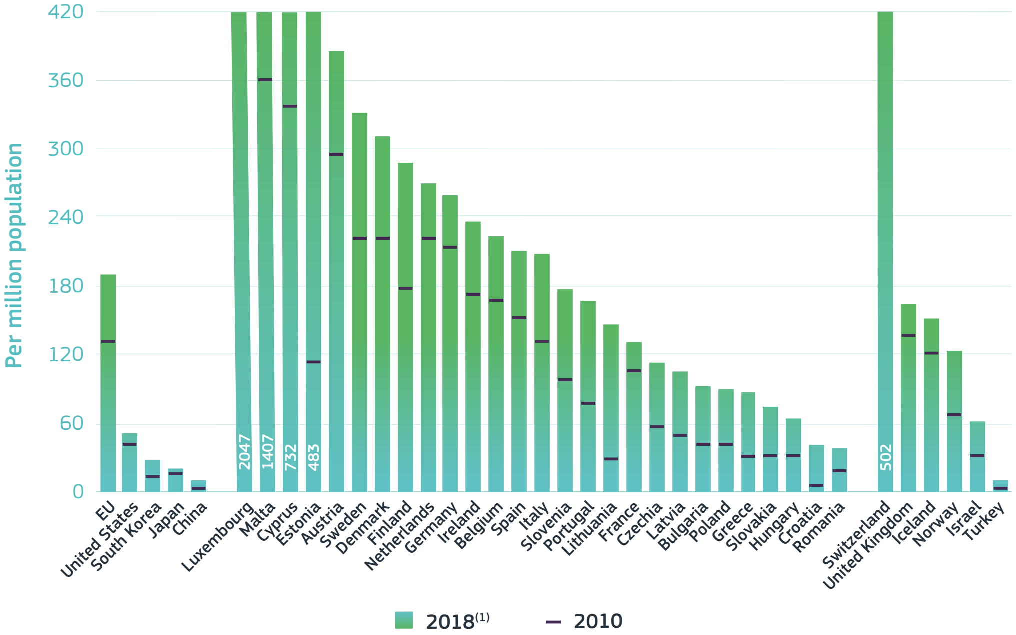
[18] Design covers the visual appearance of a product, part of a product and/or its ornamentation, i.e. A design covers the appearance of a product but cannot protect its functions, which fall under the regime of patent protection. A trademark is a distinctive sign that identifies certain goods or services such as those provided by a specific person or organisation and distinguishes them from those of other organisations. Trademarks can be words, pictures, stylised words, logos, a colour or colour combination, a shape, a sound or a combination of those signs.

Figure 6.3-13 Trademark applications to the EU Intellectual Property Office (EUIPO) per million population, 2010 and 2018



Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on data produced by Science-Metrix using data from the EUIPO database, Eurostat and World Bank data

Note: (1)US, KR, JP, CN: 2017.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter63/figure-63-13.xlsx

Innovative companies use significantly more IPRs than non-innovative companies. Intellectual property rights are one of the main tools used by companies to extract a benefit from investment in R&I and to protect their innovations[19]. The extent to which IPRs are used among innovative companies diverges among EU countries. As shown in Figure 6.3-14, in Germany, almost 60 % of innovative companies use IPRs, whereas in Romania, the share is just above 10 %. Moreover, there are certain differences between innovation leaders and modest innovators; for example, a substantial share of innovative enterprises in Bulgaria and Czechia use IPRs, while the shares of innovative enterprises using IPRs are lower in the Netherlands and Estonia. Differences in the dominant economic sector can explain the results. In countries with higher shares, IPR-intensive sectors, such as automotive, software and equipment manufacturing, dominate the share of innovative enterprises, while in countries with lower shares, the dominant sectors are primarily services such as wholesale and retail trade, which are not IPR-intensive sectors. In addition, country-specific policies on IPRs, such as incentives and enforcement of IPR, can contribute to higher shares. For instance, in 2014, Czechia introduced a programme that supported expenses on IPR protection in businesses[20].

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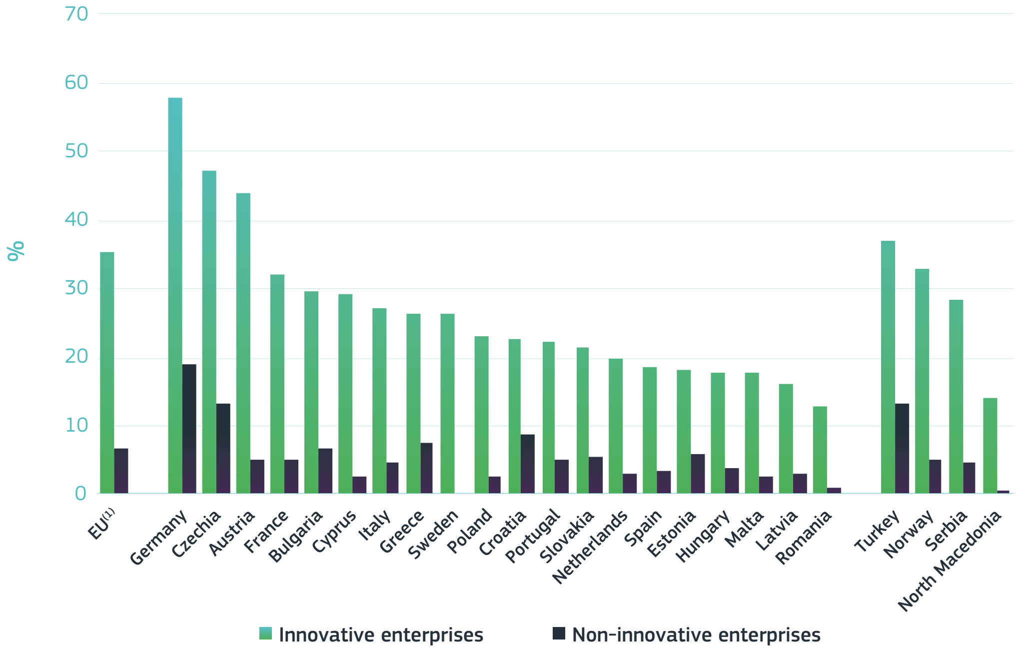
[19] European Union Intellectual Property Office (2017), Protecting innovation through trade secrets and patents: determinants for European Union firms.

[20] EC-OECD STIP COMPASS, https://stip.oecd.org/stip.html

Figure 6.3-14 Share of innovative and non-innovative enterprises (%) that used intellectual property rights (IPRs), 2016



Science, research and innovation performance of the EU 2020

Source: Eurostat - Community Innovation Survey 2016 (online data code: inn_cis10_ipr)

Note: (1)EU value estimated with the available 20 EU countries.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter63/figure-63-14.xlsx

The most commonly used IPR by innovative companies in the EU are trade secrets and trademarks and, to a lesser extent, patents, as shown in Figure 6.3-15. These figures are in line with the very high numbers shown in Figure 6.3-12 and 13 in which trademarks are used much more than patents and community designs. In fact, while patents are used mainly for products and to protect innovations that are new to the market, trade secrets and trademarks can be applied in both products/services and processes and also in innovations new to a firm[21], thereby increasing the scope of these types of IP for innovation protection. By type of IPR, Germany, followed by Austria and Czechia, show the highest shares for trade secrets in the EU; Sweden, followed by Bulgaria and Germany, show the highest shares for trademarks; and Germany, followed by Austria and Sweden, show the highest shares for patents. As for utility models, industrial design and copyright, the top countries are Germany, France and Poland, respectively. Once again, differences in the dominant economic sector to which innovative companies belong and variations in IPR legislation can explain the results. Nonetheless, the highest shares are concentrated in the more innovative countries such as Sweden, Germany and Austria.

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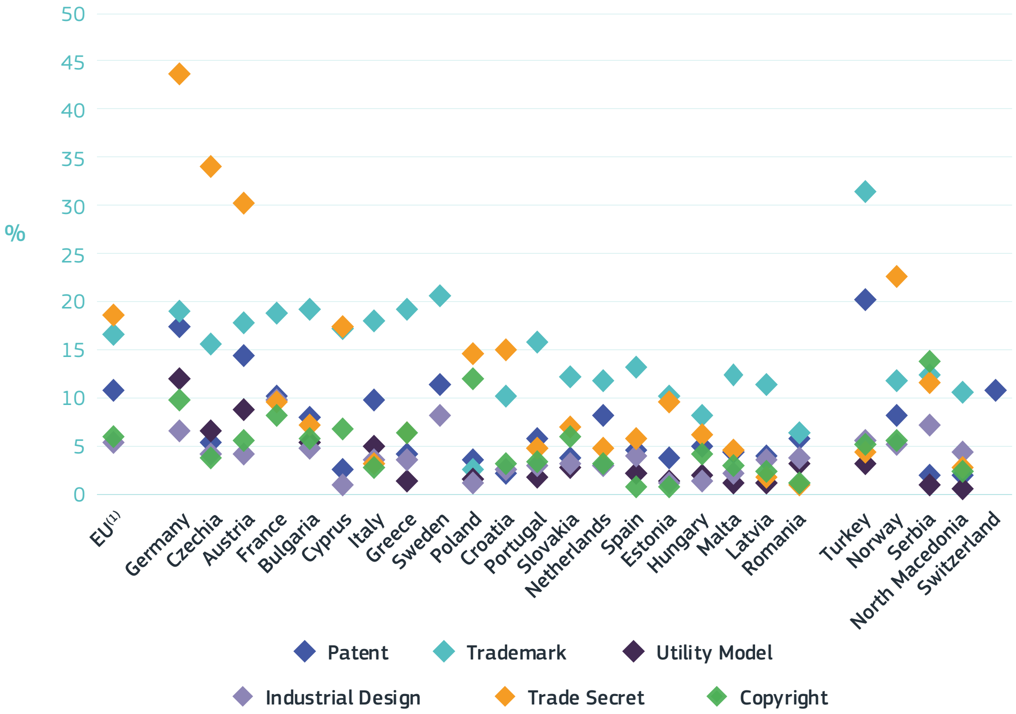
[21] European Union Intellectual Property office (2017), Protecting innovation through trade secrets and patents: determinants for European Union firms.

Figure 6.3-15 Share of innovative enterprises (%) by intellectual property rights (IPRs) and licensing in the enterprise, 2016



Source: Eurostat - Community Innovation Survey 2016 (online data code: inn_cis10_ipr)

Note: (1)EU value estimated with the available 20 EU countries.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter63/figure-63-15.xlsx

3. An unequal landscape of innovative enterprises

The share of innovative enterprises in an economy also illustrates its innovativeness. By definition, and according to the Community Innovation Survey of 2016, enterprises are considered innovative if they carried out innovation activities during the period 2014-2016, including ongoing and abandoned activities, i.e. regardless of whether the innovation activity resulted in implementation of an innovation[22].

In 2016, 48 % of EU enterprises reported innovation activities in the period 2014-2016, a decline of 5.7 percentage points since 2010. Even though innovation performance has improved over time, according to the latest European Innovation Scoreboard[23], half of the EU countries have also shown a decline in the share of innovative enterprises. On the negative side, countries such as Germany, Romania and Poland stand out with a significant decline in the share of innovative enterprises (Figure 6.3-16). Conversely, Lithuania shows a significant improvement when compared to 2010. Belgium is the EU country with the highest share of innovative companies (almost 70 %), followed by Portugal and Finland. Among all countries, Switzerland and Norway are the best performers with shares above 70 %. On the downside, Romania, Poland, Bulgaria and Hungary have the lowest shares of innovative companies (less than 30 %). Looking at the figures, the share of innovative enterprises demonstrates the innovation divide between north-western and south-eastern Europe, with some exceptions such as Portugal, Greece and Italy. Portugal, for instance, reports a relatively high share of innovative enterprises, mainly driven by a very high share of innovative SMEs in combination with a relatively high share of public support to business R&D investment and a good performance of SME investment in R&D. In addition, the share of innovative companies is connected with countries' economic structures. The higher share of SMEs in medium-high, high-tech manufacturing and knowledge-intensive services (such as ICT and finance) is likely to translate into a higher share of innovative enterprises which, for instance, might explain the results from Belgium and Luxembourg.

In terms of company size, with more resources to invest in R&D, large companies are naturally more innovative than SMEs. However, the gap in both shares varies across countries (Figure 6.3-17). More-innovative countries, such as Luxembourg, the Netherlands, Finland, Belgium and Denmark show not only a lower gap but also high shares of innovative SMEs and innovative big companies which, as mentioned previously, is partly explained by the economic structure. Portugal comes out on top with a high share of innovative SMEs and the lowest gap. On the contrary, eastern European and less-innovative countries like Romania, Bulgaria[24], Slovenia, Poland and Slovakia, where business structures are dominated by few large multinational companies that control most of the business investment in R&D, have the lowest shares of innovative SMEs as well as the largest gaps between large enterprises and SMEs.

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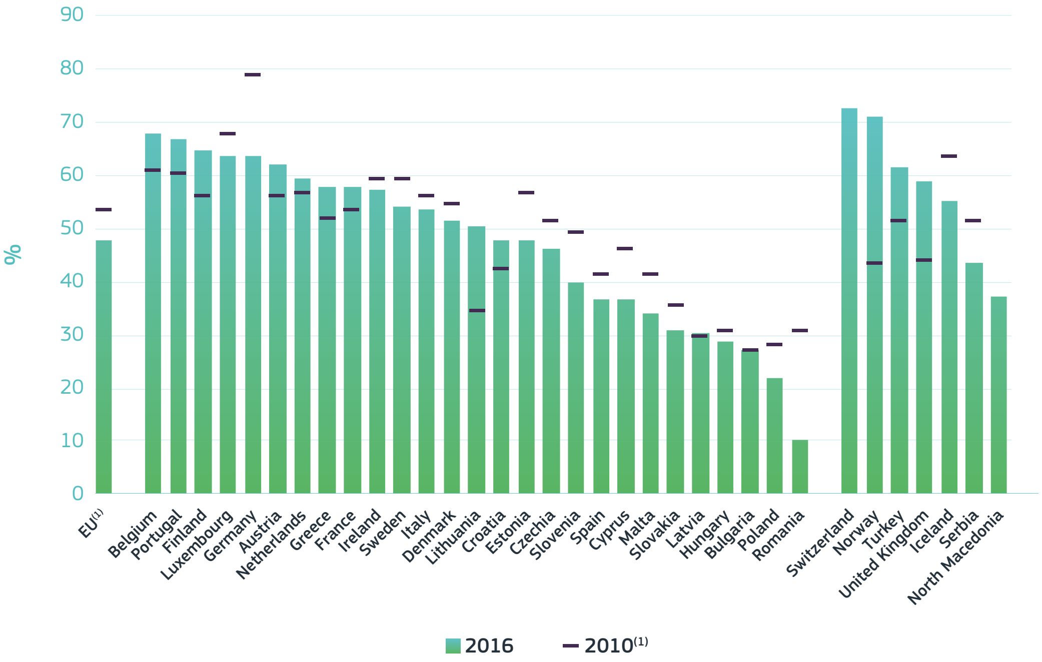
[22] The concepts are in line with those recommended by the Oslo Manual (2005, 3rd edition) which is the internationally recognised standard methodology for collecting innovation statistics.

[23] European Commission (2019), European Innovation Scoreboard 2019.

[24] European Commission (2019). European Semester – Country Report.

As regards the different types of innovation activities, the share of innovative enterprises in product and process innovation is generally higher than in organisational and marketing innovation. This is an important result because it means that companies are investing more in new or significantly improved products and/or services rather than promoting existing ones.

Figure 6.3-16 Innovative enterprises as % of total number of enterprises, 2010 and 2016



Source: Eurostat - Community Innovation Survey 2016 and 2010 (online data code: inn_cis10_type and inn_cis7_type)

Note: (1)EU estimated and not including EL. EL: 2012.

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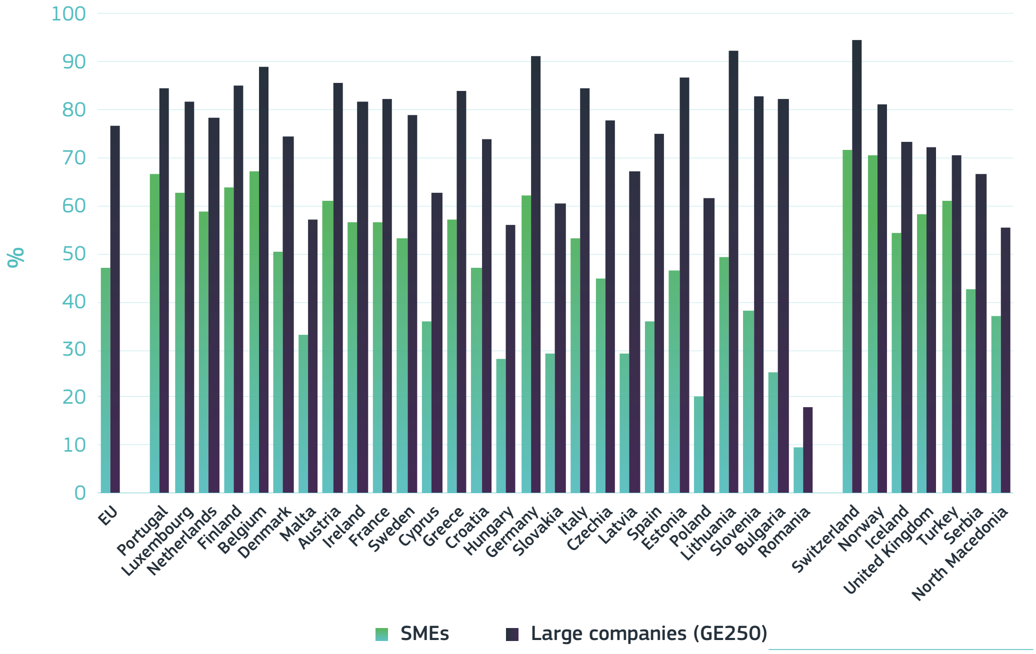
Figure 6.3-17 Share of innovative enterprises by size, 2016



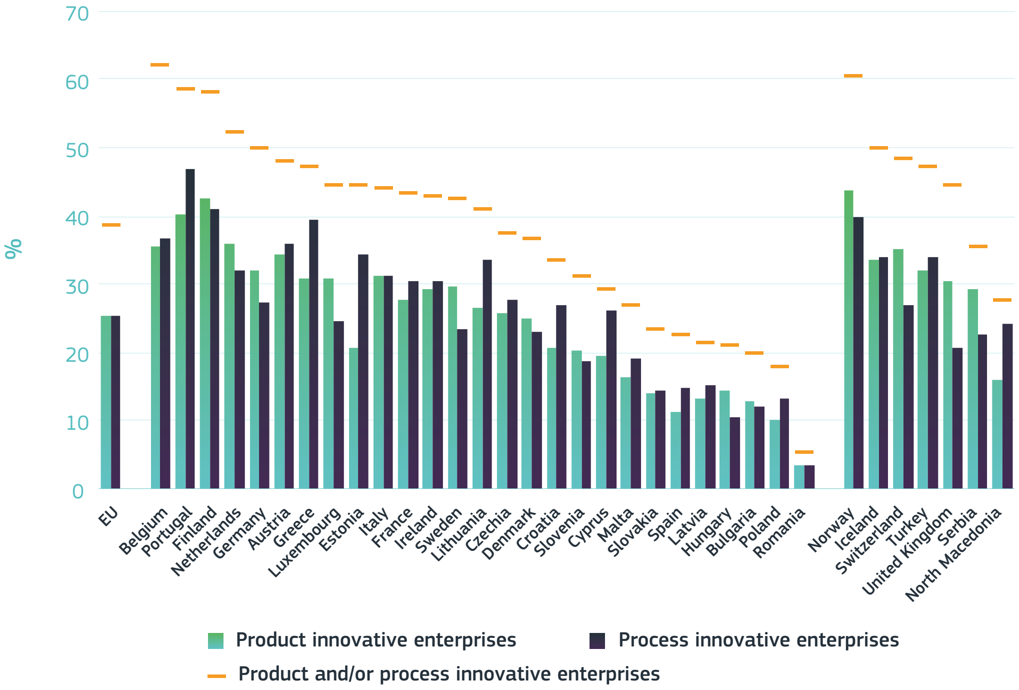
Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on Eurostat - Community Innovation Survey 2016 (online data code: inn_cis10_type)

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter63/figure-63-17.xlsx

In geographical terms, there is generally a divide between leading innovative countries performing better in both types of innovation and less-innovative countries performing poorly equally in both types of innovation. However, some exceptions, such as Portugal and Greece, stand out with high shares and both types (Figures 6.3-18 and 6.3-19). In addition, countries such as the Netherlands, Estonia, Belgium and Finland perform much better in product and process innovation than in organisational and marketing innovation. In more detail, the majority of countries perform better in organisational than marketing innovation and tend to do better in process rather than product innovation. However, because product innovation requires more and better resources, leading innovative countries such as Finland, the Netherlands, Denmark and Sweden show higher shares in product innovation as against process innovation.

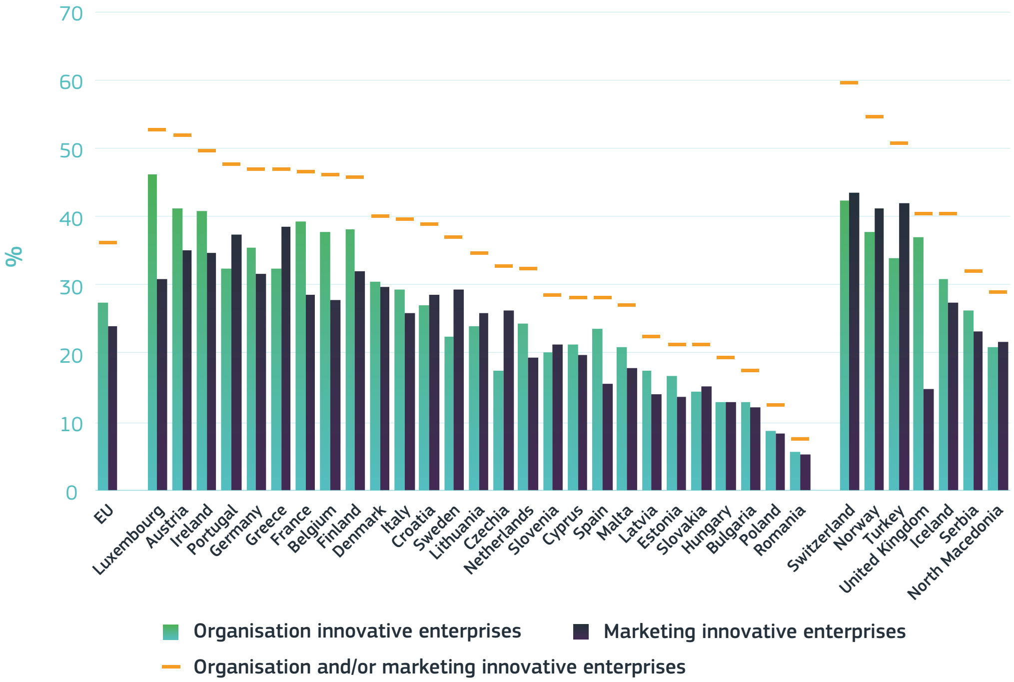
Figure 6.3-18 Innovative enterprises by type of innovation activity as % of total enterprises, 2016



Source: Eurostat - Community Innovation Survey 2016 (online data code: inn_cis10_type)

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter63/figure-63-18.xlsx

Figure 6.3-19 Innovative enterprises by type of innovation activity as % of total enterprises, 2016



Science, research and innovation performance of the EU 2020

Source: Eurostat - Community Innovation Survey 2016 (online data code: inn_cis10_type)

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter63/figure-63-19.xlsx

At the EU level, approximately 30 % of product- and/or process-innovative enterprises received public funding for their innovation activities during the period 2014-2016. Public funding is an important tool to support business innovation activities, either through tax incentives or direct public support[25]. Figure 6.3-20 shows there is no clear innovation divide between the most- and least-innovative countries. For instance, France reports the highest share of product and process innovation enterprises that have received public funding, followed by the Netherlands and Romania. However, the source of funding diverges. While enterprises in countries with better innovation capacities and more public support for business investment in R&D, such as France, the Netherlands, Finland and Luxembourg, show relatively higher shares of funding from national sources, in less-developed public innovation systems, like Bulgaria, Czechia, Romania, Latvia and Slovakia, companies tend to use relatively more funding from the EU. Furthermore, these figures show that companies might look for public support to fund their innovation activities either as the result of a well-developed public investment system, when the highest share comes from national sources, or because of poor framework conditions that are

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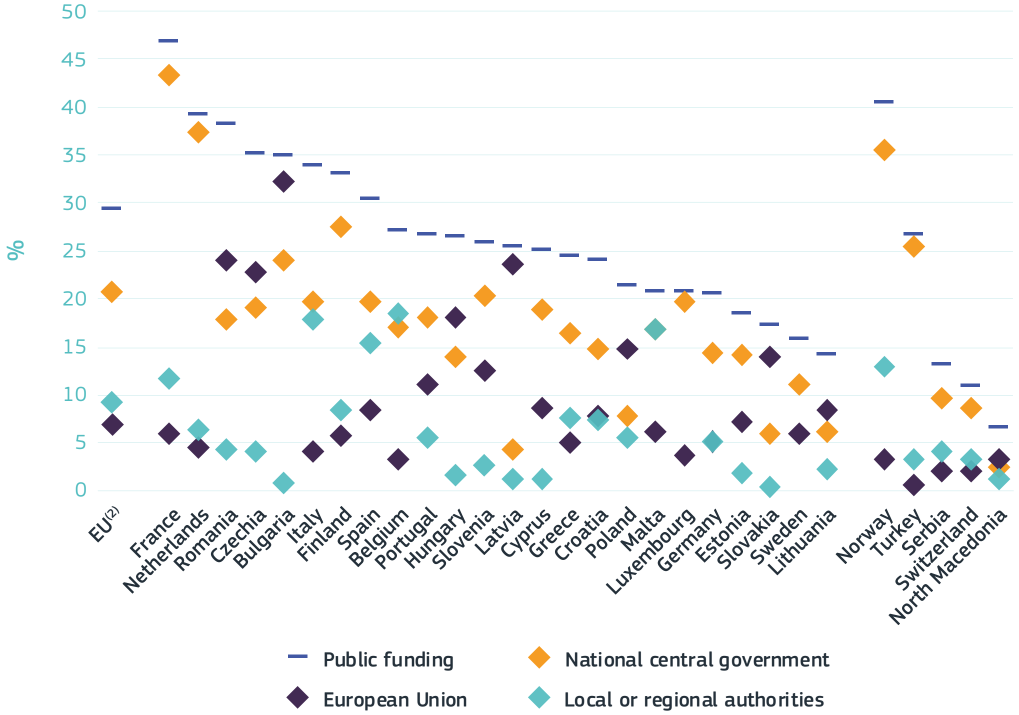
[25] European Commission (2017), The economic rationale for public R&I funding and its impact.

unable to secure business investment in R&D, when the highest share comes from external sources. As a consequence of deprived national investment systems, the results confirm the importance of European funding in helping innovative companies to fund their activities , especially in the countries that are more distant from the technological frontier.

Figure 6.3-20 **Share of product and/or process-innovative enterprises(1) (%) that received public funding for innovation activities by source of funding, 2016**



Source: Eurostat - Community Innovation Survey 2016 (online data code: inn_cis10_pub)

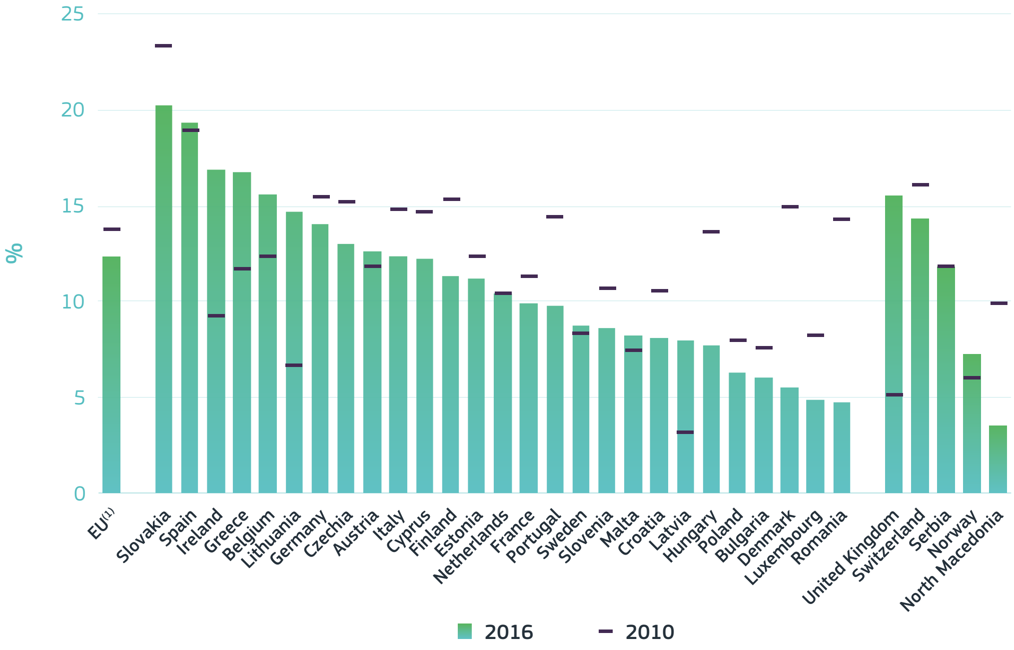
Notes: (1)Public funding includes financial support via tax credits or deductions, grants, subsidised loans, and loan guarantees. (2)EU value estimated with the available 24 EU countries.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter63/figure-63-20.xlsx

4. The economic impact of innovation illustrates diverse national economic structures

In 2016, innovation turnover in the EU, measured as sales of new-to-market and new-to-firm innovations, was 12.4% of total turnover. Even though in absolute terms, innovation turnover increased by 7%, the share is slightly lower than in 2010. In addition, the share of innovation turnover fell in 17 of the 27 EU countries. The decrease is particularly significant in Denmark, Romania and Hungary (Figure 6.3-21). On the other hand, a few countries have shown big improvements, such as Ireland, Latvia and Lithuania. Slovakia, followed by Spain and Ireland, show the highest shares of innovation turnover while Romania, Luxembourg and Denmark display the lowest shares. In Denmark, the result seems to be linked to a high concentration of a few very large R&D-intensive industries, especially in the pharmaceutical sector. Similarly, a concentration of a few very large R&D-intensive industries in Luxembourg's services sector might explain its low share. Therefore, these figures indicate that innovation turnover does not seem to be aligned to the share of innovative enterprises or the country's innovation capacity. However, it is important to note that, while data on company shares includes several types of innovation and are dominated by the high number of SMEs, as regards turnover, larger companies play a bigger role, especially multinational companies that import innovations from the headquarter country. Countries with a relatively large high-tech and medium-high-tech manufacturing sector also tend to show higher innovation turnover.

Figure 6.3-21 **Sales of new-to-market and new-to-firm innovations as % of total turnover, 2010 and 2016**



Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on Eurostat - Community Innovation Survey 2016 and 2010 (online data code: inn_cis10_prodt and inn_cis7_prod) and European Innovation Scoreboard 2019

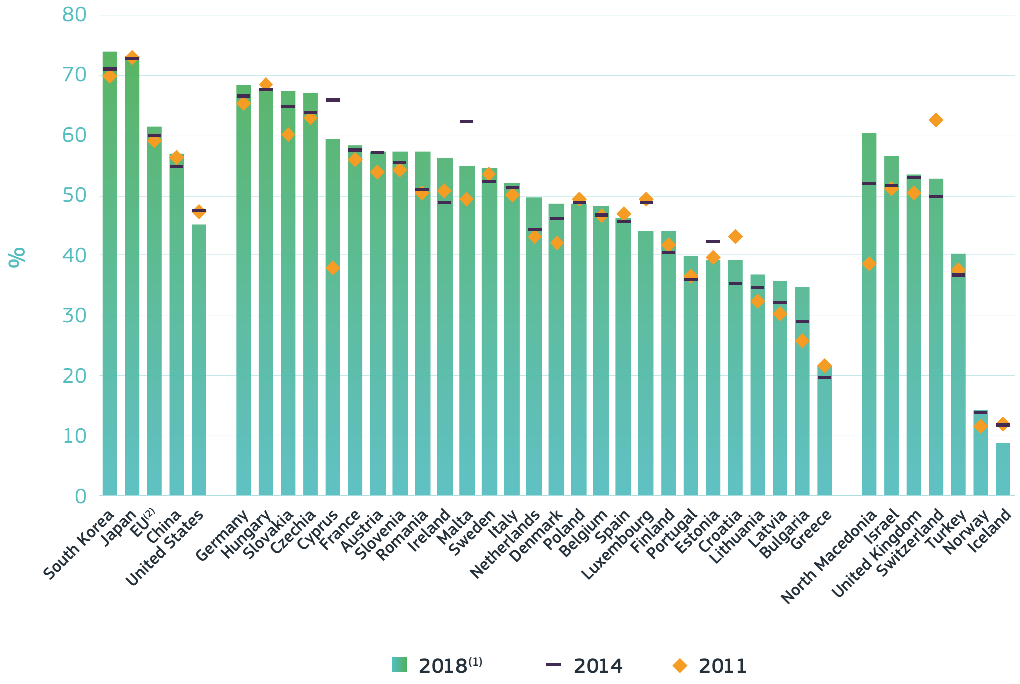
Note: (1)EU value was estimated.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter63/figure-63-21.xlsx

As regards the export share of medium- and high-tech products, South Korea and Japan, with strong ICT hardware and automotive industries, show the best performance. While the EU lags behind those two countries, it performs better than China and the United States. As key drivers of economic growth and productivity, medium- and high-technology products might reflect a country's ability to commercialise the results of R&D in international markets.

Within Europe, Germany, with its strong R&D-intensive automotive and equipment industries, shows the best performance. Central and eastern Europe, in particular Hungary, Slovakia and Czechia, also report very good performances as a result of their foreign affiliate companies' strong automotive, machinery and pharmaceutical exporting sectors. Over time, most countries have improved their shares of medium- and high-tech exports, particularly Bulgaria and Cyprus (Figure 6.3-22). Certain leading innovation countries, such as Finland which has a very strong R&D-intensive industry in the ICT hardware sector, is not able to translate the investment into exports of internationally competitive high-tech products. However, as with the innovation turnover indicator, the

Figure 6.3-22 Exports of medium- and high-technology products as % of total product exports, 2011, 2014 and 2018



Source: European Commission, DG Joint Research Centre based on Eurostat, Comext 'DS-018995' and UN Comtrade (Vértesy and Damioli, 2020, Figure 4)

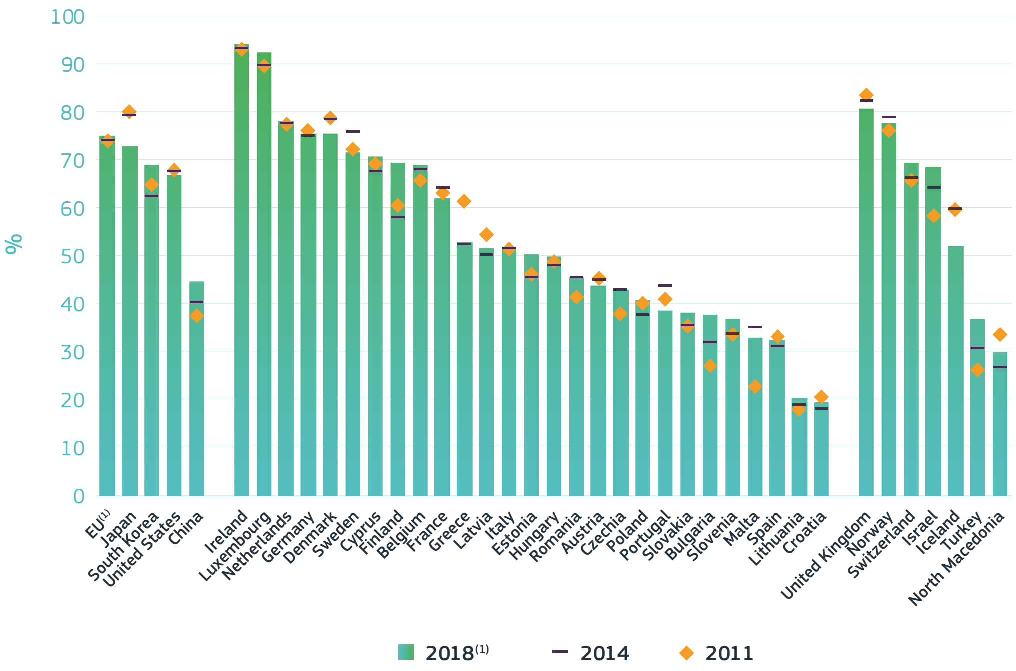
Note: (1)CN, KR, NO: 2017. (2)Two sets of values are available: values for worldwide comparison that exclude foreign trade between EU countries and values for European comparison that include it. The values for worldwide comparison are shown on the graph. The value for EU comparison for 2018 is 56.6.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter63/figure-63-22.xlsx

results seem to be linked more closely to the country's economic structure (i.e. the weight that certain sectors have in the economy), rather than its innovation capacity.

The EU shows the highest share of knowledge-intensive service exports, ahead of Japan, South Korea, the United States and China. Within the EU, countries with a high share of R&D-intensive financial and ICT services in their economies, like Ireland and Luxembourg, are leading the EU (Figure 6.3-23). On the other hand, those with a high share of tourism-related services, such as Spain, Croatia and Malta, tend to perform poorly in this indicator, notwithstanding their R&D investment in professional, scientific and technical services. Contrary to the previous indicators, the share of KIS exports seems to be in line not only with the country's economic structure but also with its innovation capacity. Leading innovative countries, such as the Netherlands, Sweden, Denmark and Finland, perform very well while less-innovative countries, such as Lithuania, Slovakia and Bulgaria, perform poorly. This might be an indication that digitalisation and new technologies are changing the way innovation is happening, with investments in R&D and innovation more easily translated into competitive innovative services than innovative goods.

Figure 6.3-23 Exports of knowledge-intensive services as % of total services exports, 2011, 2014 and 2018



Science, research and innovation performance of the EU 2020

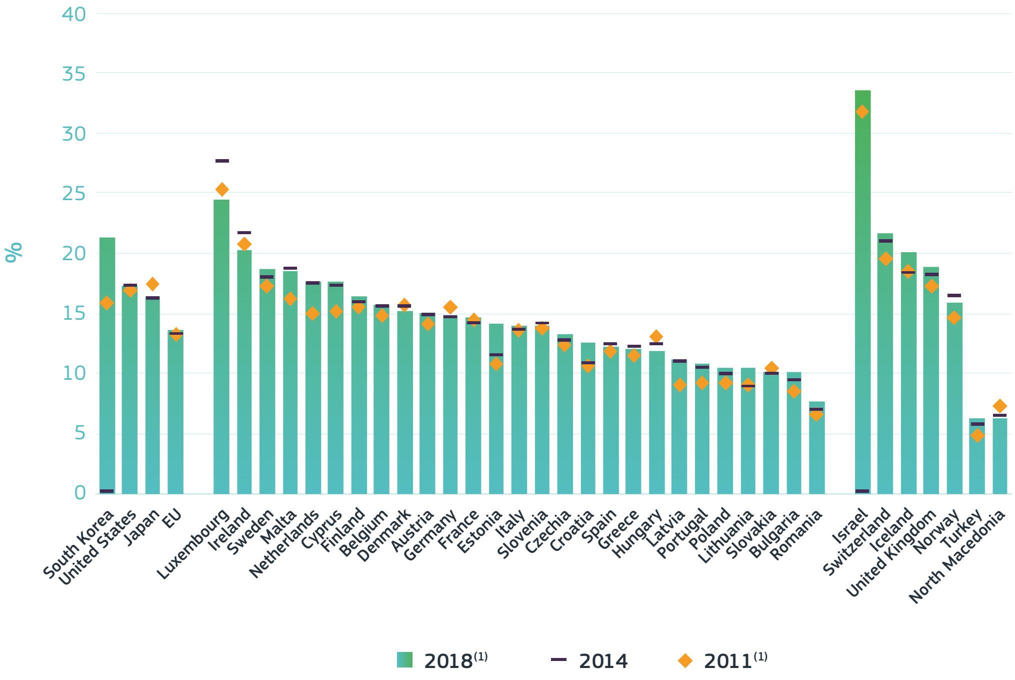
Source: European Commission, DG Joint Research Centre based on Eurostat (bop_its6_det), OECD (TISP_EBOPS2010) and ITC (Vértesy and Damioli, 2020, Figure 5)

Note: (1)Two sets of values are available: values for worldwide comparison that exclude foreign trade between EU countries and values for European comparison that include it. The values for worldwide comparison are shown on the graph. The value for EU comparison for 2018 is 68.4.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter63/figure-63-23.xlsx

In terms of employment in knowledge-intensive activities[26], which measures the economic impact of R&I activities towards the creation of new high-skilled jobs, the United States, Japan and South Korea outperform the EU. Within the EU, this performance indicator reflects the innovation divide between north-western Europe and south-eastern Europe, with some exceptions such as Malta, Cyprus and Estonia which have seen their shares increase over time due to their growing R&D investments in ICT and professional and scientific services (Figure 6.3-24). Once again, economic structure plays an important role: Luxembourg and Ireland, which have a high share of financial services and ICT services, respectively, top the ranking in the EU.

Figure 6.3-24 **Employment in knowledge-intensive activities in business industries as % of total employment, 2011, 2014 and 2018**



Science, research and innovation performance of the EU 2020

Source: European Commission, DG Joint Research Centre based on Eurostat (htec_kia_emp2) Japan Statistical Office, US BLS CBP and OECD (Vértesy and Damioli, 2020, Figure 3)

Note: (1)KR, IL: 2015. KR: 2009.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter63/figure-63-24.xlsx

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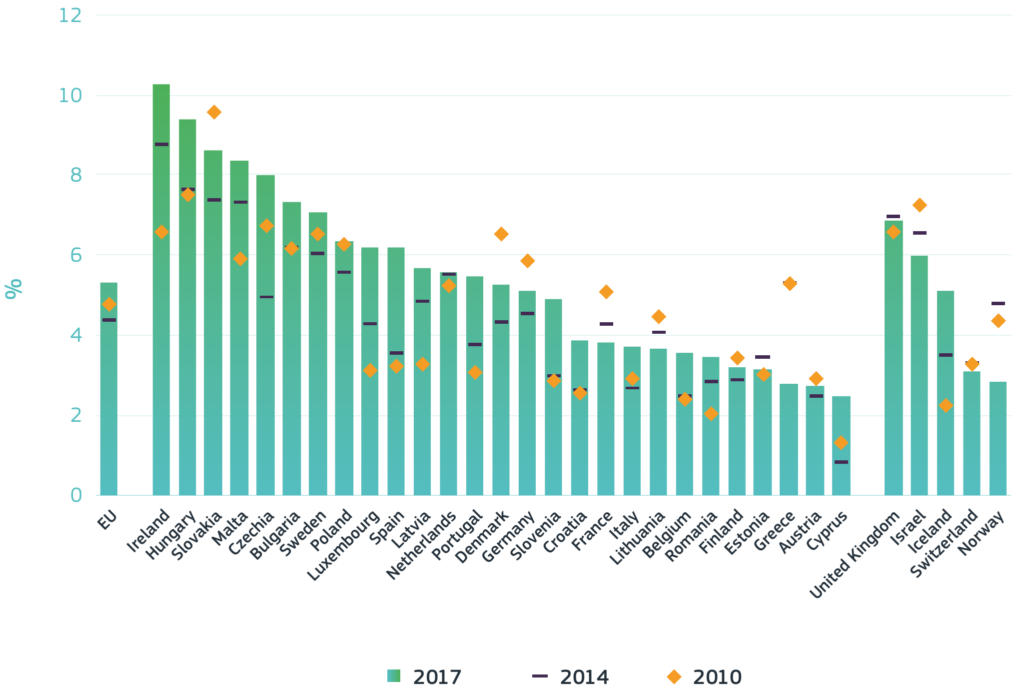
[26] By definition, an activity is classified as knowledge-intensive if the tertiary educated people employed represent more than 33 % of total employment in that activity.

The last component of the Innovation Output Indicator builds on the dynamism of fast-growing enterprises in the most-innovative sectors and tries to capture countries' capacity to respond to new needs and emerging demands. At the EU level, there is no clear innovation divide, with good performances among both the most-innovative and least-innovative countries. Ireland, followed by Hungary and Slovakia, show the highest shares (Figure 6.3-25). However, while the shares in Ireland reflect its strength in the knowledge-intensive services sector, in Hungary and Slovakia they are reflected in the medium-high-technology manufacturing sector. In addition, these countries have shown high rates of economic growth in recent years, which subsequently has contributed to strong employment growth. On the downside, Cyprus, Austria and Greece show the lowest shares. Over time, Slovenia, Luxembourg and Spain have seen the biggest improvements.

Figure 6.3-25 Employment in fast-growing enterprises in the top 50% most innovative sectors as a percentage of total employment, 2010, 2014 and 2017



Science, research and innovation performance of the EU 2020

Source: European Commission, DG Joint Research Centre based on Eurostat (online data code: bd_9pm_r2) (Vértesy and Damioli, 2020, Figure 6)

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter63/figure-63-25.xlsx

BOX 6.3-2 Innovation beyond its economic impacts and the importance of social innovation

Beyond the impacts of innovation in job creation, new products and markets, and sustainable economic growth, impacts can also be seen in a more social context, such as through engagement with citizens and local communities, reflecting the importance of social innovation.

In 2018, Athens was awarded with the European Capital of Innovation prize for the way in which the capital's authorities responded to the deepening economic and refugee crisis. Athens used innovation to engage citizens, revive the local community, boost creativity and dynamism, and open the city to the world.

After major cuts in resources and greater pressure on public services, Athens revamped its policymaking processes to innovate quickly so that, along with its citizens, it could revive the local economy, build up infrastructure and rebuild the residents' confidence in their city. Inclusion and cooperation with citizens and civil society is, more than anything else, what has made this approach work. The innovation-support processes were accountable and transparent, while citizens were consulted on decisions throughout. This helped to regenerate neighbourhoods, integrate refugees, and improve education and digital access. Athens now brings groups together to improve the city rather than directing change from the top, showing that innovation enables cities to do more with less. In the end, the city has new businesses, a more attractive urban environment a revived cultural scene and better services.

As the previous Commissioner, Carlos Moedas stated: 'Athens stands out as an example that a city facing many challenges can achieve great things. Through innovation, Athens has found new purpose to turn around the economic and social crisis.'

Examples of initiatives include:

- The **POLIS2**[27] project aimed to revitalise abandoned buildings by providing small grants to residents, small enterprises, creative communities and other civil society groups and to bring life to all corners of Athens.
- The **Curing the Limbo**[28] initiative gives refugees and migrants the possibility to connect with other residents in order to learn the language, develop new skills, find employment opportunities, and engage in active citizenship.
- The **Digital Council**[29] brought together companies and educational institutions in the city to provide training on digital literacy and civic technology as well as to promote sustainable innovations like smart recycling bins

In 2019, Athens passed its title to the city of Nantes, awarded for its open and inclusive governance approach, involving citizens in 'grand debates' and discussions on major societal challenges, leading to concrete initiatives. In addition, the city has built a dynamic and thriving digital and start-up community, driving the city's innovative ecosystem and providing cutting-edge solutions to local challenges.

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[27] http://www.polis2.thisisathens.org/en/

[28] https://www.uia-initiative.eu/en/uia-cities/athens

[29] http://athenspartnership.org/news/

Nantes' flagship policies and projects include:

- 15 places to be reinvented[30]: a competitive selection of ideas submitted by citizens that resulted, for instance, in turning an unused chapel into an urban mushroom farm or creating a zero-waste awareness hub in a former art school.
- Nantes CityLab[31] helps innovators test new solutions in real life by providing physical and digital infrastructure, such as a 3D-printed social house constructed in 3 days or an autonomous shuttle powered exclusively by a solar road.
- Creative factory[32], a support system for creative and cultural industries, and the Eco-innovation factory[33], a programme that selects projects such as one which uses bicycle trailers to collect biowaste from restaurants and offices for local composting.
- **The** Nantes French Tech Capital[34] programme fosters start-ups, scale-ups, attracting talents and breakthrough technologies, and enables the coordination and promotion of the regional innovation ecosystem.
- **Ecossolies**[35] is a network that gathers private and public members to develop initiatives in the field of social and solidarity economy and promote them by awarding the best social innovation solutions, such as the Hacoopa[36] project for housing the elderly or the **Bout' à** Bout' association[37] which is reducing the impact of the used glass bottles.
- MySMARTLife[38] is an innovative European project focusing on smart solutions for urban transition.

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[30] https://www.nantes.fr/15lieux
[31] https://twitter.com/NantesCitylab
[32] https://www.creativefactory.info/
[33] http://www.nantes.fr/home/actualites/ville-de-nantes/economie/2017/ecoinnovation.html
[34] https://lacite-nantes.fr/nantes-labellisee-capitale-french-tech-465488.html
[35] https://ecossolies.fr/
[36] https://www.hacoopa.coop/decembre-2018-laureat-du-prix-de-linnovation-sociale/
[37] http://www.boutabout.org/
[38] https://www.mysmartlife.eu/cities/nantes/

5. The need for a stronger knowledge valorisation policy in Europe

Innovation encompasses several dimensions. As shown previously, innovation output – as defined by the composite indicator produced by the Joint Research Centre – includes four indicators: patents, employment in knowledge-intensive activities, the competitiveness of knowledge-intensive goods and services, and a measure of employment in fast-growing firms in innovative sectors (Vértesy and Damioli, 2020). The patents component includes inventions that use the knowledge generated by investing in R&D and innovation, and which can be transformed into successful technologies. Similarly, indicators for the intensity of skilled labour employment, in knowledge-intensive activities and in fast-growing firms provide an indication of an economy's orientation towards the production of goods and services with innovation added value. Finally, the trade flows associated with these commodities measure their capacity to reach global markets[39].

It is necessary to go beyond the approach of innovation output only, towards a more holistic approach in order to understand how knowledge is valorised, i.e. the process of creating value from knowledge and turning the results into sustainable solutions with economic value and societal benefits. This holistic approach should also include investments, knowledge flows, scientific performance and citizens' engagement. R&I can only play a decisive role in shaping the climate-ecological, social and economic transitions if excellent results are made available quickly and put to practical use on a large scale. This is fully in line with the Council Resolution of 29 May 2018 on 'Accelerating knowledge circulation in the EU'[40].

There is a need to reinforce knowledge valorisation in Europe. When looking at Figure 6.3-26, even though the EU outperforms the United States in terms of scientific output and number of researchers, it is surpassed in scientific quality, technological progress and the share of high-tech sectors in the economy. More worryingly, the EU lags significantly behind in terms of business-academia linkages. If Europe wants to catch up and become more competitive internationally, it needs to address its deficiencies by promoting a culture of knowledge valorisation in European R&I system, ensuring that the knowledge-based institutions know how to manage their intellectual capital and improving the links between academia, industry, citizens and policymakers.

A strong valorisation policy relies on a toolbox of instruments that acknowledges different knowledge valorisation channels. Many strategies, instruments and measures have been developed at the European, national and regional level, by private and public players, to enhance knowledge transfer and valorisation. For instance:

- **Academia-industry connections** as well as the interaction of innovative companies in different sectors provide key channels for knowledge diffusion and valorisation. The EU Framework Programmes and Member States support these collaborations through, for example, collaborative research, public-private partnerships, innovation brokers and other intermediaries, mobility programmes, knowledge clusters, startup finance schemes, etc. Digital solutions such as platforms

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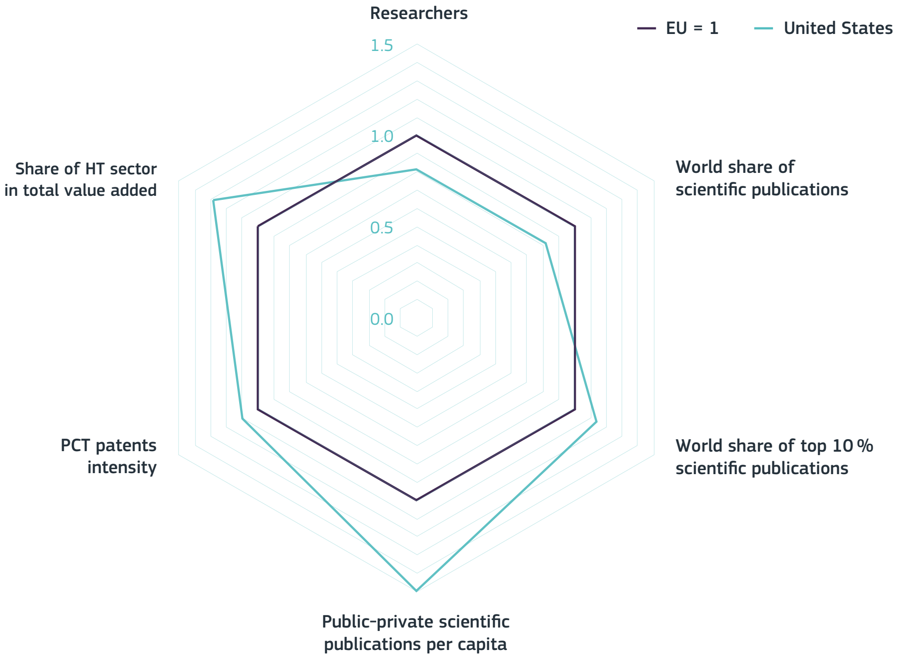
[39] COM(2013), Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions.

[40] https://data.consilium.europa.eu/doc/document/ST-9507-2018-INIT/en/pdf

Figure 6.3-26 Knowledge-valorisation approach, latest available year



Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on Eurostat, data produced by Science-Metrix using data from the Scopus database and OECD data

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter63/figure-63-26.xlsx

provide new opportunities for industry cross-fertilisation and for better linking the various actors in the innovation system, for instance, to connect the demand side, including end-user expectations, with the supply of innovations.

- Without **citizen engagement** even the best-designed strategies and activities for valorisation would not achieve the highest impact or sufficiently support the economic, social and ecological transition in an inclusive way – so that no community or region across Europe is left behind. A European knowledge valorisation policy also needs to ensure that it benefits all citizens, including by enabling research results and innovations to feed solutions in cities and regions across Europe that respond to their needs.

- **Intellectual property** fosters innovation, creativity and knowledge sharing, as the basis for progress, growth and employment. IP protection is a tool to balance the interests of both society and innovators. **Standardisation** facilitates the access to and spreading of new products in the market.

Examining and sharing experiences and best practices of knowledge valorisation can be a powerful way to improve national and European strategies and policies and to enhance the societal and economic uptake of research-based solutions across the Union.

6. Conclusions

This chapter shows that innovation output in the EU continues to lag behind Japan and the United States. Compared to the United States, the **EU is stronger in exporting high-tech manufacturing products and knowledge-intensive services**, but weaker in terms of qualified employment and patent applications. On the other hand, **Japan and South Korea are leading in patent applications and exports of high-tech products**. In terms of PCT patent applications, the EU and the United States have been losing their share to countries like Japan and China, while in the case of China, its growth has been particularly impressive, putting additional competitive pressure on the EU. The findings show that **if the EU wants to remain competitive and catch up with its main competitors it needs to make extra efforts, especially in supporting European IP policy, in fostering science-industry interaction and in improving its knowledge valorisation policy**.

The innovation divide within the EU remains stable. While north-western Europe performs relatively well in most of the indicators, south-eastern Europe performs relatively poorly. Despite the fact that the countries' economic structure also plays an important role in explaining the differences in innovation performance, the EU can still do more to reduce the innovation divide among its Member States by supporting the improvement of national innovation systems and facilitating knowledge circulation. Ultimately, tackling the innovation divide will help the EU as a whole to become more competitive and innovative worldwide.

The chapter also shows that **the share of innovation companies and innovation turnover fell in the EU between 2010 and 2016**. Nearly half of the companies in the EU are innovative, with higher shares for product and/or process innovation. In addition, around half of European SMEs are innovative. **Encouraging the creation of innovation-intensive sectors and upgrading the technology profiles of Member States** would definitely help the EU to have more innovative enterprises that can boost jobs and economic growth.

Last but not least, the figures show that the **EU is leading technological progress in the fields of transport, climate and energy**, where it shows the highest shares in terms of patent applications, while the United States leads in the health, bioeconomy and food and security sectors. In all fields, China has reported extraordinary increases in its share. Given the importance of innovation and technological progress in addressing the SDGs, the EU should **not only continue to invest in scientific leadership in these areas but should also promote a culture of knowledge valorisation able to benefit fully from its research results**.

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CHAPTER
7

R&I ENABLING ARTIFICIAL INTELLIGENCE

KEY FIGURES

60 %
of all AI science is in fields other than computer science

22 %
EU share in global AI publications

19 %
EU28's share in world AI firms

8 %
EU28's share of global AI private investments

>€20 bn
per year of EU private and public investments over the next decade

What can we learn?

- **AI is a potential game changer for productivity and sustainability**, providing the right complementary skills, infrastructure and management culture are in place.
- **R&I solutions are needed to mitigate the environmental footprint of AI.**
- **AI is a vital tool in the fight against the new coronavirus**. At the same time, the use of AI tracking and surveillance tools in the context of this pandemic has shown the need for global ethical governance of AI.
- **Data explosion, stronger computational power, more sophisticated algorithms and open source software** have enabled breakthroughs in AI R&I.
- **'AI dynamics'**: exploring the boundaries of scientific fields beyond computer science, with intersectoral and intensified cross-country collaboration, EU included.
- **The EU ranks among global leaders in AI science but trails in AI innovation**, although it is in line with its share in global R&D.
- **A gender diversity gap in AI research persists** but is less pronounced in Europe than in other regions worldwide.
- **Private investments and acquisitions of AI startups are on the rise. EU investments remain insufficient**. The United States leads, followed by China.
- **AI talent is relatively scarce worldwide** and appears more predominant in the United States than in the EU.
- **AI is increasingly blending with digital technologies**, such as blockchain, **and with the physical world** in fields like advanced manufacturing and materials science.

What does it mean for policy?

- **AI can play a big role in the economic, social and ecological transition** Europe is undergoing.
- **The EU should capitalise on its scientific and industrial strengths to lead in AI development** and to foster technologies that both benefit and augment its potential.
- **The EU and Member States need to join forces** to raise the level of public and private investments in AI, deepen the Digital Single Market, move towards AI technology sovereignty, and diffuse AI practices across the Union.
- **The EU needs to promote AI talent** production and retention in the EU (while attracting foreign talent), **investments and capacity-building in related digital technologies**, such as high-performance computing, European cloud and microelectronics, and research and digital infrastructure, notably 5G.
- The EU's guiding principles of **trustworthy, human-centric, and ethical AI are a strength and not an obstacle to the EU AI innovation ecosystem**. These will also improve the 'trust in tech' and safeguard privacy.

1. Artificial intelligence: a potential game changer for productivity and sustainability

Artificial Intelligence (AI) as a field of study is already 70 years old. In 1950, Alan Turing put forward the so-called 'Turing test' as a way of determining if a computer is capable of thinking like a human. John McCarthy, a computer scientist, then coined the term 'artificial intelligence' during a conference in 1955. Between 1955 and 1997 – when IBM's Deep Blue defeated Gary Kasparov, world chess champion – there were periods of progress in the field, often restricted to highly specific applications and notably in natural language processing and neural networks. However, there were also periods known as 'AI winters', brought about by overly big expectations, a lack of practical applications of AI and, ultimately, reductions in AI research funding. In 2006, developments in deep learning generated further enthusiasm around AI. Importantly, the rise of big data allied to greater cloud and computing-processing capabilities boosted numerous developments in the field. Nowadays, AI is not only present as a tool in scientific research and industry activities but is also increasingly in everyday life.

Although there is currently no established global definition of AI, a recent definition put forward by the High-Level Expert Group on AI, set up by the European Commission[1], is presented in Box 7-1. It includes the sub-disciplines described in Figure 7-1, namely machine learning (and, within this category, deep learning and reinforcement learning), reasoning processes as well as intersections with robotics fields, for example, sensors.

BOX 7-1 Towards an AI definition

Artificial intelligence (AI) systems are software (and possibly also hardware) systems designed by humans that, given a complex goal, act in the physical or digital dimension by perceiving their environment through data acquisition, interpreting the collected structured or unstructured data, reasoning on the knowledge, or processing the information derived from this data and deciding the best action(s) to take to achieve the given goal. AI systems can either use symbolic rules or learn a numeric model, and can also adapt their behaviour by analysing how the environment is affected by their previous actions.

As a scientific discipline, AI includes several approaches and techniques, such as machine learning (of which deep learning and reinforcement learning are specific examples), machine reasoning (which includes planning, scheduling, knowledge representation and reasoning, search, and optimisation), and robotics (which includes control, perception, sensors and actuators, as well as the integration of all other techniques into cyber-physical systems) (see Figure 7-1).

Source: European Commission (2019), Report by the High-Level Expert Group on AI set up by the European Commission

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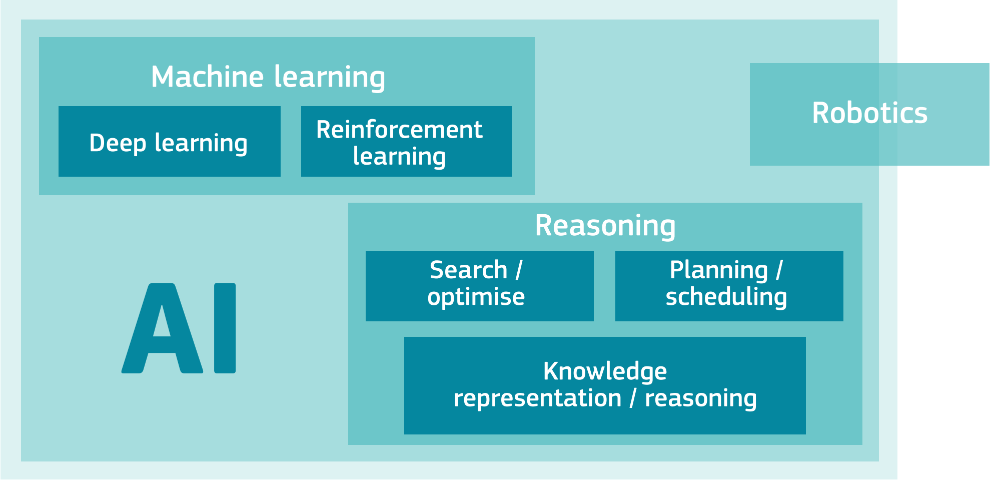
[1] Based on European Commission (2019), Report by the High-Level Expert Group on AI set up by the European Commission.

Figure 7-1 A simplified overview of AI's sub-disciplines and their relationship



Science, research and innovation performance of the EU 2020

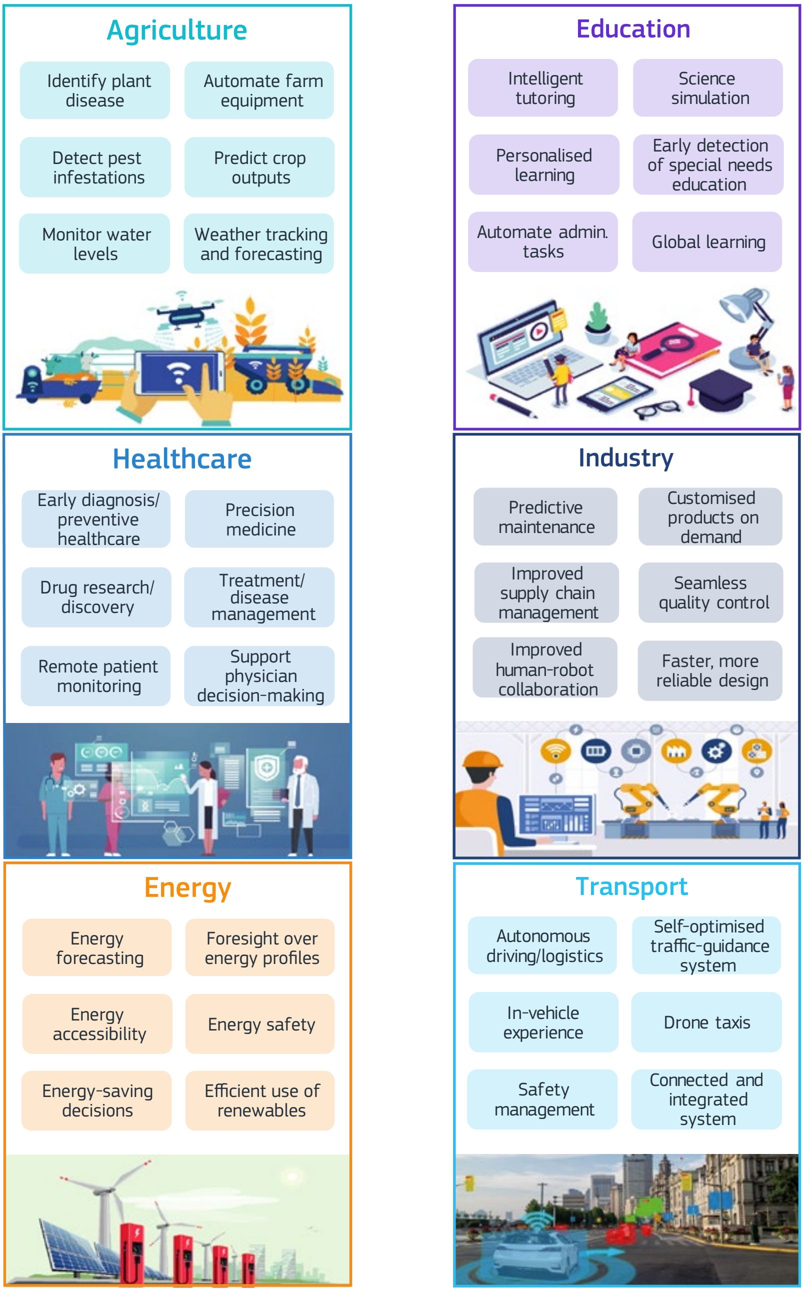
Source: European Commission (2019), Report by the High-Level Independent Expert Group on AI

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter7/figure-7-1.xlsx

Achieving the full potential of AI for productivity depends on having in place the right complementary skills, infrastructure, and management culture. The fact that AI is seen by many as the 'new electricity' relates to its cross-cutting applications that make it a general-purpose technology capable of driving efficiency and productivity in virtually all sectors of the economy. By optimising operations and enabling accurate predictions, AI can also potentially be a powerful tool to help achieve the Sustainable Development Goals. However, while digital technologies such as AI hold a lot of promise for boosting growth and competitiveness, productivity growth remains lackluster. Chapter 3.1 - Productivity puzzle and innovation diffusion highlights potential explanations for this, notably the widening productivity gap between the most- and least-productive firms due to insufficient innovation diffusion and the rising market concentration around 'superstar firms'.

In the specific case of AI, Brynjolfsson et al. (2017) point to the time lag in implementing new technologies such as AI, or potential productivity mismeasurements following a 'J-curve' (Brynjolfsson et al., 2018). Moreover, AI investments depend on other complementary efforts and intangible investments that may take some time to materialise. These might include organisational and managerial changes and the need to acquire new skills or retrain staff, among others. The authors refer to the steam engine, electricity, and the internal combustion engine to argue that their impact also took some years (even decades) to be felt. Furthermore, AI can enable faster scientific discovery (OECD, 2018a) especially at a time when research productivity may be falling and new ideas seem harder to find, as highlighted by Bloom et al. (2017). Finally, AI can help increase productivity by helping humans use increased capabilities faster, and enabling more reliable forecasting, more flexibility in operations based on huge amounts of data, more precision, etc. On the other hand, automation entails risks as regards replacing many jobs and tasks as well as other issues related to the future of work, as addressed in Chapter 4.1- Innovation, the future of work and inequality.

Figure 7-2 Examples of cross-sector applications of AI as a general-purpose technology to optimise operations and increase efficiency



Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on Statista - AI report (2019), fao.org - State of food nutrition, futurefarming.com, Forbes - How Is AI Used In Education, European Commission (2018), PwC, Forbes with Intel – Sizing Up AI's Predictive Analytics Powers In Healthcare: Top Use Cases, softwebsolutions.com. Images © Ico Maker, #265312009, 2019; © Monopoly919, #188158746, 2019; © Francois Poirier, #209725591; © irinastrel123, #206006119, 2019; © mast3r, #180336886, 2019; © Mykola, #284569356, 2019; © petovarga, #166430109, 2019. Source: stock.adobe.com

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter7/figure-7-2.xlsx

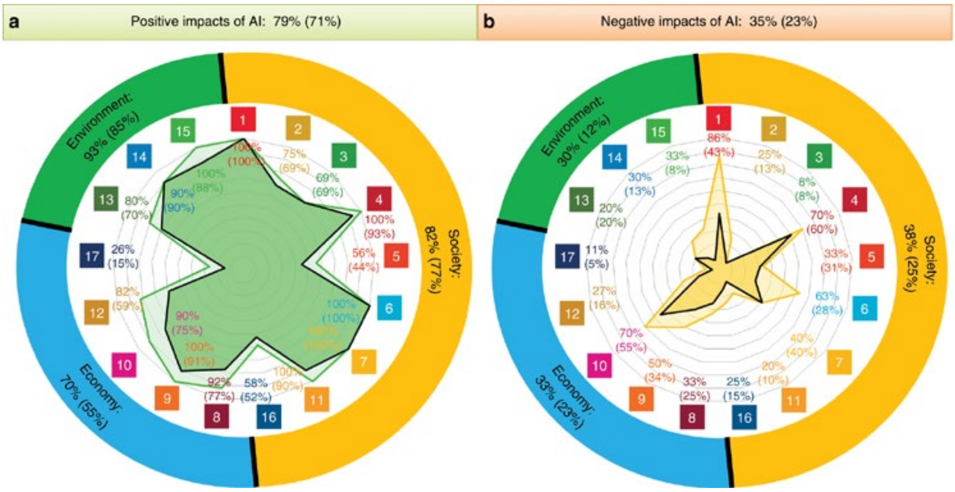
As a general-purpose technology, AI applications can boost productivity, improve predictions, and contribute to greater energy efficiency in virtually any sector of the economy. Figure 7-2 provides some concrete examples of AI applications across different sectors of the economy. For example, in agriculture, AI technologies can better predict crop outputs and detect pest infestations. In healthcare, AI can contribute to drug discovery and early diagnosis. In industry, operations such as supply chain management can be optimised and quality control improved. In energy, power-grid optimisation can rationalise energy supply based on demand. However, AI applications also pose some risks or face certain obstacles. OECD (2019a) stresses that in agriculture the lack of network connections in rural areas may undermine the use of sophisticated systems, and high-tech farms may require costly investments in automation tools and sensors. In addition, in healthcare the data privacy of patients must be taken into account.

The role of AI in tackling global challenges should not be underrated. In fact, AI and other digital technologies can be important channels towards cutting global greenhouse gas emissions. At the same time, AI itself may be a contributor to further emissions, namely due to greater energy consumption resulting from, for example, data centres and supercomputers. R&I can act as a mitigator by contributing to energy-efficient computing and 'greener' solutions. According to the Global Action Summit (2018), AI and digital technologies can contribute to cutting global emissions across sectors. For instance, annual emissions from the energy supply would be reduced via better grid flexibility and storage. Efficient shipping would also be an important channel for reducing the emissions from the transport sector, and precision agriculture could reduce the sector's footprint.

With growing digitalisation and ever-larger data flows, the need for both network capacity and computing power has increased enormously. As a result, energy demand from data centres and data-transmission networks could be on the rise. Andrae (2017) estimates that data centres could account for 10% of total electricity use by 2025. Fortunately, the International Energy Agency (2019) argues that to date technological progress in energy efficiency has contributed to limiting the growth of electricity demand and usage. In fact, accordingly, there has been a *shift away from small, inefficient data centres* towards much larger cloud and hyperscale data centres. Indeed, trade-offs may occur. As discussed in Vinuesa et al. (2020), while AI can act as an enabler in 79% of all SDG targets, the progress of 35% of them may be inhibited by AI, at least to some extent (Figure 7-3). As stated by the authors, this requires policies that help direct the vast potential of AI towards the highest benefit for individuals and the environment, as well as towards achieving the SDGs.

Thus, R&I can be a powerful ally by generating 'greener' solutions. At the EU level, the EuroHPC Joint Undertaking will develop a 'world-class supercomputing ecosystem in Europe' that will also use R&I to develop a low-power processor, for example. However, concerns over the environmental footprint of AI and data centres will remain in both the short and long run. According to Strubell et al. (2019), training a deep learning model could be equivalent to that of the lifetime of five cars, which calls for the greater mobilisation of R&I efforts to boost the energy efficiency of digital technologies, and eventually to replace the most-pollutant technologies with more energy-efficient or even carbon-neutral ones.

Figure 7-3 Summary of positive and negative impacts of AI on various Sustainable Development Goals (SDGs)



Source: Vinuesa, R., Azizpour, H., Leite, I. et al. (2020)
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter7/figure-7-3.xlsx

AI-powered solutions can be important tools to help in the fight against a pandemic such as COVID-19. However, increased surveillance and tracking systems have also reinforced the need for global ethical governance of AI. Box 7-2 illustrates how AI and other digital technologies are being used to provide solutions that can help in the fight against COVID-19.

BOX 7-2 How artificial intelligence is used in the fight against the COVID-19 pandemic

AI, big data and other digital technologies are vital tools for helping to fight a pandemic such as COVID-19.

In just one week, scientists in China were able to recreate the genome sequence of the virus by using AI. The Canadian start-up BlueDot detected an outbreak[2] of pneumonia cases in Wuhan in December and identified the cities that were at the highest risk of facing their own outbreaks.

AI has been used to detect visual signs of COVID-19 on images from lung CT scans, monitoring changes in body temperature in real time, providing an open-source data platform to track and monitor the spread of the disease, and is increasingly being used to help identify potential treatments and cures. At the same

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[2] https://www.cnbc.com/2020/03/03/bluedot-used-artificial-intelligence-to-predict-coronavirus-spread.html

time, the use of AI tracking and surveillance tools in the context of this pandemic has clearly shown the need for a global ethical governance of AI.

AI solutions in the fight against COVID-19

All over the world, ambitious R&I projects and collaborations to track, monitor and contain the COVID-19 pandemic are increasingly being carried out, including AI-powered solutions.

AI-related applications have **enabled population screening, tracking the spread of the infection[3], and the detection and diagnosis of COVID-19**. The new Pan European Privacy- Preserving Proximity Tracing initiative, compromising more than 130 members across eight European countries, is one of several endeavours to set up a tracking system using mobile phones and anonymised data in compliance with the European GDPR. An important challenge in this respect would be to ensure the compatibility of such national systems across the EU.

AI is also used to further speed up the drug-development process by modelling the efficacy of these drugs prior to clinical trials. In this context, AI could also optimise the process of clinical trials to discover new and effective drugs and vaccines.

As mentioned in Ting et al. (2020), 'the utilization of various AI-based triage systems could potentially alleviate the clinical load of physicians'. This includes, for instance, online medical 'chat bots' to guide patients in understanding their symptoms, providing guidelines for hand washing, and guiding patients through the next steps should their symptoms worsen. Another important use of AI is in fighting misinformation, for instance on social media channels.

An inventory of AI and robotics solutions to tackle COVID-19

The European Commission has launched an initiative to collect ideas about deployable AI and robotics solutions as well as information on other initiatives that could help us to face the ongoing COVID-19 crisis[4]. To date, this inventory has shown that the R&I community and enterprises have been very active in coming up with such solutions. For example, the Lucentia Lab in Spain has developed a platform for big data and AI for handling patients. In Belgium, KU Leuven has deployed therapeutics for the treatment of SARS-CoV infection, and there are many other examples.

Open data based on FAIR principles[5] and high-performance computing[6] are key

Openly accessible, machine-readable, inter-operable data is needed to track, monitor and forecast the spread of COVID-19. Key datasets include clinical, epidemiological and laboratory data. At the EU level, the **Action Plan - Research data-sharing platform for the SARS-CoV-2 and COVID-19 disease**, launched by the EMBL's European Bioinformatics Institute (EMBL-EBI) and the **European Open Science Cloud** intends to speed up and improve the sharing, storage, processing of and access to research data and metadata on the SARS-CoV-2 and COVID-19 diseases.

The goal is to start making these data available from the end of April through a new European data platform which is also connected to the European Open Science Cloud. This will allow the

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[3] https://www.bruegel.org/2020/03/artificial-intelligence-in-the-fight-against-covid-19/

[4] https://ec.europa.eu/digital-single-market/en/news/join-ai-robotics-vs-covid-19-initiative-european-ai-alliance

[5] Findable, Accessible, Interoperable and Reusable by both humans and machines, https://www.go-fair.org/fair-principles/

[6] https://ec.europa.eu/digital-single-market/en/news/using-european-supercomputing-treat-coronavirus

scientific community to share, analyse and process them rapidly, openly and effectively **across the Member States** and worldwide in line with the relevant EU data legislation.

Three powerful European supercomputing centres – located in Bologna, Barcelona (Spain) and Jülich (Germany) – are participating in the EXSCALATE4CoV[7] project, along with a pharmaceutical company and several large biological and biochemical institutes. The project is now processing digital models of the coronavirus' protein and matching them against a database of thousands of existing drugs, aiming to discover which combinations of active molecules could react to the virus. The project has received EUR 3 million in funding from the EU's Horizon 2020 for research into COVID-19 vaccine development, treatment and diagnostics.

EU projects mobilised to forecast and model the pandemic[8]

The EPIWORK[9] project aimed to develop a set of tools and knowledge to design infrastructures that could forecast epidemics. It resulted in the Global Epidemic and Mobility Model project (GLEAM)[10] to deliver the analytic and forecasting power that could minimise the impact of potentially devastating epidemics. Researchers who worked on these projects are currently using the results to try to understand how the current pandemic may spread, how it may evolve over time and how containment and prevention measures may help.

AI solutions could also help to provide scenarios for a gradual exit from the lockdown by guiding the necessary social distancing and adapting the measures to the corresponding risks.

2. Global AI trends

Data explosion, stronger computational power, more sophisticated algorithms and open source software have fostered significant developments in AI R&I. The volume of data and information created has increased dramatically from just two zettabytes in 2010 to 26 in 2017 and is expected to reach 175 zettabytes by 2025 (Figure 7-4). This data explosion has been fuelled by the digital transformation of firms, economies and societies. Nowadays, the sources of data production include not only transactional and personal data, but also social interactions and machine-generated data. Indeed, the use of personal devices such as smart phones has boosted the number of interactions online through, for example, video views and engaging in social media platforms. In addition, greater cloud capacity has enabled the management and storage of big datasets. The connection of different Internet of Things (IoT) devices has also generated large amounts of new data. As a result, the increasing production of data combined with more sophisticated techniques to explore and analyse databases have enabled important developments in AI, notably in deep learning. However, not only huge amounts of data are needed for accurate predictions – the data must also be high quality. Moreover, important privacy and ethical issues related to data should also be taken into account, as highlighted later in this chapter.

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[7] https://www.exscalate.eu/en/

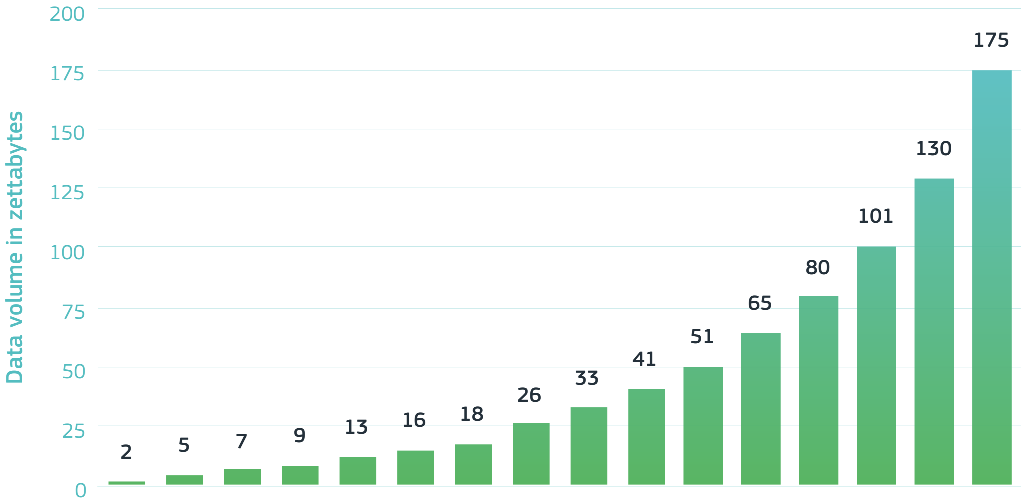
[8] https://ec.europa.eu/digital-single-market/en/news/forecasting-coronavirus-pandemic-help-eu-projects

[9] https://cordis.europa.eu/project/id/231807

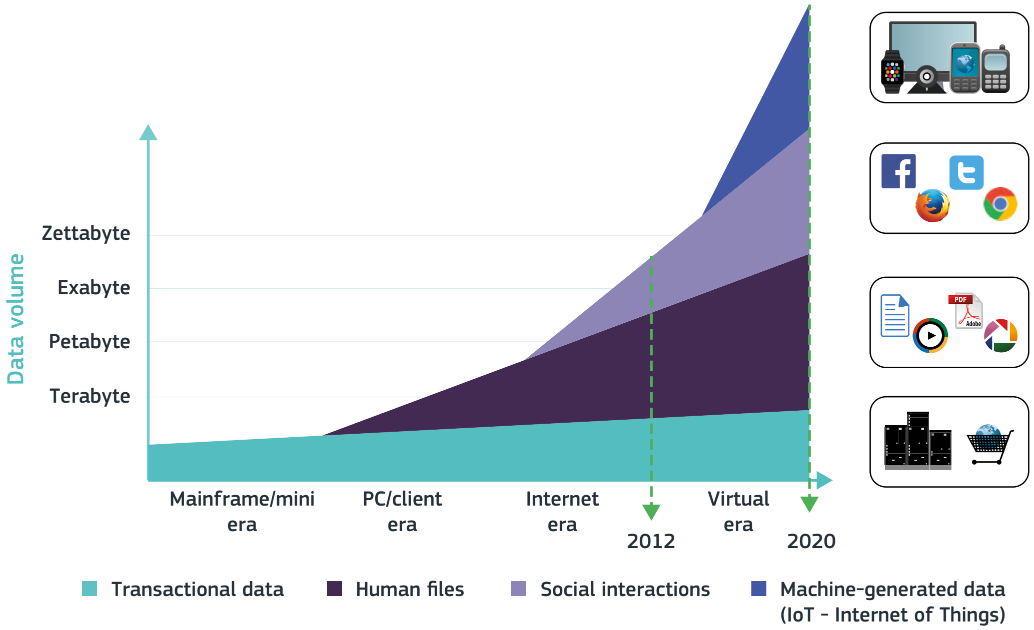
[10] http://www.gleamviz.org/

Figure 7-4 The data explosion: sources and evolution over time

Volume of data/information created and forecast worldwide in zettabytes, 2010-2025



Evolution of data (main sources)



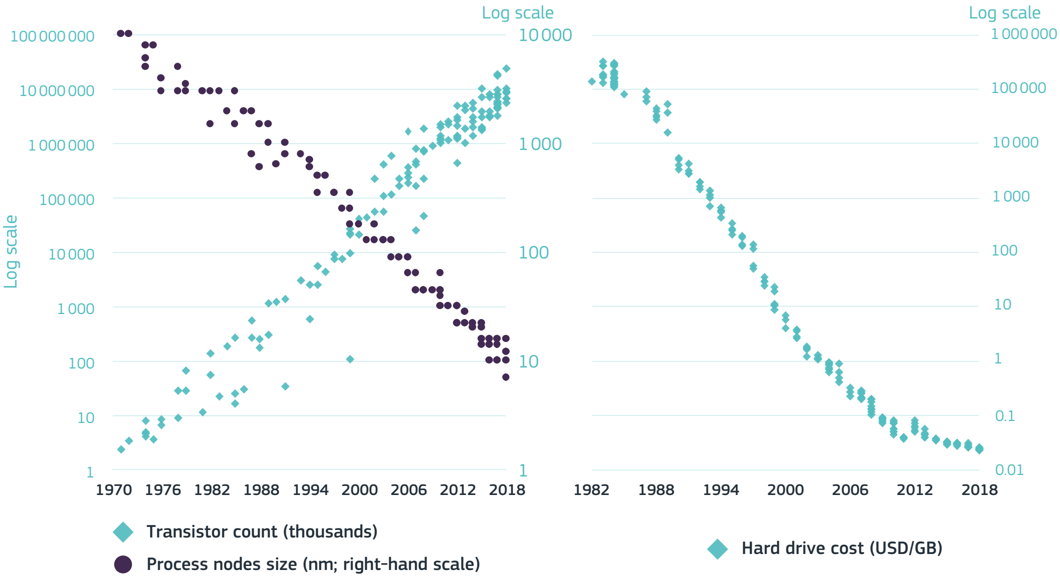
Source: https://medium.com/@melodyucros/ladyboss-heres-why-you-should-study-big-data-721b04b8a0ca, and IDC; Seagate; Statista estimates

Note: Values are estimated.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter7/figure-7-4.xlsx

Breakthroughs in computing and the decrease in the cost of storage have contributed to greater and cheaper computing capacity to process large volumes of information (Figure 7-5). Indeed, using the number of transistors per chip as a proxy for computational power, the OECD (2019a) finds that capacity has doubled every two years since the 1970s. Greater speeds and energy efficiency have also been achieved thanks to the continuing miniaturisation of transistors.

Figure 7-5 Computing power and cost of storage(1), 1970-2018 and 1982-2018



Source: OECD (2019a)

Note: (1)Number of transistors per central processing unit (CPU) microprocessor and process size (left-hand panel), cost of storage per GB (right-hand panel).

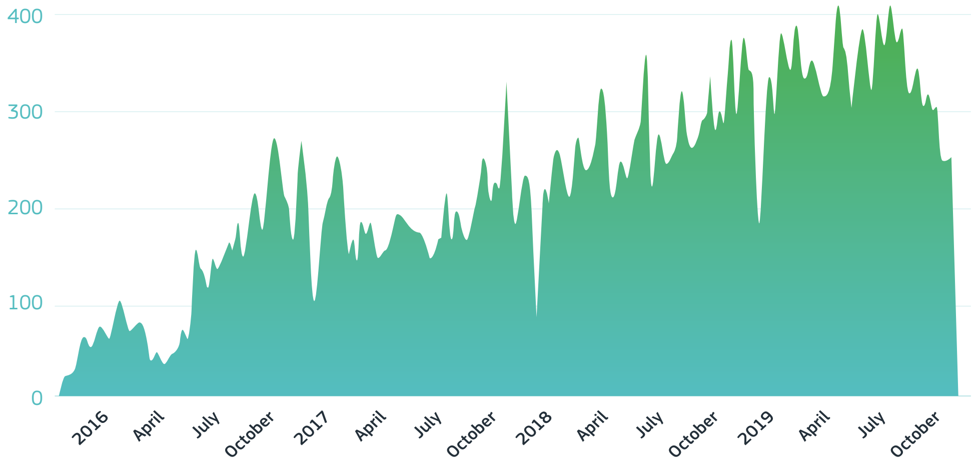
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter7/figure-7-5.xlsx

Open-source software has enabled developments in AI and, in particular, in deep learning research. In fact, open-source tools have lowered the barriers to entry in the field of AI (CBInsights, 2019a) and are contributing to advancing research (and research productivity) in the AI field by sharing code among a community of users who can build their research upon already-existing code and can potentially improve it. Figure 7-6 shows that user traffic in one of the most popular open-source software tools – TensorFlow (a machine-learning library created by Google) – has increased remarkably since it became open and free-of-charge to the world in 2015. A year later, Google also made available to developers its DeepMind Lab training environment codebase on GitHub so that the community could use it to train AI systems on Google's code.

Sharing code is, however, not a practice specific to Google; on the contrary, it is also done by other organisations and

researchers[11]. Users benefit from these open and collaborative environments, as do the companies making it freely available as a community of contributors will be helping them in turn to accelerate their AI-related research. There are clearly important implications for new business opportunities, as companies can build on open source software and create new solutions, boosting innovation. On the other hand, this has important implications for cybersecurity. Also important in this context is the role of data – and data openness (data that are used for research questions but also for new solutions and business opportunities).

Figure 7-6 **Number of users contributing to TensorFlow every month on GitHub, November 2015 - November 2019**



Source: GitHub, accessed on 19-11-2019

Note: Contributions to master, excluding merge commitments.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter7/figure-7-6.xlsx

BOX 7-3 The vision of the Horizon 2020 project AI4EU, the AI-on-demand platform

The development and deployment of AI technologies in Europe are still being hindered by a number of gaps and challenges: a fragmented AI research landscape, difficulties in scaling up startups, limited uptake of AI technologies, instability of funding for AI research labs, and limited industrial investments. Among the projects funded under the European research and innovation programme (Horizon 2020), **AI4EU**[12] is aiming to tackle some of these issues.

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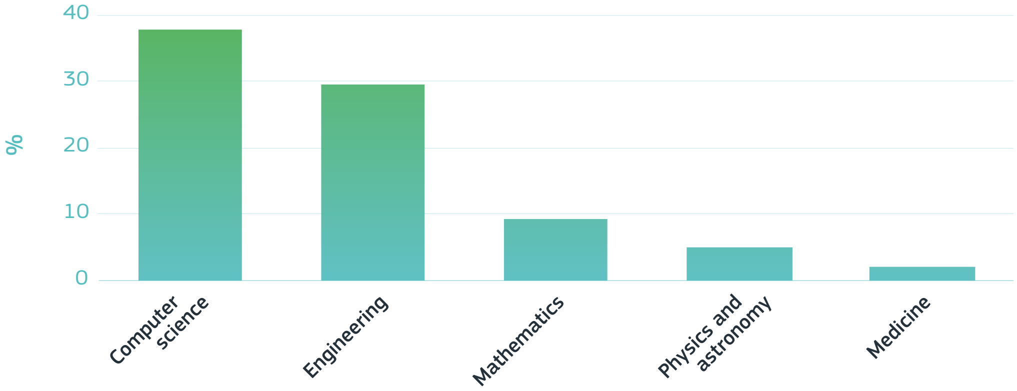
[11] Other examples of open platforms include Amazon Machine Learning (AML), Microsoft Azure Machine Learning Studio, Microsoft CNTK, Caffe, etc.

[12] https://www.ai4eu.eu/

AI4EU, the AI-on-demand platform, is gradually building a platform which allows the AI community to publish and exchange AI assets and skills. It will serve as a **channel** providing access to all **European AI resources** to all related communities, both researchers/developers and users, identifying synergies, avoiding fragmentation and sharing resources, expertise and skills. This platform will also collaborate with the network of Digital Innovation Hubs[13] distributed all over Europe which is helping local economies to take advantage of what technologies such as AI have to offer. In addition, as access to data in Europe is often in silos, with no standard data structures, the AI4EU on-demand platform can improve the facilitation of access to data and knowledge sources.

'Deep-tech' and, in particular, AI, are the result of the co-development of hard-core science and technology. AI is increasingly exploring the boundaries of scientific fields beyond computer science. Deep-tech innovations are typically very 'science-intensive' and allied to sophisticated technology. Using text-mining techniques, the OECD (2019) compiled the scientific fields underpinning AI-related documents between 1996 and 2016 (Figure 7-7). Although computer science has (as expected) made a major contribution to AI science, of almost 40 % to AI publications, 60 % of which actually refer to other scientific fields: engineering corresponds to 30 %, followed by mathematics (9 %), physics and astronomy (5 %) and medicine (2 %). The remaining 13 % are spread across a wide diversity of fields (Figure 7-8).

Figure 7-7 Top 5 scientific fields for AI-related scientific documents as a percentage of all AI-related documents, 1996-2016



Source: OECD (2019a), Measuring the Digital transformation

Note: Calculations based on Scopus Custom data, Elsevier, Version 1.2018, January 2019.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter7/figure-7-7.xlsx

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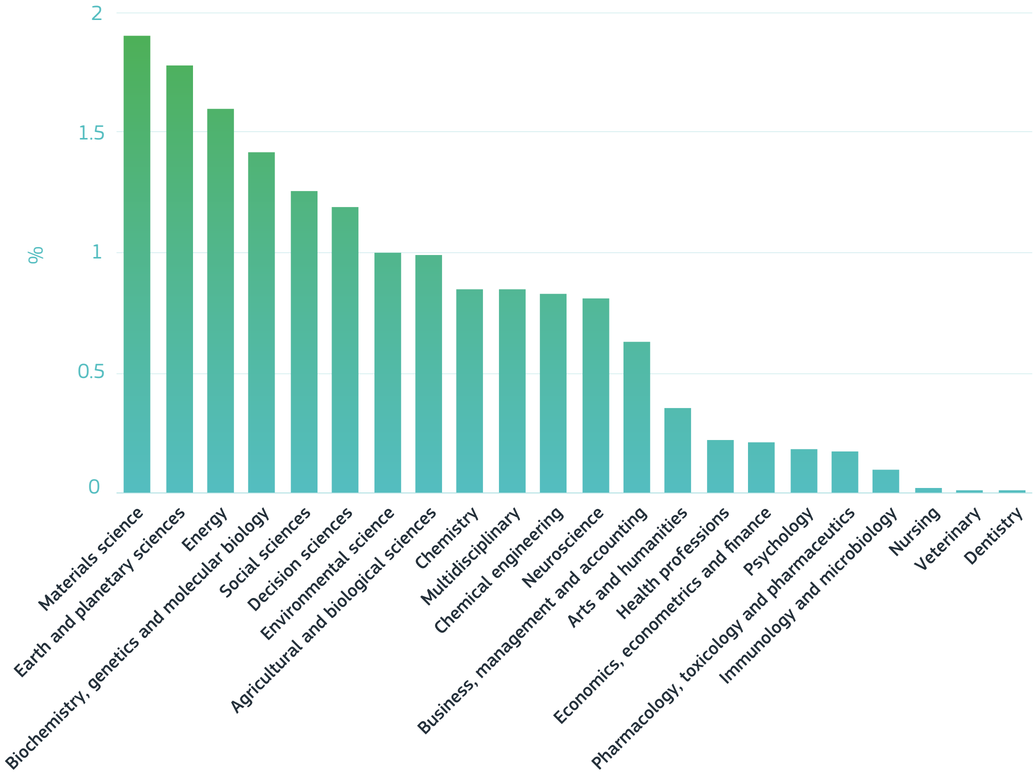
[13] https://ec.europa.eu/digital-single-market/en/digital-innovation-hubs

Figure 7-8 Other scientific fields for AI-related scientific documents as a percentage of all AI-related documents, 1996-2016



Source: OECD (2019a), Measuring the Digital transformation

Note: Calculations based on Scopus Custom data, Elsevier, Version 1.2018, January 2019.

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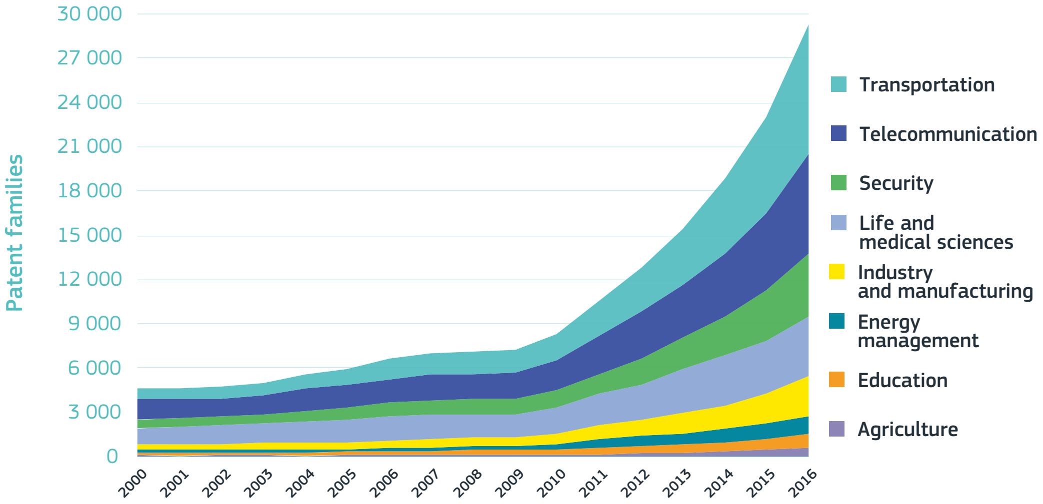
In the case of AI, Motohashi (2018) found that the co-development of science (proxied by research articles) and technology (proxied by patents) in AI has been fostered by the intersectoral mobility between academia and firms, i.e. ‘those who had published AI-related publications in public research organisations later became involved in patenting activities at a private company (either through a joint appointment or by moving job)’. Hence, academia and public research organisations have an increasingly important role in AI-driven innovations which has been intensified by greater mobility.

The role of intellectual property (IP) in AI spin-offs also needs to be better understood. For example, it has been suggested that the standard technological discovery model does not apply in spin-outs based on machine learning that may rely instead on know-how on the part of the academic founders, which is central to the new business (Royal Society, 2017).

Since 2009, there has been a boom in AI patenting, notably in the fields of transportation, telecommunications, security, and life and medical sciences. Figure 7-9 depicts the evolution of patent families for the top selected AI application categories between 2000 and 2016. It can be seen that, since 2009, patenting activity has grown across all sectors identified in the graph, with the most pronounced increases in transportation, telecommunications, security, and life and medical sciences.

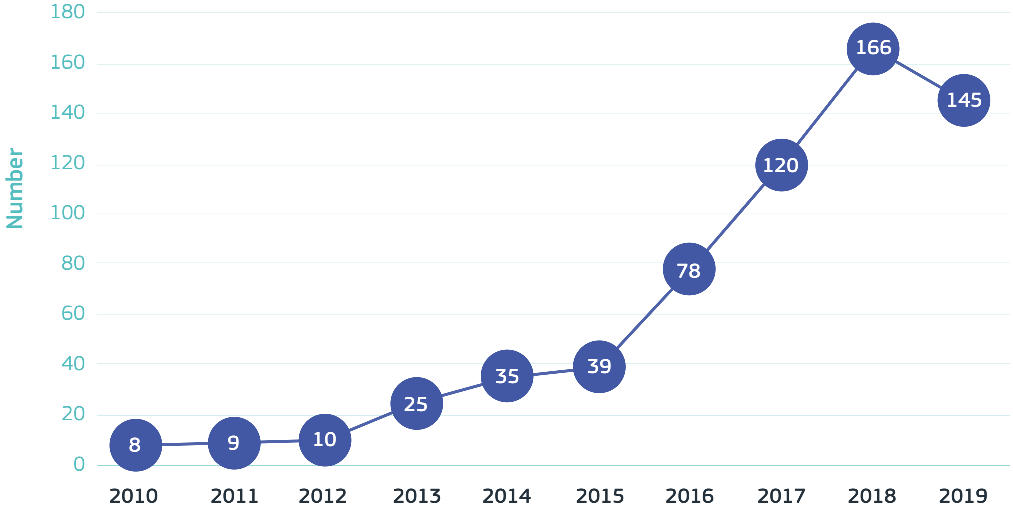
Acquisition of AI startups is increasingly regarded as a strategic move by acquirer companies to acquire data and absorb new AI knowledge and capacities. Cumulatively, CBInsights reports that between 2010 and 2019 (August) there were 635 acquisitions of AI companies. According to the WIPO (2019), most of the companies acquired are young startups with a median age of three years old. Accordingly, these companies tend to specialise in virtual assistants, big data analytics for recommendation systems, and image recognition, using machine learning as the main technology. From Figure 7-10 it is possible to conclude that acquisitions have become more common in recent years – in particular, around two thirds of all AI acquisitions occurred between 2017 and 2019. This is also in line with the general trend in the growing number of acquisitions worldwide, as described in Chapter 8 - Framework conditions. Moreover, the WIPO (2019) highlights that acquisitions in the AI sector can complement IP and development efforts since they may reduce the need for the acquirer to patent. The authors illustrate this argument with the example of Alphabet which has acquired a substantial number of AI companies 'while at the same time reducing its patent filing activity over the last several years'.

Figure 7-9 Patent families for top selected AI application patent field categories, by earliest priority year, 2000-2016



Source: WIPO Technology Trends 2019: Artificial Intelligence, based on Questel Orbit Intelligence, Fampat Database, March 2018
Note: A patent may refer to more than one category.
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter7/figure-7-9.xlsx

Figure 7-10 Number of AI acquisitions by acquisition year, 2010-2019[(1)]



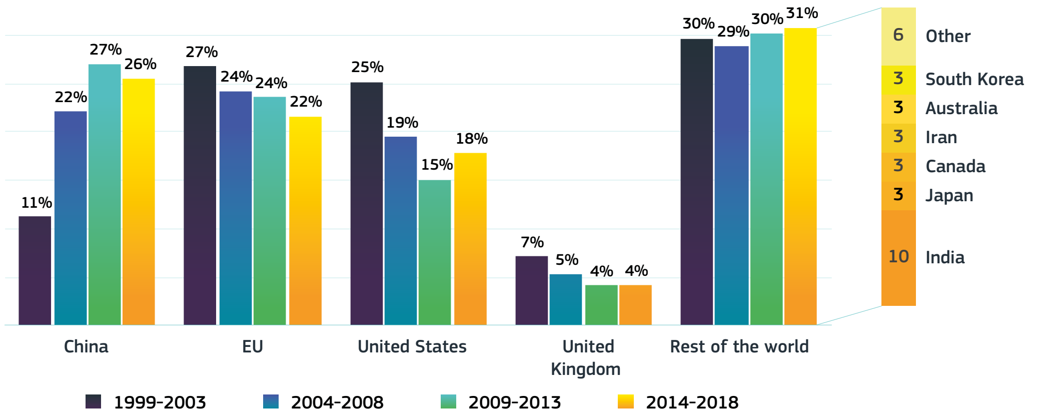
Source: CBInsights (2019), 'The Race For AI: Here Are The Tech Giants Rushing To Snap Up Artificial Intelligence Startups'
Note: [(1)]Data as of 31/08/2019 hence not covering the whole year.
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter7/figure-7-10.xlsx

3. EU ranks among global leaders in AI science

Although the EU ranks among global leaders in AI scientific production and excellence, its position has been deteriorating over time, while China has risen quickly. Globally, the weight of EU publications in AI has been on the decline since 2003, although it still ranks among the global leaders in AI scientific production (Figure 7-11). Indeed, between 2013 and 2017, the EU accounted for 22 % of world publications in AI, down from 27 % from 1999-2003. This compares with 26 % in China (up from only 11 %), and 18 % in the United States (down from 25 %). Thus, China has been emerging quickly as the global leader in scientific production in the AI domain. Other players, such as India (with a 10 % share) and the United Kingdom (with a 4 % share) have also been quite active in AI publishing.

Within the EU, Germany, France and Spain are the top producers of AI publications though the highest shares relative to national publications are in Luxembourg, Greece, and Cyprus. In the EU, Germany, France, Spain and Italy are the top producers of publications in AI (Figure 7-12). The United Kingdom also stands out as a major AI publishing nation in Europe. However, the size of these countries (e.g. GDP, population) is potentially correlated with the number of publications. For this reason, we have looked into the share of AI publications in relation to national publications. Having taken the size of the country into account, Luxembourg, Greece and Malta emerge as the EU Member States with the highest shares of AI scientific publications, corresponding to 3.7 %, 3.3 %, and 3.3 %, respectively, of all publications. The average citation impact is highest in the Netherlands, Austria, Belgium and Denmark. Switzerland's AI publications have the largest citation impact of the group of Associated Countries in the graph.

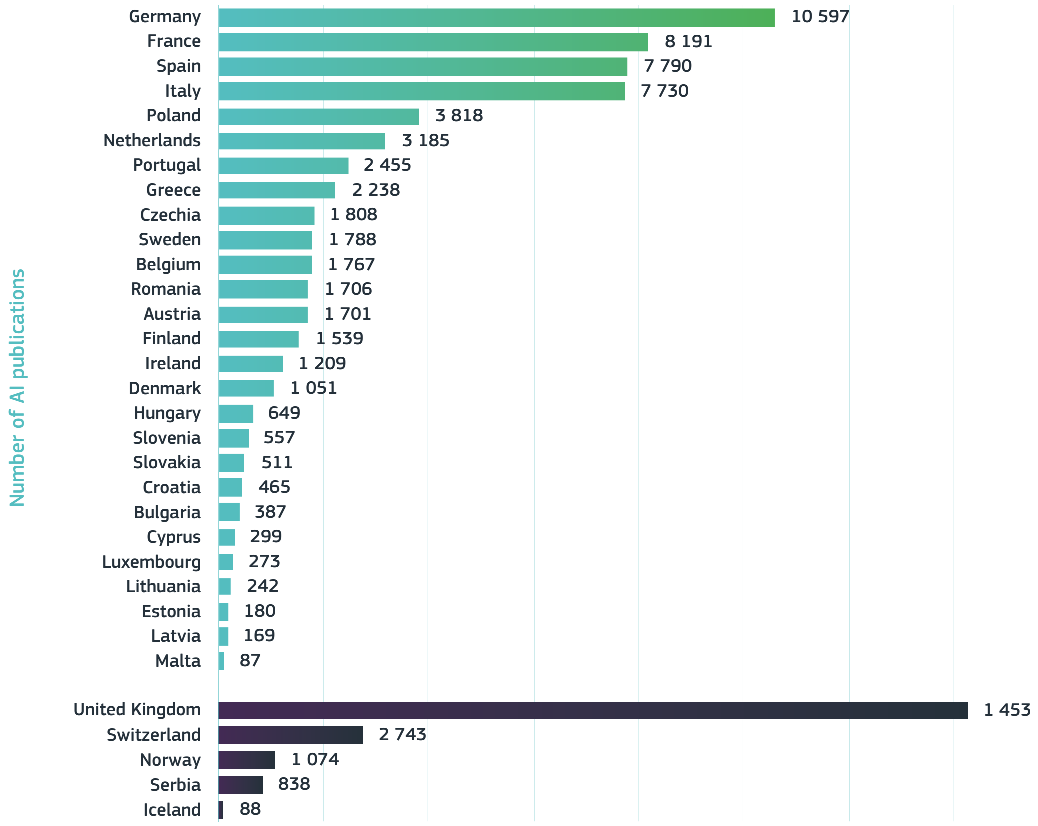
Figure 7-11 Share of world publications in artificial intelligence in selected regions (%), 1999-2018

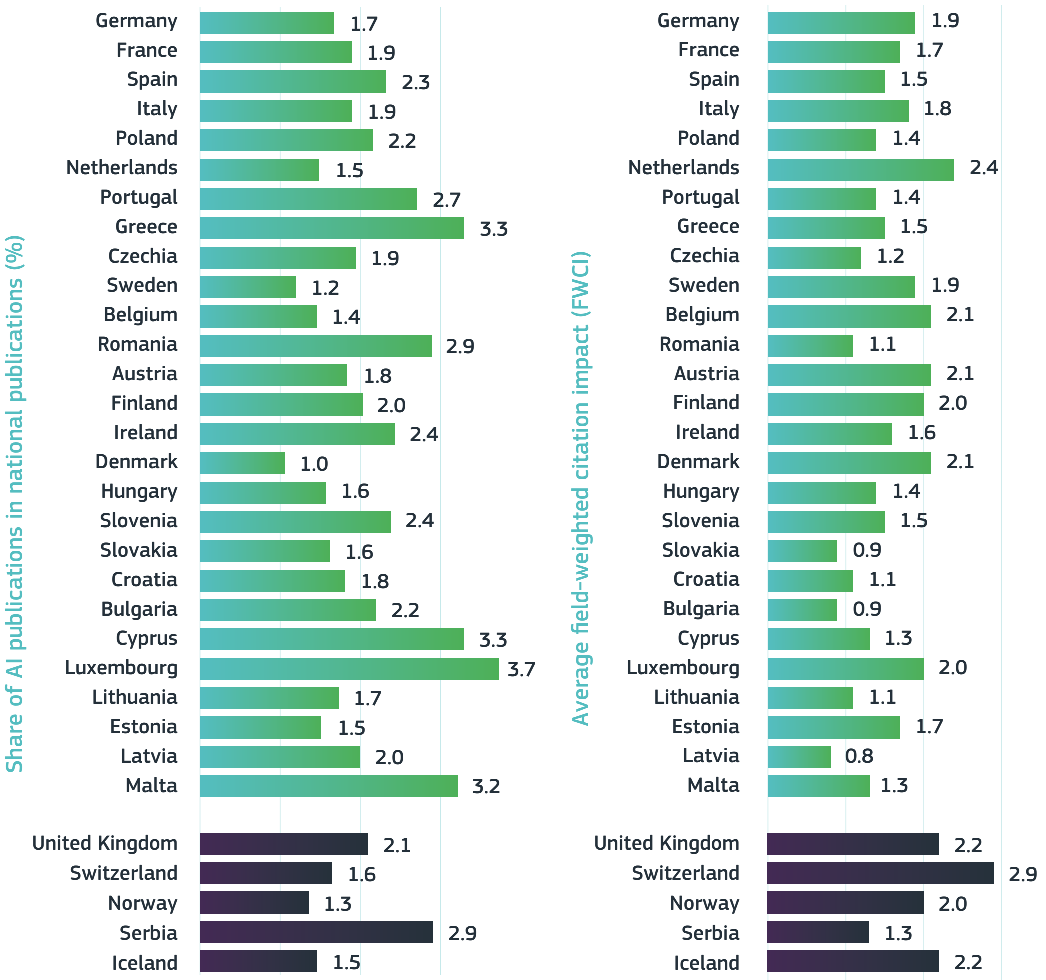


Source: Elsevier (2018)

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter7/figure-7-11.xlsx

Figure 7-12 Number and share of publications in AI by country, and related field-weighted citation impact (FWCI) by country, 2015-2018



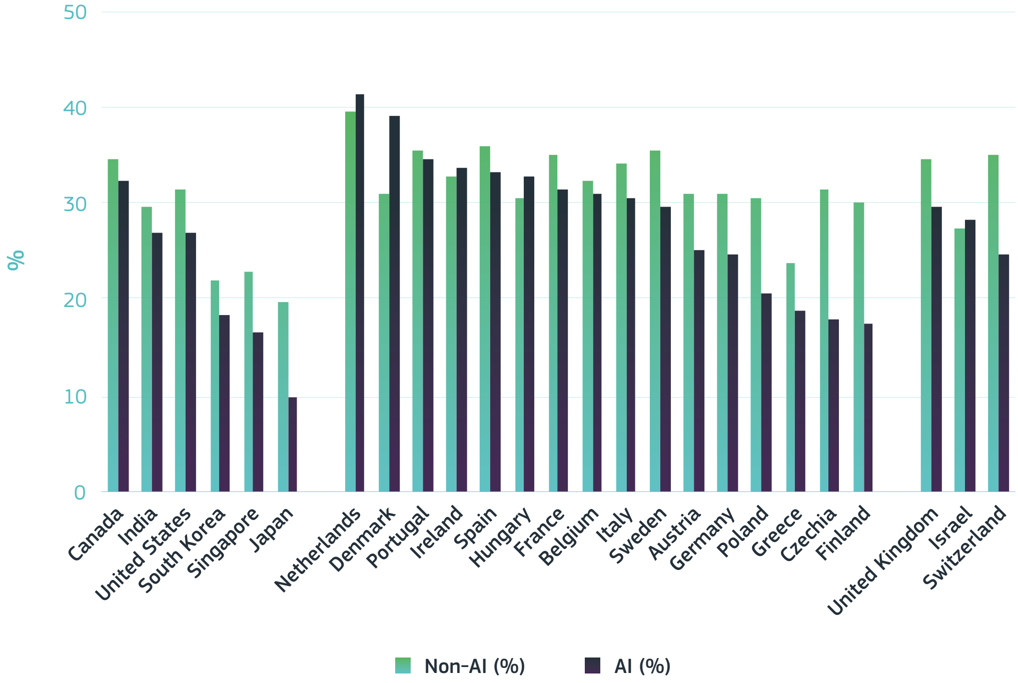


Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on Elsevier (2018)
Note: Both the AI publications and the total publications used to compile the ratio of AI publications in all publications reflect only publication types, articles, reviews, and conference proceedings to ensure they are comparable.
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter7/figure-7-12.xlsx

The lack of gender diversity in AI research persists, although there has been progress over time, notably in European countries. As reported by NESTA (2019), a gender diversity gap in AI research (using the arXiv repository) continues to be prominent (Figure 7-13). Within the EU, in 2018, the share of papers with at least one female author was highest in the Netherlands (42 %), Denmark (39 %) and Portugal (35 %). Moreover, in most EU Member States represented in the study, gender diversity was higher than in non-EU countries such as Canada, the United States, South Korea and Japan. It is also interesting to note that in the Netherlands, Denmark, Ireland and Hungary, the share of female authors in AI papers actually appears higher than in non-AI papers, contrary to the global picture. When looking at trends over time, the AI Index 2019 highlights the growth of female authorship between 2000 and 2018, with the most visible increases overall taking place in European

Figure 7-13 Percentage of AI and non-AI papers with at least one female author by country, 2018



Science, research and innovation performance of the EU 2020

Source: AI Index 2019, based on NESTA, arXiv, 2019

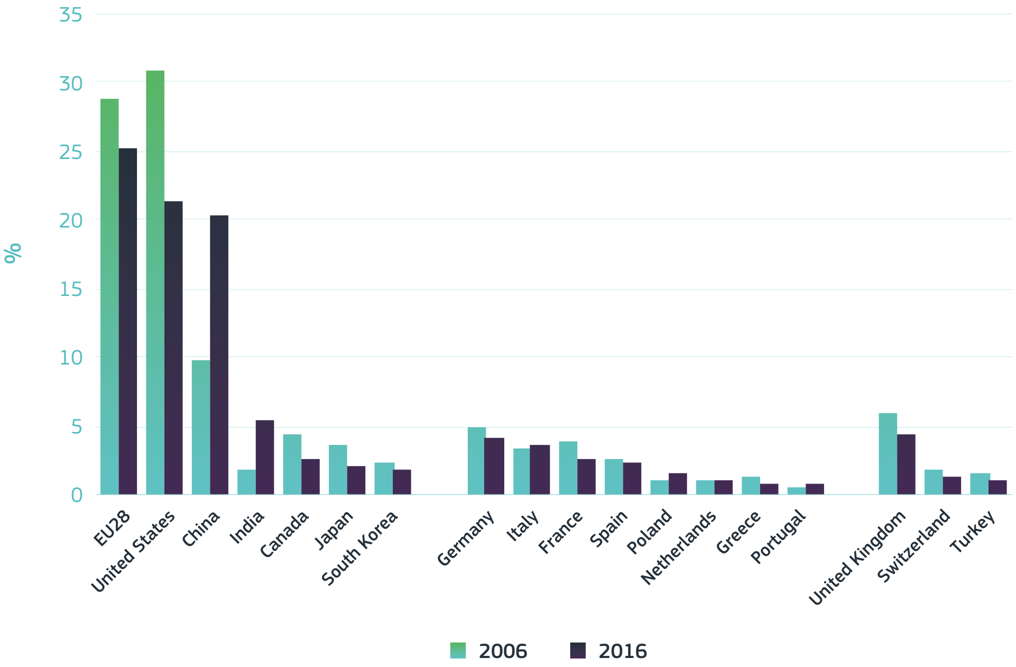
Note: Graph ranks countries based on the share of female co-authors in AI papers. NESTA (2019) uses author affiliations at the date of publication as a proxy of their location and focus on countries with at least 5 000 publications and more than 50 % of the authors gender-labelled with a high degree of confidence.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter7/figure-7-13.xlsx

countries, namely in the Netherlands, Ireland, Hungary, France and Belgium. On the contrary, international economies, such as the United States and Japan, reported a decline over time in female authorship in AI.

The EU28 is a leader in scientific excellence in the AI field, as measured by the share of AI-related documents in the top 10 % most-cited publications worldwide (Figure 7-14). In 2016, the EU represented 25 % of the top most-cited AI publications, closely followed by the United States (21 %), and China (20 %). Both the EU and the United States saw a decline in their relative importance in AI excellence between 2006 and 2016, the EU down from 29 % and the United States down from 31 %. China, on the other hand, registered a remarkable increase in scientific excellence in the AI field, doubling its relative weight in just a decade. Within the EU, the German, Italian and French economies are the highest ranking in AI scientific excellence.

Figure 7-14 Top-cited scientific publications related to AI[1], 2006-2016



Science, research and innovation performance of the EU 2020

Source: OECD (2019), Measuring the Digital Transformation: a Roadmap for the Future

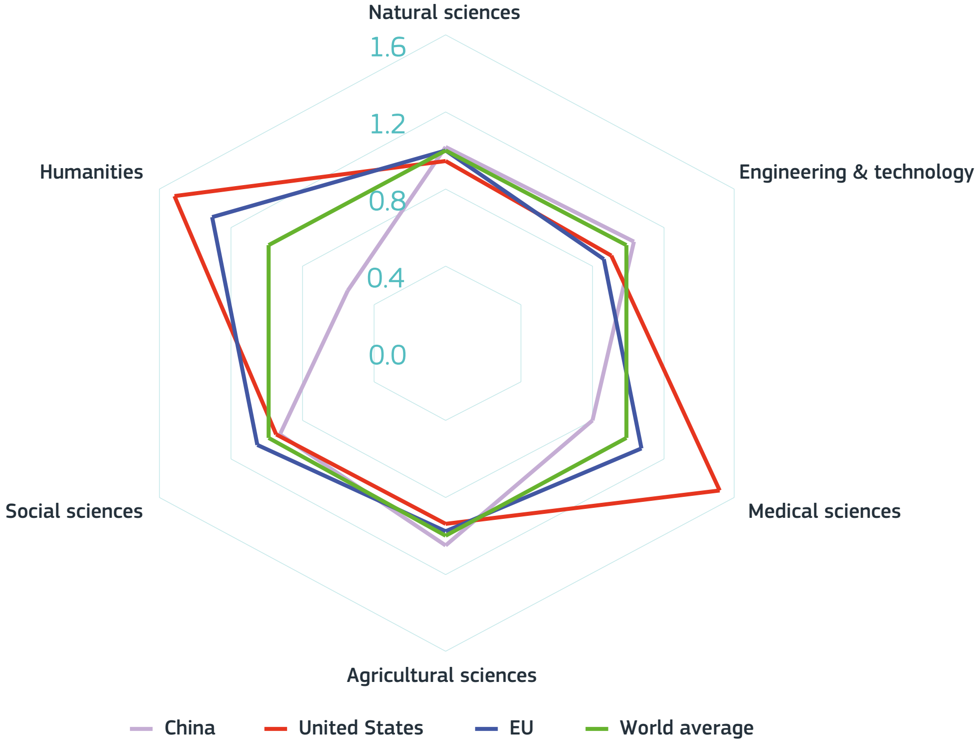
Note: [1]Selected countries with the largest number of AI-related documents among the 10% most-cited publications (%). OECD calculations based on Scopus Custom Data, Elsevier, Version 1.2018 and 2018 Scimago Journal Rank from the Scopus journal title list (accessed March 2018), January 2019. Fractional counting used.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter7/figure-7-14.xlsx

Global AI specialisation profiles show that the EU's AI research is more oriented towards humanities and to a lesser extent also in medical sciences. China is more specialised in agricultural sciences and engineering and technology, and the United States in medical and health sciences as well as humanities. Figure 7-15 displays the specialisation profiles of AI publications by field and major economy relative to the world average. The EU's top specialisation appears to be in humanities, and the United States in both humanities, and medical and health sciences, and to a greater extent than in the EU. China exhibits a different orientation of AI research activity from both the EU and the United States, with AI publications more oriented towards agricultural sciences and engineering and technology. Elsevier (2018) explains that the apparent focus of the EU and the United States on the humanities could be driven by a 'very low number of publications and may be influenced by language'.

The top five entities contributing to AI publications in Europe appear to be from all universities or public research organisations in France, the United Kingdom and Spain. The same pattern applies to China. However, in the United States, the top five is a mix of contributors from both the public and private sectors.

Figure 7-15 Relative Activity Index(1) of AI publications (all document types) per FORD category per region, 2018



Science, research and innovation performance of the EU 2020

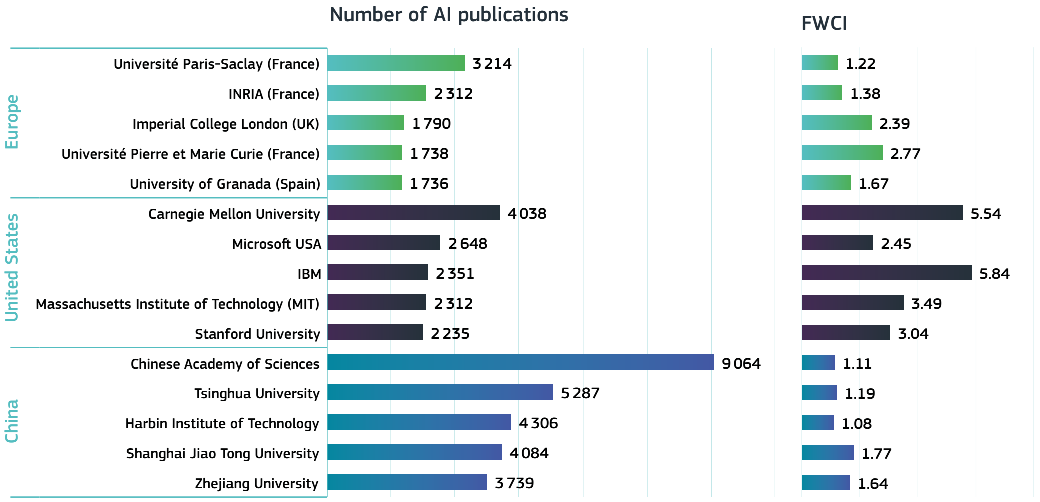
Source: Elsevier (2018)

Note: OECD Fields of Research and Development (FORD) categories show R&D expenditure and personnel by fields of research and development. A value of 1.0 indicates that a country's research activity in AI corresponds exactly with the global activity in AI; higher than 1.0 implies a greater emphasis, while lower than 1.0 suggests a lesser focus.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter7/figure-7-15.xlsx

In Europe, the top contributors of scientific publications on AI are the Université Paris-Saclay, the Institut national de recherche en sciences et technologies du numérique (INRIA), the Université Pierre et Marie Curie (all three based in France), Imperial College London in the United Kingdom, and the University of Granada in Spain (Figure 7-16). Thus, the top five institutional contributors to AI research in Europe are universities and public research institutes. The picture is different in the United States where companies such as Microsoft and IBM also play a key role in producing AI publications. The US universities listed include Carnegie Mellon, the Massachusetts Institute of Technology (MIT) and Stanford University.

Figure 7-16 Top 5 institutional contributors per region by number of AI publications (all document types) and related field-weighted citation impact, 2013-2017



Europe	Université Paris-Saclay (France)	3 214	1.22
	INRIA (France)	2 312	1.38
	Imperial College London (UK)	1 790	2.39
	Université Pierre et Marie Curie (France)	1 738	2.77
	University of Granada (Spain)	1 736	1.67
United States	Carnegie Mellon University	4 038	5.54
	Microsoft USA	2 648	2.45
	IBM	2 351	5.84
	Massachusetts Institute of Technology (MIT)	2 312	3.49
	Stanford University	2 235	3.04
China	Chinese Academy of Sciences	9 064	1.11
	Tsinghua University	5 287	1.19
	Harbin Institute of Technology	4 306	1.08
	Shanghai Jiao Tong University	4 084	1.77
	Zhejiang University	3 739	1.64

Source: Elsevier (2018)
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter7/figure-7-16.xlsx

4. AI technological collaboration has intensified over time

Co-publications between academia and the private sector in the AI field are more common in the United States than in Europe. They also have a higher citation impact. Academic-corporate collaboration in AI is increasingly driving AI developments. It seems more apparent in the United States, where 9% of the AI publications involve academia and the private sector. It also has inherently a higher citation impact than in Europe or in China (Figure 7-17). In Europe, AI co-publications account for close to 4% of AI publications, which is similar to the share of scientific output resulting from public-private co-publications in the EU28[14]. This compares with only around 2% in China. However, Chinese AI co-publications appear to have a higher citation impact than Europeans.

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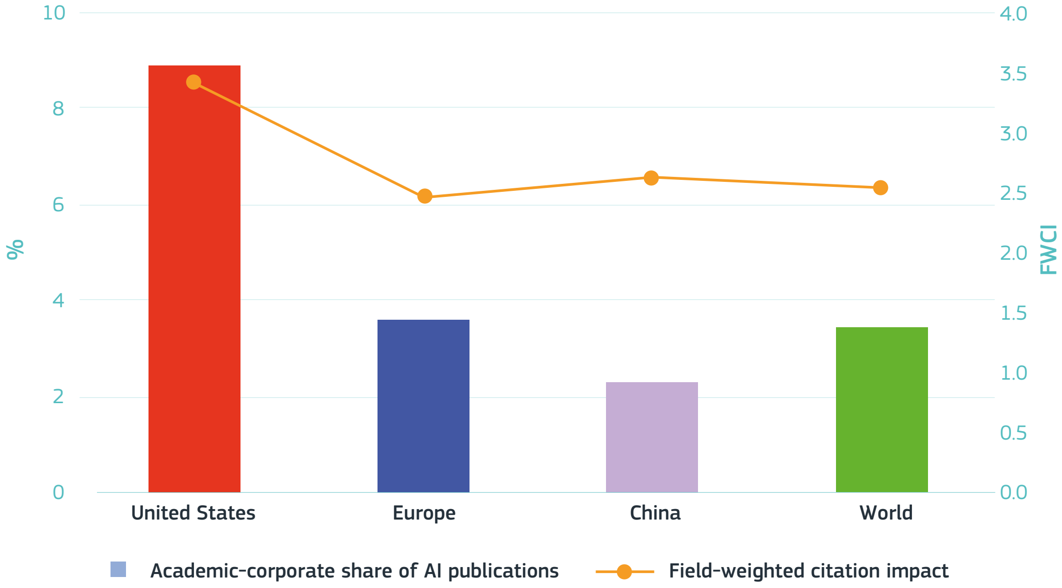
[14] The share of scientific public-private co-publications in scientific output was of 4.5% from 2000-2018 in the EU28 (full count). Data: Science-Metrix using data from the Scopus database.

Figure 7-17 Academic-corporate share of AI publications (% total AI publications by region) and related field-weighted citation impact, 1998-2017



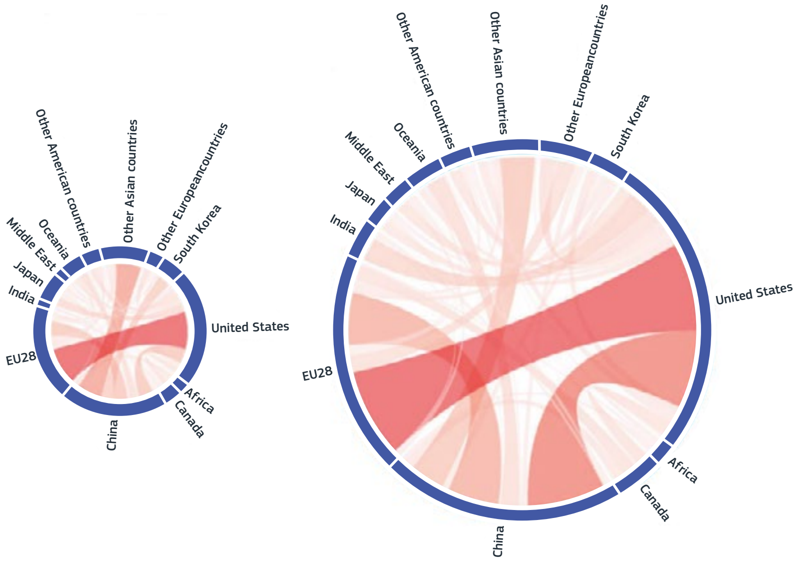
Science, research and innovation performance of the EU 2020

Source: Elsevier (2018)

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter7/figure-7-17.xlsx

In recent years, international collaborations on AI technology around the world have intensified. In particular, EU28 players have significantly increased their collaboration with the United States and China in the AI domain. As shown in Chapter 6.2 - Knowledge flows, science is increasingly 'open to the world' in order to tackle global challenges and contribute to scientific advances/discoveries. In this context, international collaboration on AI between R&D players all over the world can also be beneficial to AI science and innovation. Figure 7-18 represents the evolution of the intensity of bilateral AI technological collaborations (namely co-publications and co-patents) across the globe, in three different periods. a bigger radius in the diagram means that collaboration was higher over that period. More recently, the level of international collaboration in AI has expanded remarkably. Furthermore, EU28 R&D players are not only collaborating more with the United States but with China, too.

Figure 7-18 AI technological collaborations between geopolitical areas[1], 2012-2017



2012-2014

2015-2017

Source: De Prato et al. (2019)

Note: [1]Number of bilateral collaborations (i.e. co-publications and co-patenting) between players active in R&D in the AI domains and located in different countries, in the indicated periods. The radius of the diagrams is proportional to the amount of external collaborations in the corresponding period of time.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter7/figure-7-18.xlsx

Countries are also collaborating at the EU and global level to agree on common principles governing AI. To date, the EU has taken the lead here. In its **Communication on 'Artificial Intelligence for Europe'** (April 2018), the European Commission identified the need to develop an ethical approach to AI, in accordance with core European values. a high-level expert group, representing academia, business and civil society, was set up to this end. Building on the group's ethical recommendations, the Commission issued a **Communication on 'Building Trust in Human-Centric Artificial Intelligence'** (April 2019) which confirms the European ambition to create trustworthy AI (Box 7-4). The Commission would like to bring this European approach to the global stage by opening up cooperation to all non-EU countries that share the same values.

BOX 7-4 Towards trustworthy, ethical and innovative AI in the EU

In itself, AI is neither good nor bad; nor is it neutral (Kranzberg, 1986). As with any impactful new technology, the way in which it is further developed and applied will determine either a positive or negative outcome. AI-powered cameras with facial recognition capabilities can make your neighbourhood safer but may also help oppressive regimes to identify and silence dissidents. Receiving targeted advertising based on the contents of your e-mails may be acceptable but having similar AI systems use your data for manipulating your voting behaviour is not.

For AI to have the positive impact we want, we should carefully reflect on the choices we make while developing and applying it. '**AI ethics**' is about identifying the core principles to guide us in our quest to maximise the technology's benefits while minimising its risks. Companies working with AI could use such principles to self-regulate their developments; governments could go a step further and enforce compliance through regulation.

For the Commission, **seven** key **requirements** define **trustworthy AI**:

1. Human agency and oversight
2. Technical robustness and safety
3. Privacy and data governance
4. Transparency
5. Diversity, non-discrimination and fairness
6. Societal and environmental well-being
7. Accountability

In order to operationalise these principles, the high-level expert group's ethical guidelines present an assessment list to check compliance with each of these requirements. During a piloting phase, stakeholders from a large range of sectors and types of organisations are currently testing and working with this assessment list. Their feedback will be used to optimise the list and turn it into a reliable and operational guide for the development of trustworthy AI in Europe.

The 'ethics-by-design' approach will play a key role in ensuring that ethical and legal principles are embedded at the very outset of system development. The European Commission has thus committed to exploring the opportunities for introducing the **ethics-by-design** principle in relevant calls for proposals under the EU-funded research programme.

The ethical principles for ethical, trustworthy AI may very well become the foundations on which a general European regulation for AI is built.

For AI 'made in Europe', the ethics-by-design approach will play a key role in ensuring that ethical and legal principles are embedded at the very outset of system development. Thus, the European Commission has committed to exploring the opportunities for introducing the ethics-by-design principle in relevant calls for proposals under the EU funded research programme[15].

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[15] https://ec.europa.eu/knowledge4policy/publication/coordinated-plan-artificial-intelligence-com2018-795-final_en

Following these important initiatives, in May 2019, 42 OECD member countries adopted a set of AI principles that ensure that AI fosters innovation while respecting human rights and democratic values (May 2019). As established in OECD (2019b), the guidelines are developed around five main principles, quoting:

- 'AI should benefit people and the planet by driving inclusive growth, sustainable development and well-being.
- AI systems should be designed in a way that respects the rule of law, human rights, democratic values and diversity, and they should include appropriate safeguards (...) to ensure a fair and just society.
- There should be transparency and responsible disclosure around AI systems to ensure that people understand AI-based outcomes and can challenge them.
- AI systems must function in a robust, secure and safe way throughout their life cycles, and potential risks should be continually assessed and managed.
- Organisations and individuals developing, deploying or operating AI systems should be held accountable for their proper functioning in line with the above principles.'

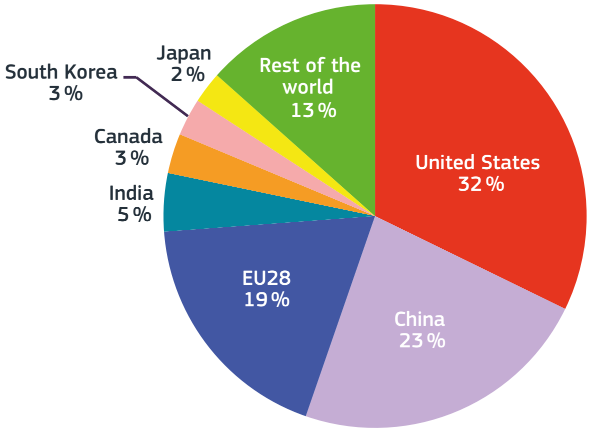
There are important privacy and ethical issues linked to AI. The EU is committed to building an AI ecosystem that spurs innovation within a clear and adequate legal and ethical framework.

5. EU trails in AI innovation

Despite ranking among global leaders on AI scientific excellence, the EU trails when it comes to AI innovation performance, both in the number of companies and patenting. However, the EU's performance is in line with its share in global R&D investments. Nearly one third of the world's AI firms can be found in the United States. China ranks second, with close to one quarter of AI companies. Hence, the two countries together account for slightly more than half of all AI startups. The EU28 represents 19% of firms active in AI worldwide (in accordance with the EU's approximate 20% share in global R&D investments), followed by India, Canada, South Korea and Japan (Figure 7-19). Today, AI applications are widespread across different industries. CBInsights' 2019 list of 'the most promising 100 AI startups' points precisely to the sectoral diversity of AI startups with 'high-potential' including in healthcare, finance, retail, cybersecurity, marketing and agriculture, among others (CBInsights, 2019c).

The EU's gap in AI innovation relative to the United States and China can also be observed in terms of the number of firms active in patenting in AI in each region. Indeed, outstandingly, Chinese AI companies account for almost 60% of all AI firms' patenting applicants. This compares with 14% in the United States but only around 7% in both South Korea and the EU28 (Figure 7-20) between 2009 and 2018.

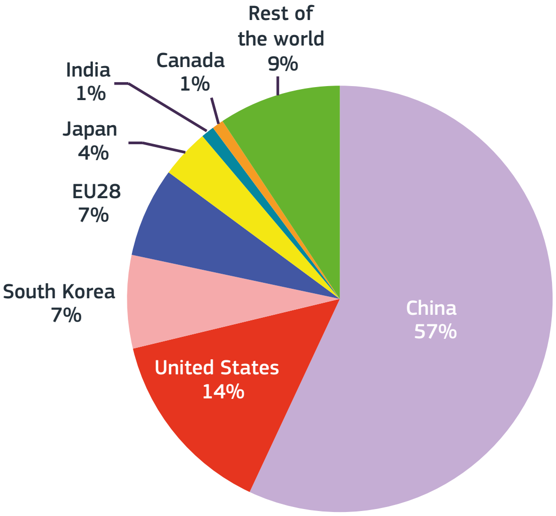
Figure 7-19 Distribution of AI firms worlwide (%), 2009-2018



Science, research and innovation performance of the EU 2020

Source: De Prato et al. (2019)
Note: Percentage over total number of firms active in the AI domain.
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter7/figure-7-19.xlsx

Figure 7-20 Share of firms' patenting applicants in the AI domain by region, 2009-2018

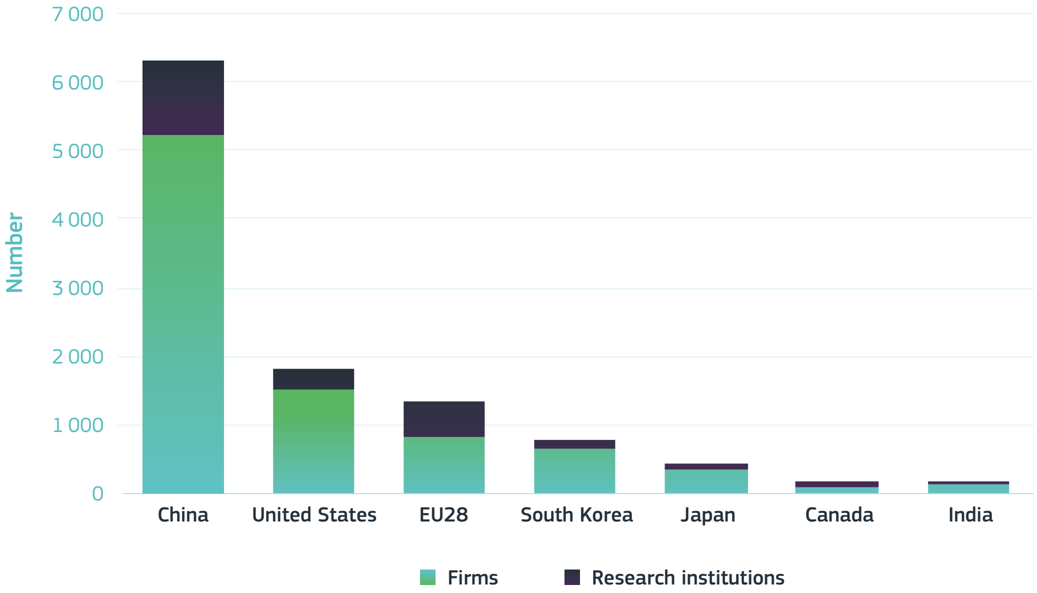


Science, research and innovation performance of the EU 2020

Source: De Prato et al. (2019)
Note: Percentage over total number of firms active in patenting activities in the AI domain.
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter7/figure-7-20.xlsx

China's striking leadership position is also visible in Figure 7-21 which shows the absolute figures for both firms and research institutions active in AI-related patenting activities. It is interesting to note that, in relative terms, EU28 research organisations account for almost 40% of AI patenting applicants in the EU28 and hence make the largest relative contribution to AI patenting when compared to the distribution among other nations.

Figure 7-21 Number of firms and research institutions active in AI-related patenting activities and frontier research in selected economies, 2009-2018



Science, research and innovation performance of the EU 2020

Source: De Prato et al. (2019)

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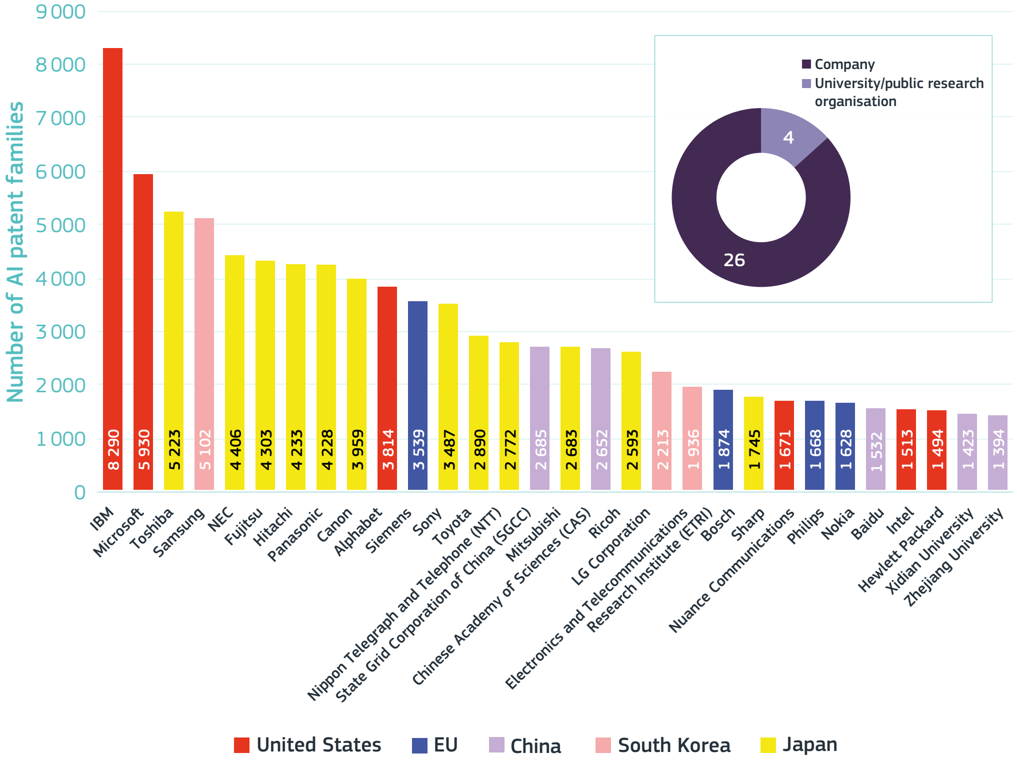
The majority of the world's top AI patent applicants are companies in IT, consumer electronics, electric power and automobile manufacturing. Almost half of the top patent applicants in the AI field are Japanese. The EU is represented by four companies – Siemens, Bosch, Philips and Nokia. Looking into patent applications in the AI field can provide an indication of who the global AI innovators are. Figure 7-22 shows that 26 of the top 30 applicants are companies, while only four are universities and public research organisations from China (three) and South Korea (one). Japan stands out as the nation with the largest number of companies (12) represented in the top 30, with Toshiba leading the Japanese group. The United States come next with six companies. In fact, IBM is the clear leader in AI patenting with a number of patent applications almost equivalent to the total sum of patents from Zhejiang University, Xidian University, Hewlett Packard, Intel, Baidu and Nokia. The EU has four companies in the list, namely Siemens, Bosch, Philips and Nokia, although none of them feature in the top 10. Finally, China has five companies, universities and public research organisations in the global top 30, while South Korea is represented by three entities.

Figure 7-22 Top 30 world patent applicants by number of AI patent families, region and type of organisation, 2018



Science, research and innovation performance of the EU 2020

Source: WIPO Technology Trends 2019: Artificial Intelligence, based on Questel Orbit Intelligence, Fampat Database, March 2018

Note: Fujitsu includes PFU; Panasonic includes Sanyo; Alphabet includes Google, Deepmind Technologies, Waymo and X Development; Toyota includes Denso; and Nokia includes Alcatel.

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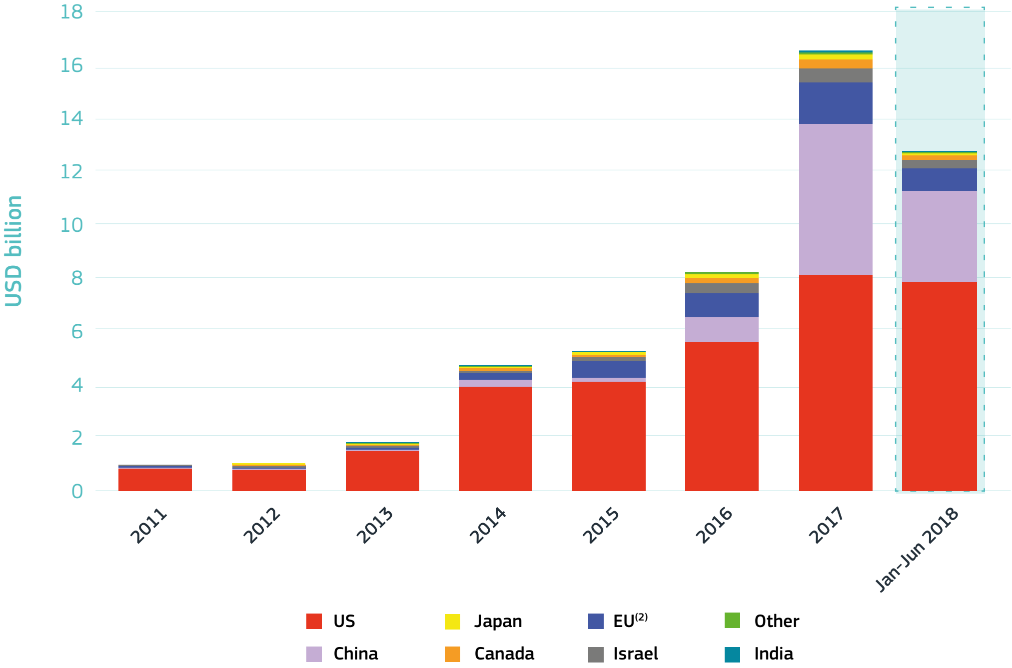
6. Enabling AI: capital and people investments

With the unlocking of the potential of AI, private investments in AI startups are on the rise. The United States leads, followed by China. Although the EU has also made some progress in recent years to attract private capital, investments remain well below that of its main global competitors. Since 2016, private investments in AI startups have registered a significant boost worldwide, having doubled between 2016 and 2017 alone. Developments and breakthroughs in the AI field have attracted growing interest from private investors who are aware of the high potential of AI applications to disrupt several sectors. Indeed, OECD (2018) found that in the first half of 2018, 'AI startups attracted around 12% of all worldwide private equity investments, a steep increase from just 3% in 2011'.

Figure 7-23 provides evidence of the United States' global leadership in terms of equity investments in AI startups. According to the OECD (2018), US startups have attracted around two thirds of total private investments since 2011. However, more recently, China has rapidly increased its rate of private investments in AI companies, climbing from just 3 % in 2015 to 36 % of all AI private-equity investments worldwide in 2017. EU28 startups seem to be less attractive to private investors compared to US and Chinese AI startups, although it is important to note the substantial progress made in recent years – from only 1 % in 2013 to 8 % of global AI private investments in 2017.

Figure 7-23 Total estimated equity investments in AI startups[1] (USD bn) by startup location, 2011-2017 and first half of 2018



Source: OECD estimates based on Crunchbase (July 2018)

Notes: [1]AI startups are companies founded after the year 2000 and categorised in the 'artificial intelligence' technological area of Crunchbase, as well as companies that use AI keywords in the description of their activity. The sample is restricted to companies located in OECD and BRICS countries and for which sufficient information is reported. Numbers for 2018 are likely conservative due to possible delays in the input of new deals in the database. [2]EU includes United Kingdom.

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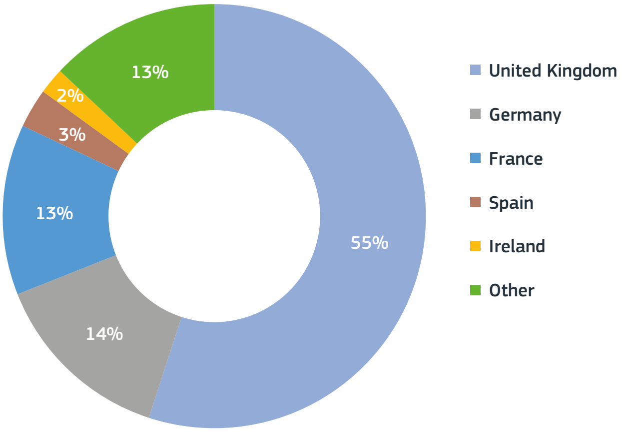
Within Europe, UK-based AI startups are the top recipients of more than half of all private equity investments targeted towards AI startups in the EU28. The United Kingdom has a sizeable attraction potential for AI private investments, attracting 55 % of all AI equity investments in the EU28 (Figure 7-24). German AI startups rank second and account for 14 % of AI private investments, followed by France (13 %), Spain (3 %) and Ireland (2 %).

Figure 7-24 Share of private equity investments in AI startups based in the EU28, 2011 to mid-2018, % total amount invested in EU-based startups over the period



Science, research and innovation performance of the EU 2020

Source: OECD estimates based on Crunchbase (April 2018)

Note: AI startups are companies founded after the year 2000 and categorised in the 'artificial intelligence' technological area of Crunchbase, as well as companies that use AI keywords in the description of their activity.

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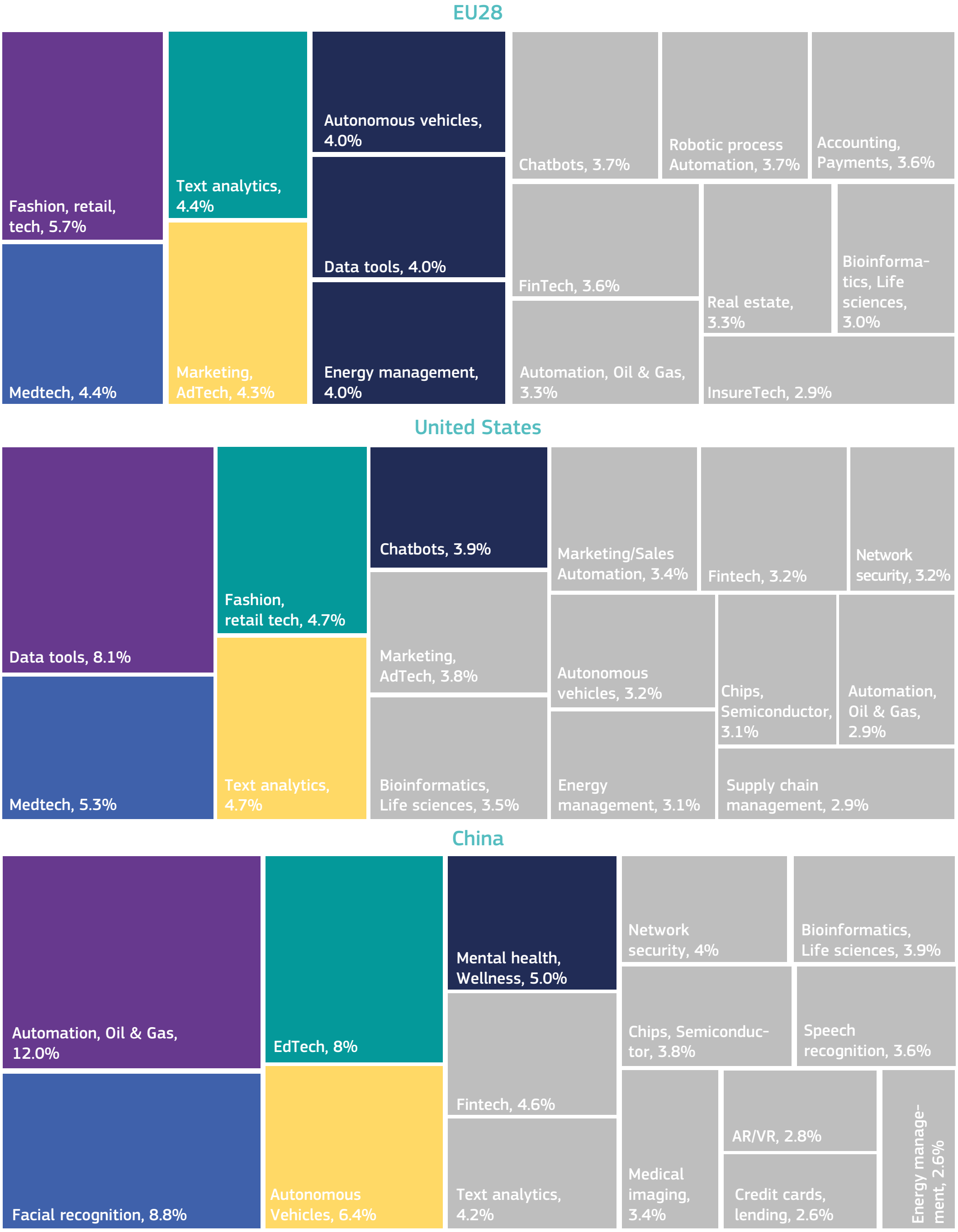
The focus areas of AI startups that have received funding in recent years point to the rise of AI as a general-purpose technology along with some geographical differences. Between 2018 and 2019, the EU AI startups that received most funding focused on fashion and retail tech (5.7 %), medtech (4.4 %), text analytics (4.4 %), marketing and adtech (4.3 %), autonomous vehicles (4.0 %), data tools (4.0 %) and energy management (4.0 %). This distribution and ranking is somewhat different in the United States and China (Figure 7-25). In particular, the top five focus areas for those US startups receiving funding were data tools (8.1 %), medtech (5.3 %), fashion and retail tech (4.7 %), text analytics (4.7 %) and chatbots (3.9 %). In China, top-funded AI startups focused on automation, oil and gas (12.0 %), facial recognition (8.8 %), edtech (8.0 %), autonomous vehicles (6.4 %) and mental health and wellness (5.0 %). In addition, the AI Index 2019 reports that both the United States and Europe have a very diverse range of AI applications, *each with some representation across all 36 sectors* identified in the study.

Figure 7-25 Top 15 focus areas of AI Startups in the EU28, the United States and China that received funding over July 2018-July 2019



Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on AI Index 2019, CAPIQ, Crunchbase and Quid data, 2019

Note: The top 5 focus areas for the three regions are coloured purple (#1), lighter blue (#2), green (#3), yellow (#4) and darker blue (#5).

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter7/figure-7-25.xlsx

It is likely that the recent upsurge in AI capital has enabled the growth of more AI startups into the next unicorns. This is particularly the case in the United States and China. Figure 7-26 shows that the number of new AI startups becoming the next unicorns has increased remarkably especially since 2017, having more than doubled between 2017 and 2018 alone (see Chapter 3.3 - Business dynamics and its contribution to structural change and productivity growth for more on unicorn companies). Between 2015 and 2019, 46 new AI-related unicorns came into the picture (11% of the current total number of private unicorns), with half (or 23) being US-based. China accounts for slightly more than a quarter of all AI unicorns, followed by the United Kingdom with four, Israel with two, and France, Japan, Canada and Singapore with one each. Hence, only one unicorn in the AI field was found in the EU over the period 2015-2019 (Figure 7-27). However, UiPath, an 'AI unicorn' with headquarters in the United States, has 'EU DNA' as the company's founders are Romanian and the headquarters were initially based in Bucharest. Considering that the amount of funding received is a key component of private valuations, this increase could be partly explained by greater interest on the part of private investors in AI technologies due to their potential to boost innovation and productivity.

Figure 7-26 Number of new private unicorns in AI, 2015-2019

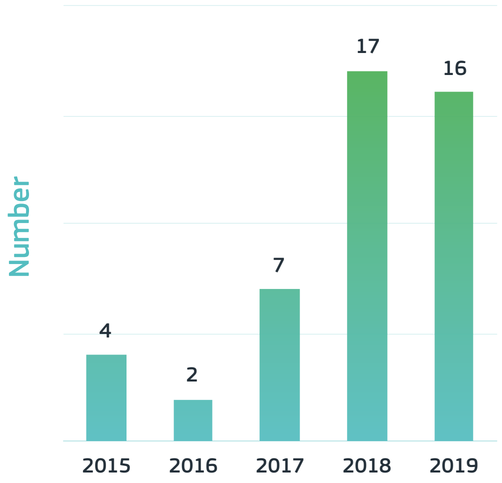
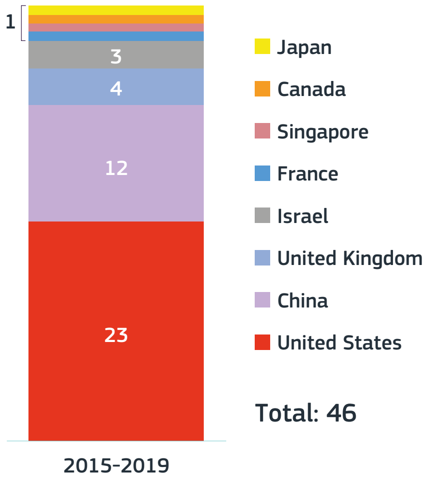


Figure 7-27 Number of AI unicorns by country, 2015-2019



Source: CBInsights Unicorn Tracker, accessed on 11/12/2019

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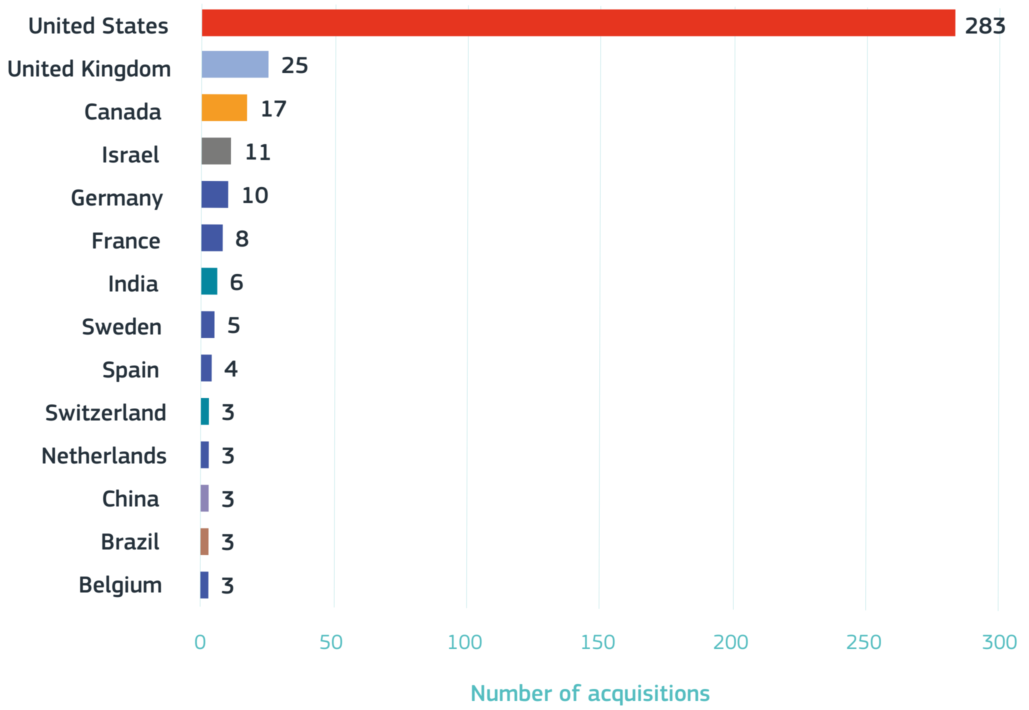
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter7/figure-7-27.xlsx

Acquisitions are on the rise. Around two thirds of acquisitions in the AI sector were in the United States, where one third of all AI firms are located, too. The United Kingdom comes next with 25 British startups acquired over the same period. In the EU, there were AI-related acquisitions of by 10 German, 8 French, 5 Swedish, 4 Spanish, 3 Dutch and 3 Belgian AI companies (Figure 7-28).

Figure 7-28 Acquisitions in the AI sector by country of acquired company, 1998-2018

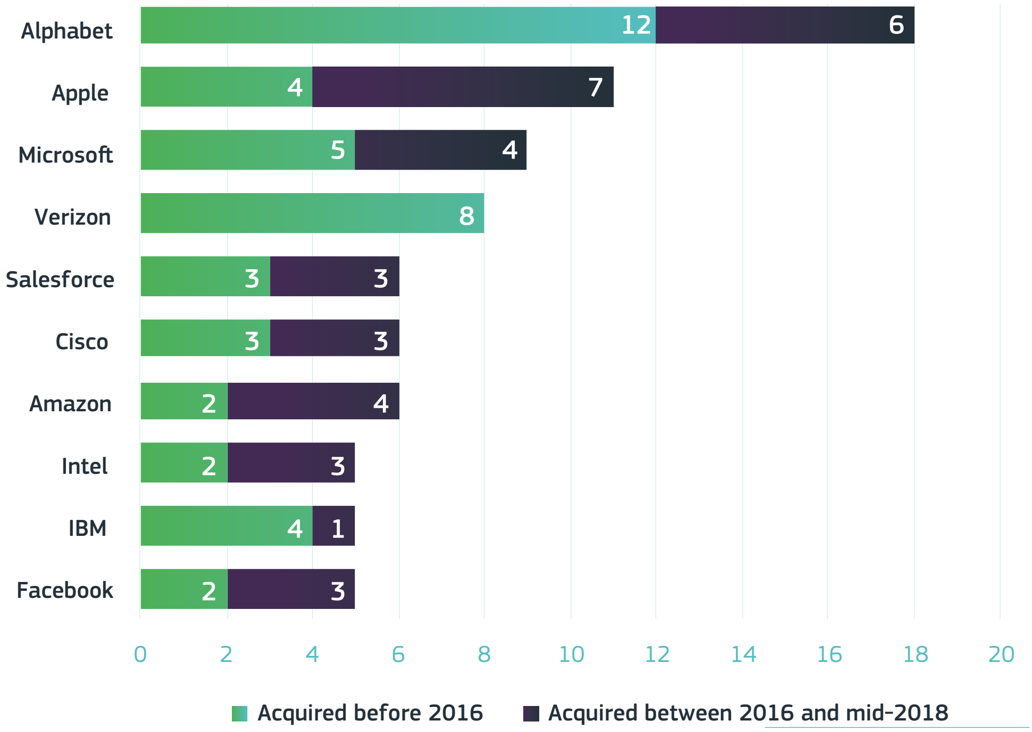


Science, research and innovation performance of the EU 2020

Source: WIPO 2019 report, based on CrunchBase database, May 2018
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter7/figure-7-28.xlsx

The top 10 acquirers of AI companies are mainly 'tech' or 'digital giants' from the United States. Together they account for almost 20 % of all AI-related acquisitions, and their pace of acquisitions has accelerated since 2016. Figure 7-29 shows the number of AI-related companies acquired by a top acquirer, both before and after 2016 (up to May 2018). Most of the top 10 acquiring companies are US multinationals in tech, which also have high market capitalisation. Alphabet leads the list with 18 acquisitions, Apple ranks second with 11 and Microsoft comes third with nine. Cumulatively, up to mid-2018, the top 10 acquirers made 79 AI acquisitions. Furthermore, the number of acquisitions has accelerated since 2016 as companies increasingly perceive AI as a technology to boost their R&D and innovation capacities, productivity and competitiveness. The overall state of play of acquisitions worldwide is further discussed in Chapter 8 - Framework conditions.

Figure 7-29 Number of AI companies acquired by top acquiring companies, before and after 2016 up to mid-2018



Science, research and innovation performance of the EU 2020

Source: WIPO 2019 report, based on CrunchBase database, May 2018

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter7/figure-7-29.xlsx

Besides acquisitions, 'tech giants' are also adopting a set of different strategies to lead in AI development, from investing heavily in R&D labs for AI to programmes designed to attract overseas talent. Although acquisitions are one of the top strategies used by top tech companies to gain 'AI superiority' relative to their competitors, there are certainly others, as indicated in Figure 7-30. These include investing heavily in R&D labs to foster AI research, initiatives to attract top talent, democratising access to AI, and gaining public trust around how AI is built and used, among others.

Figure 7-30 Examples of efforts in a selection of US and Chinese tech giants to lead the AI race

Company	Company efforts to promote AI - examples

Alibaba (China)	▸ USD 15 billion investment into R&D
	▸ The DAMO (Discovery, Adventure, Momentum and Outlook) Academy:
	  ▸ programme to set up research and development labs world in 7 different locations worldwide[(1)]
	  ▸ focus on foundational and disruptive technology research in areas such as data intelligence, natural-language processing, quantum computing, and machine learning

Tencent (China)	▸ AI research lab in Seattle, United States ▸ Open platform to drive AI projects in other companies
Baidu (China)	▸ Collaborative projects with telecom, smart home-appliance-maker companies ▸ Collaboration with top Chinese universities ▸ Campus recruiting campaigns in top US universities to work in company´s HQ in Beijing
Alphabet (United States)	▸ Open-source TensorFlow library for machine-Learning computations ▸ Google AI Principles for responsible AI, and People + AI Research (PAIR) for human-centred AI ▸ Google AI Residency Program, mentoring ▸ Quantum AI, to develop quantum algorithms to accelerate machine learning
Microsoft (United States)	▸ Microsoft Ventures: new fund for startups ▸ Microsoft Research AI, focused on AI R&D ▸ Microsoft AI School ▸ Initiatives within the 'AI for Good' program
Apple (United States)	▸ Overton AI development tool ▸ 'Hiring the competition' - hired Google's chief of search and artificial intelligence, to run its ML and AI strategy

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on multiple media and company websites´ sources: https://qz.com/1099535/alibaba-is-plowing-15-billion-into-rd-with-seven-new-research-labs-worldwide, https://damo.alibaba.com/labs/, https://www.cnbc.com/2017/05/02/tencent-ai-research-lab-seattle.html; https://blog.aimultiple.com/baidu/, https://www.scmp.com/tech/big-tech/article/2164765/tencent-releases-open-platform-help-drive-ai-projects-other-companies, https://www.popsci.com/google-ai/, https://ai.google/research/teams/applied-science/quantum/, https://www.forbes.com/sites/jonyounger/2019/01/16/googles-ai-and-ml-research-priorities-freelancers-take-note/#36a9b4a8344c, https://www.techworld.com/picture-gallery/data/tech-giants-investing-in-artificial-intelligence-3629737/, https://venturebeat.com/2019/09/13/apple-details-overton-ai-development-tool-whose-models-have-processed-billions-of-queries/

Note: (1)The locations include Beijing and Hangzhou, Singapore, Moscow, Tel Aviv, Seattle and Silicon Valley, hence none in the EU, according to the article. All the examples listed above are merely illustrative and not exhaustive.

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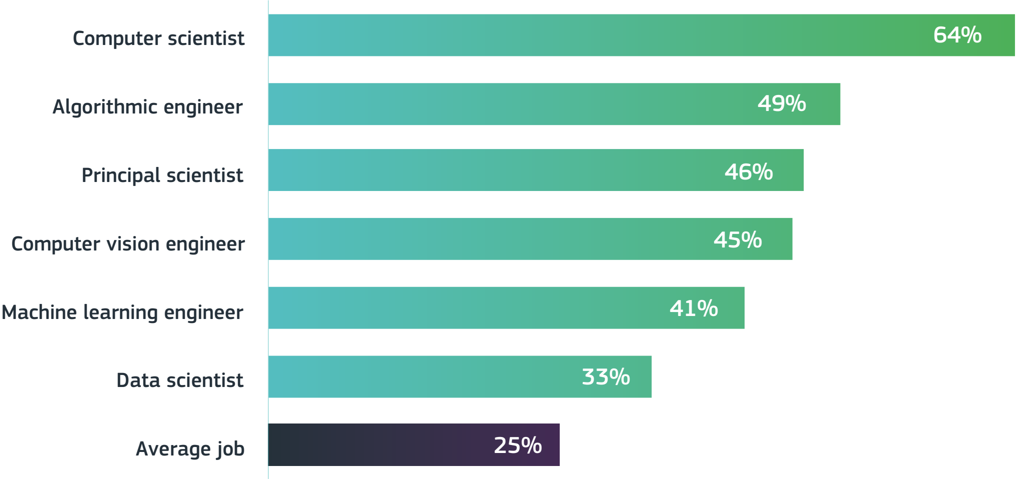
The race for AI talent is on. Currently, AI talent is relatively scarce worldwide but appears more predominant in the United States. The EU faces a shortage in AI professionals which could undermine its ambition to galvanise its AI innovation landscape. AI-related jobs seem harder to fill compared to the 'average job' (Figure 7-31) which hints at a limited pool of AI talent worldwide. In particular, the profiles of computer scientists, algorithmic engineers and principal scientists are proving to be the hardest AI-related vacancies to be filled. For example, in the Indeed portal – a job-search portal – 64% of the computer scientist vacancies were still open after 60 days of being published on the portal.

Figure 7-31 Percentage of AI-related jobs on Indeed open after 60 days, and comparison with average job



Science, research and innovation performance of the EU 2020

Source: Priceoconomics data studio – Which Industries are investing in Artificial inteligence (18 November 2018) based on Indeed data

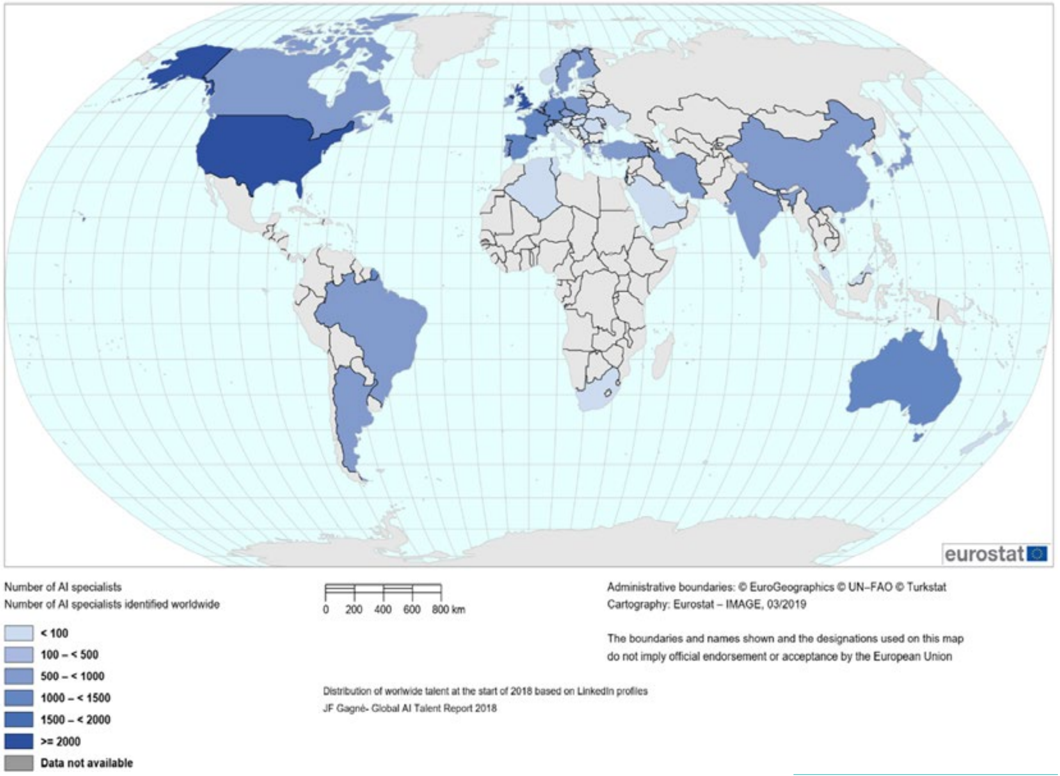
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter7/figure-7-31.xlsx

Official statistics on the existence and production of AI talent are still lacking. However, certain external efforts have provided some indication of the geographical distribution of AI specialists worldwide. J.F. Gagné (2018) used the LinkedIn job platform to identify AI specialists all over the world (Figure 7-32). One caveat of the analysis is that the use of LinkedIn is more common in the West, so there may be a bias in the data collected which may underestimate the presence of AI specialists, for example, in China. The United States appears to have more AI talent available than, for example, the EU or China. In addition, most tech giants are based in the United States. In light of the scarcity of AI talent, these multinationals offer highly competitive salaries and alluring benefits to attract and retain top talent.

For the EU, this means that, on the one hand, it is important to increase the number of students and professionals with an AI-related academic background

and/or AI technical competences and skills acquired, for instance, in trainings that also reflect the potential risks of AI technologies. On the other hand, the EU should enable the right environment for them to work in the EU (i.e. to retain AI talent) and attract more talent from abroad, as highlighted in the 2018 European Commission Communication on 'Artificial Intelligence for Europe', for example through the 'Blue Card scheme'.

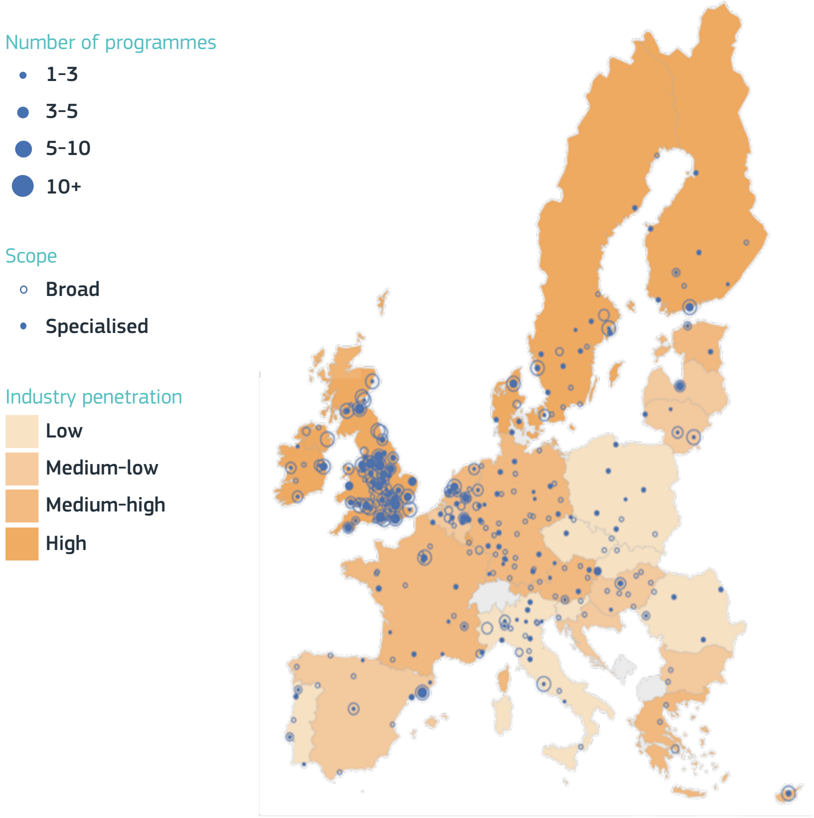
Figure 7-32 Global AI talent pool based on AI Specialist LinkedIn profiles, 2018)



Source: J.F. Gagné - Global AI Talent Report 2018
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter7/figure-7-32.xlsx

Within Europe, AI industry is more dense in Malta, the United Kingdom, Denmark, Ireland, Finland, Luxembourg and Sweden. The AI academic offer is concentrated in top urban centres. Four of the top five European cities offering specialised programmes on AI are in the United Kingdom. Figure 7-33 combines data on industry penetration by AI (i.e. the number of AI enterprises in total enterprises) with an academic offer on AI (i.e. the number of bachelor and master's programmes) in Europe. Malta, the United Kingdom, Denmark, Ireland, Finland, Luxembourg and Sweden stand out as the European countries with the highest industry penetration rates. The top five cities in terms of the supply of AI academic programmes are London, Southampton, Edinburgh, Barcelona and Manchester, which means four of the top cities are in the United Kingdom.

Figure 7-33 Industry penetration of AI(1) and AI academic offer(2) in the EU28



Source: De Prado et al., 2019

Notes: (1)The number of AI enterprises over total number of enterprises. (2)Total number of programmes (bachelor's and master's degrees) identified as AI-specialised.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter7/figure-7-33.xlsx

7. AI can lead to public-sector innovation but not all EU Member States are embracing it

It is time for the public sector to embrace the opportunities created by AI. While some EU Member States rank high internationally in 'government AI readiness', in others a greater effort is needed to roll-out AI capabilities. AI-related technologies can also lead to greater efficiency in the public sector, enhancing the quality of public services and enabling better techniques to process and analyse data, as well as acting as a support tool for policy evaluation. In the EU, the public sector is one of the most data-intensive sectors. Clearly, the reuse of open data can contribute to the development of AI. For this reason, many countries worldwide, including EU Member States, are embedding public sector AI innovation into their national AI strategies. The OECD (2019c) describes some of the main elements of public sector-focused AI strategies, including, for example:

- 'Experimentation with AI in government and the identification of specific AI projects currently under way or that will be developed in the near future;
- Collaboration across sectors, such as through public-private partnerships;
- Fostering of cross-government councils, networks and communities to promote systems approaches;
- Automation of routine government processes to enhance efficiency.

Despite these benefits, there are also concerns about bias, privacy, transparency and the overall complexity of data accessibility and usability. The 'Open Data Directive' (Directive (EU) 2019/1024)[16], which entered into force on 16 July 2019, provides more guidance and clarity on the use of open data in the public sector. Under the new rules:

- All public sector content that can be accessed under national access to documents rules is in principle freely available for reuse. This could allow more SMEs and startups to enter new markets in providing data-based products and services.
- A particular focus is placed on high-value datasets such as statistics or geospatial data.
- Public undertakings in the transport and utilities sector generating valuable data when providing services in the general interest will have to comply with the principles of transparency, non-discrimination and non-exclusivity set out in the Directive, and ensure the use of appropriate data formats and dissemination methods. They will still be able to set reasonable charges to recover the costs of producing the data and of making it available for reuse.
- Publicly-funded research data enters into the scope of the Directive: Member States are required to develop policies for open access to publicly funded research data while harmonised rules on reuse will be applied to all publicly funded research data which is made accessible via repositories.

Building trust and broad social acceptance around AI is key for its success. Most Europeans agree that robots and AI require careful management (Figure 7-34), while the same applies to the United States. As a result, policies to foster AI should follow a human-centric, transparent and trustworthy approach in order to promote public trust in this field.

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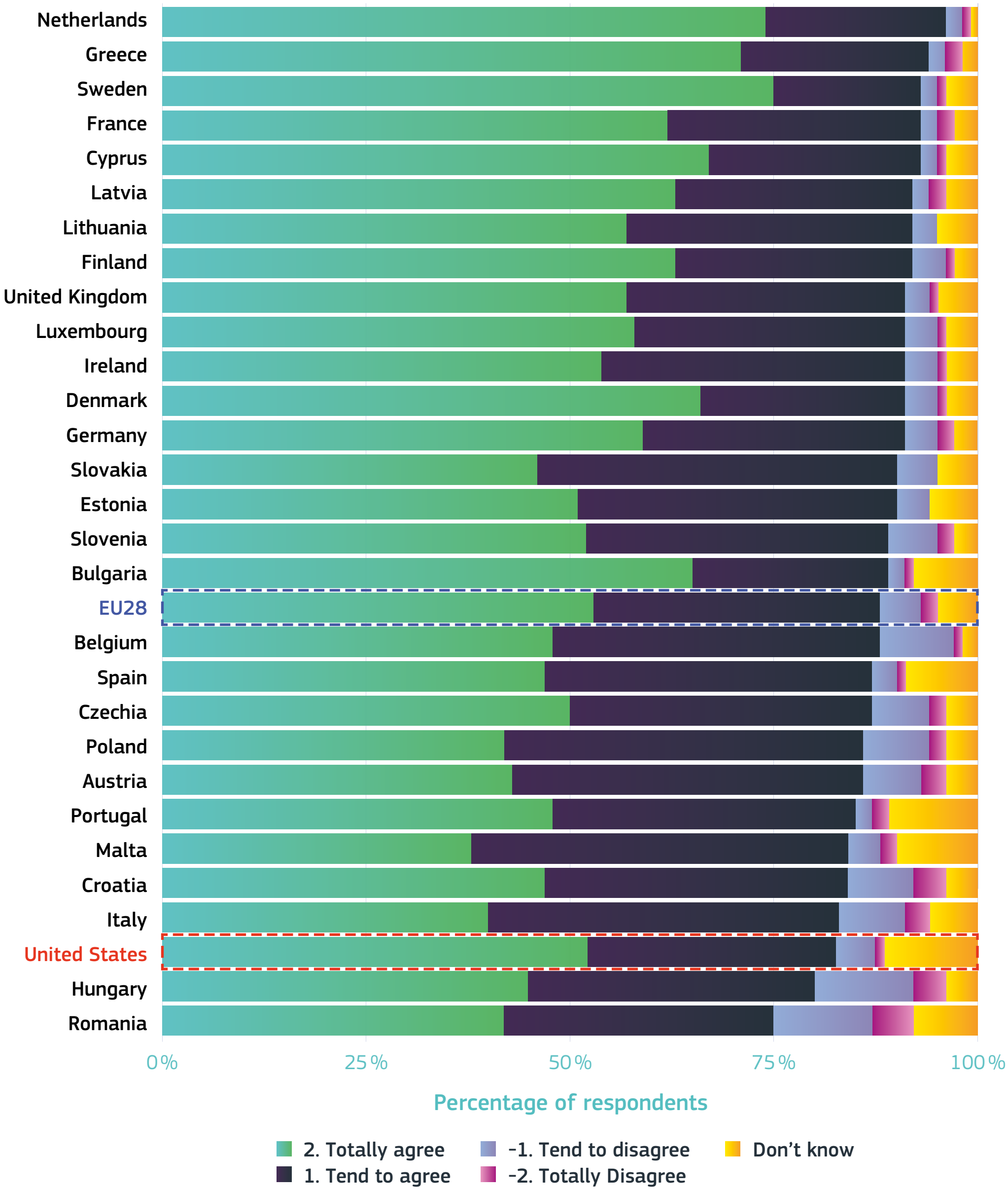
[16] https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1561563110433&uri=CELEX:32019L1024

Figure 7-34 Agreement with statement that robots and AI require careful management[1], in the EU28 and the United States



Source: Centre for the Governance of AI and Eurobarometer

Note: [1]EU28 data from 2017 Special Eurobarometer #460.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter7/figure-7-34.xlsx

The 'Government AI Readiness Index' ranks the governments of 194 countries and territories based on their 'preparedness to use AI in the delivery of public services' based on four clusters covering aspects linked to governance, infrastructure and data, skills and education and, finally, government and public services. Figure 7-35 shows the 2019 results. Germany, Finland, Sweden, France and Denmark rank in the top 10 governments well-prepared to embrace AI opportunities to improve their efficiency. However, in other EU Member States such as Hungary, Greece, Cyprus, Romania and Croatia, considerable efforts are still needed to support the uptake of AI in the public sector.

Figure 7-35 Overall rankings for Government AI Readiness 2018/19(1)

Top 10 and rank of EU Member States

Rank	Country	Score
1	Singapore	9.186
2	United Kingdom	9.069
3	**Germany**	8.810
4	United States	8.804
5	**Finland**	8.772
6	**Sweden**	8.674
7	Canada	8.674
8	**France**	8.608
9	**Denmark**	8.601
10	Japan	8.582
(...)		
14	Netherlands	7.659
15	Italy	7.533
16	Austria	7.527
23	Estonia	6.968
24	Belgium	6.859
25	Luxembourg	6.857

Rank	Country	Score
27	Poland	6.835
30	Portugal	6.693
31	Czechia	6.673
33	Latvia	6.548
34	Ireland	6.542
36	Spain	6.332
37	Lithuania	6.288
38	Slovenia	6.232
43	Malta	5.961
45	Slovakia	5.923
47	Bulgaria	5.806
48	Hungary	5.794
49	Greece	5.760
53	Cyprus	5.668
55	Romania	5.540
62	Croatia	5.273

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Source: Government Artificial Intelligence Readiness Index 2019 – Oxford Insights and International Development Research Centre

Note: (1)The overall score is comprised of 11 input metrics, grouped under four high-level clusters: governance; infrastructure and data; skills and education; and government and public services. The data is derived from a variety of resources, ranging from desk research into AI strategies, to databases such as the number of registered AI startups on Crunchbase, to indices such as the UN eGovernment Development Index.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter7/figure-7-35.xlsx

Box 7-5 The EU Digital Package: European Strategy for Data & White Paper on AI

On 19 February 2020, the Commission published a White Paper and two Communications pertaining to the Digital Single Market, together referred to as the '**Digital Package**'.

In '**Shaping Europe's digital future**'[17] , the Commission presents its overall vision and goals for the development and use of digital technologies in Europe, as well as a roadmap for future actions, Communications and regulatory initiatives.

The aim of '**A European strategy for data**'[18] is for Europe to have a genuine single market for data so that the EU's share of the data economy could correspond to its economic weight. The strategy includes setting up a governance framework (including regulatory action), increasing investment, and creating sector-specific common European data spaces. Data spaces for industry (manufacturing), the Green Deal and health data, are among those being proposed, as well as the European Open Science Cloud.

The '**White Paper on Artificial Intelligence – A European approach to excellence and trust**'[19] outlines the Commission's vision for a European approach to AI, building on its existing strengths (research, robotics, manufacturing, EU research funding, coordinated plan with the MS), respecting European values (ethics, privacy protection) and presenting the main challenges. In order to overcome these challenges, the White Paper describes actions to build an 'ecosystem of excellence' to encourage investment, on the one hand, and an 'ecosystem of trust' through a regulatory framework, on the other.

An **ecosystem of excellence** is required to support the development and uptake of AI across the EU economy and public administration. The proposed actions are focused on:

1. revising the existing coordinated plan between the Member States;
2. extending and creating new excellence and testing centres;
3. investing in advanced skills and higher education;
4. expanding Digital Innovation Hubs with a focus on AI, and providing equity financing (a pilot in 2020 which can be scaled up in 2021);
5. creating public-private partnerships under the new Horizon Europe framework programme, including one on 'AI, data and robotics'; and
6. facilitating public procurement.

The **ecosystem of trust** would consist of an appropriate regulatory framework providing legal certainty and trust in AI and addressing its significant risks. An initial basis has been developed by the high-level expert group on AI, in the form of seven key requirements for trustworthy AI, operationalised in an assessment list, which is under review following extensive stakeholder consultation (see Box 7-4).

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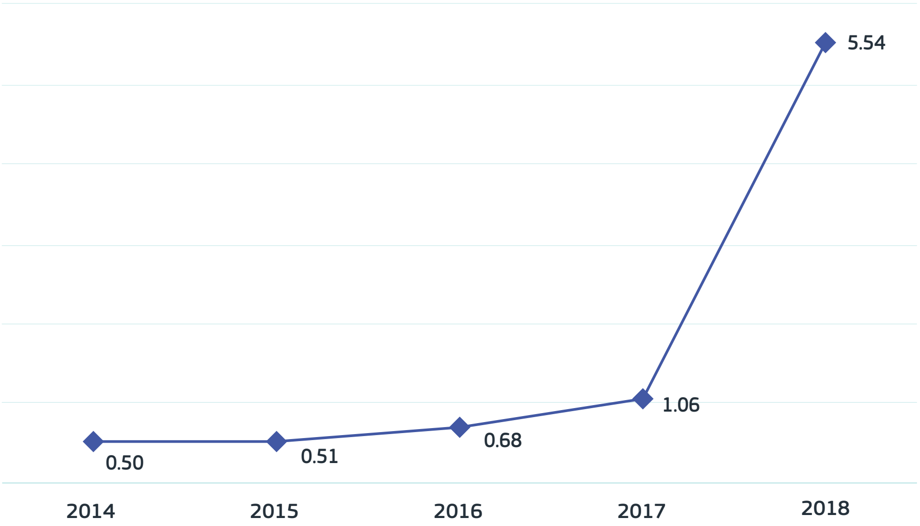
[17] https://ec.europa.eu/info/sites/info/files/communication-shaping-europes-digital-future-feb2020_en_3.pdf
[18] https://ec.europa.eu/info/sites/info/files/communication-european-strategy-data-19feb2020_en.pdf
[19] https://ec.europa.eu/info/sites/info/files/commission-white-paper-artificial-intelligence-feb2020_en.pdf

8. ‘Digital meets digital’: how other digital technologies can augment the potential of AI

Blockchain technology has attracted a lot of interest lately, as regards applications that go beyond bitcoin and cryptocurrencies. Blockchain is a technology that allows for sharing and exchanging data in a peer-to-peer way, i.e. without the need for an intermediary. Data in the blockchain are stored in blocks that are linked with each other using cryptographic methods. Multiple copies of the blockchain will then circulate in a blockchain network, making it difficult to alter the data because if someone wanted to alter an entry she/he would need to alter the entire blockchain and then get consensus in the network that his/her version of the blockchain was the correct one rather than those held by the others.

The interest around AI is particularly true in the financial sector, but increasingly so in other sectors of the economy. Indeed, data is increasingly becoming a key element across many sectors of the economy. With the introduction of the Internet of Things (IoT) in areas like manufacturing, mobility, health, logistics, etc., managing the amount of data produced in a secure way will require new innovative technologies like blockchain. The interest around blockchain is reflected in Figure 7-36 which shows the exponential increase in venture capital investment in blockchain technologies between 2017 and 2018.

Figure 7-36 Global venture capital invested in blockchain companies in USD bn, 2014-2018



Science, research and innovation performance of the EU 2020

Source: MIT Technology Review 2 April 2019 based on Pitchbook data
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter7/figure-7-36.xlsx

This interest is also reflected in the job market. Figure 7-37 gives an indication of this in the US market. In particular, it is possible to see that blockchain developer was the top 'emerging job' on LinkedIn between 2014 and 2018, with job postings growing 33 times over that period.

Figure 7-37 Emerging jobs on LinkedIn by growth over 2014-2018

	2018 Top 5 emerging jobs	Growth (2014-2018)
1	**Blockchain Developer**	**33x**
2	**Machine Learning Engineer**	**12x**
3	Application Sales Executive	8x
4	**Machine Learning Specialist**	**6x**
5	Professional Medical Representative	6x

Science, research and innovation performance of the EU 2020

Source: LinkedIn 2018 Emerging Jobs in the US Report

Note: Analysis of LinkedIn Economic Graph data between 2014-2018.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter7/figure-7-37.xlsx

Blockchain and other distributed data technologies could provide technical solutions that guarantee the authenticity of the data to be used in machine-learning algorithms. The success of machine learning is based on the availability of data – not just any data but data that can be trusted. In this respect, verifiable provenance of data used in ML algorithms is essential. Data protection of private data requires the consent of data subjects for its use. In that sense, blockchain could provide technical solutions that give control of the data to those to whom the data belong. For example, the research project DECODE[20] funded by Horizon 2020 is using blockchain to offer tools that give individuals control over their personal data.

The United States and China lead in terms of blockchain startups, while the EU28 only account for 15 % of all blockchain startups. **Funding for blockchain startups also appears more readily available in the United States than in the EU**. Figure 7-38 shows the geographical distribution of both blockchain startups (left-hand chart) and the funding received by these startups (right-hand chart). The United States and China both account for 28 % of all blockchain startups worldwide, and in total for almost 60 % of all startups in the field. The EU28, however, only represents 15 % of the global blockchain startup ecosystem, followed by Canada and Israel (both with a 2 % share), and India (1 %). US blockchain startups appear to have raised more funding than EU or Chinese startups: the United States represents one third of all funding mechanisms, compared to 22 % in the EU28, 21 % in China, 3 % in Israel and 2 % in Canada.

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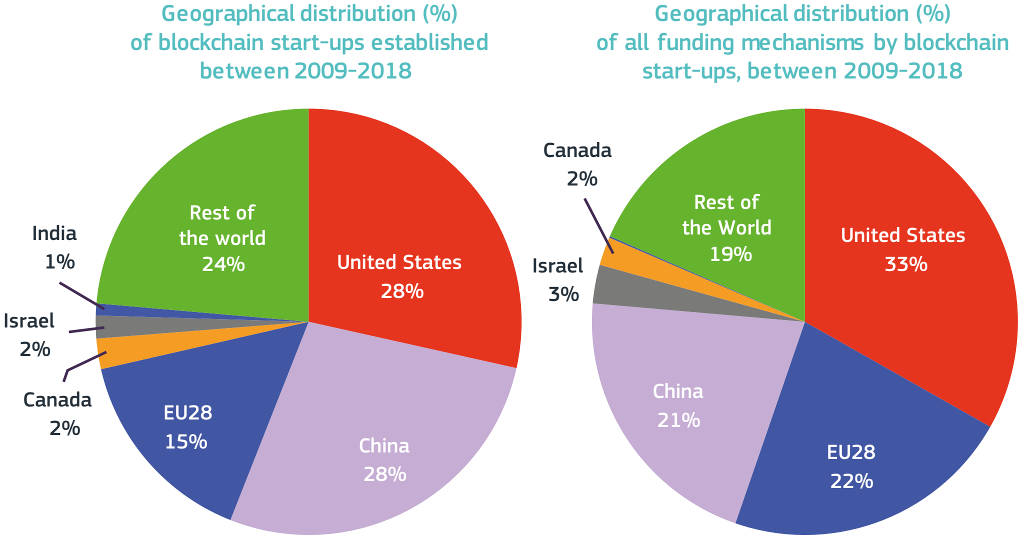
[20] https://decodeproject.eu/

Figure 7-38 Blockchain: startups and funding, 2009-2018



Science, research and innovation performance of the EU 2020

Source: Anderberg et al. (2019) based on Venture Scanner – Dow Jones

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter7/figure-7-38.xlsx

Horizon 2020 supports the development of blockchain applications. Through Horizon 2020, around EUR 200 million have already been allocated to blockchain-related projects in areas such as managing and controlling access to medical and personal data, IoT, smart homes and grids, cybersecurity, transport, energy, environment and social media. The 2019 'Blockchain for Social Good' Horizon 2020 prize awarded five prizes of EUR 1 million each to the best decentralised social innovations leveraging on distributed ledger technologies such as blockchain.

The EU wants to be at the forefront of blockchain policy action globally, by monitoring, regulation and governance of blockchain technologies. The Commission is monitoring the development of blockchain technologies and assessing the need for regulation. It has set up an EU Blockchain Observatory and forum[21] to monitor trends, developments and use cases in blockchain across sectors. In 2018, the Commission had already adopted the FinTech action plan[22] Communication in which it identifies blockchain, distributed ledger technologies, AI and other digital technologies as those that are changing the financial services. The action plan sets out a number of actions to assess the regulatory framework and to set up regulatory sandboxes.

The European Blockchain Partnership (EBP) agreement between all Member States plus Norway and Lichtenstein aims to cooperate in putting in place the European Blockchain Services Infrastructure (EBSI) for the use of blockchain technologies by the public sector initially and later the private sector, too. The EBSI is expected to be operational in 2020-2021, with the first cross-border digital public services.

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[21] https://www.eublockchainforum.eu/

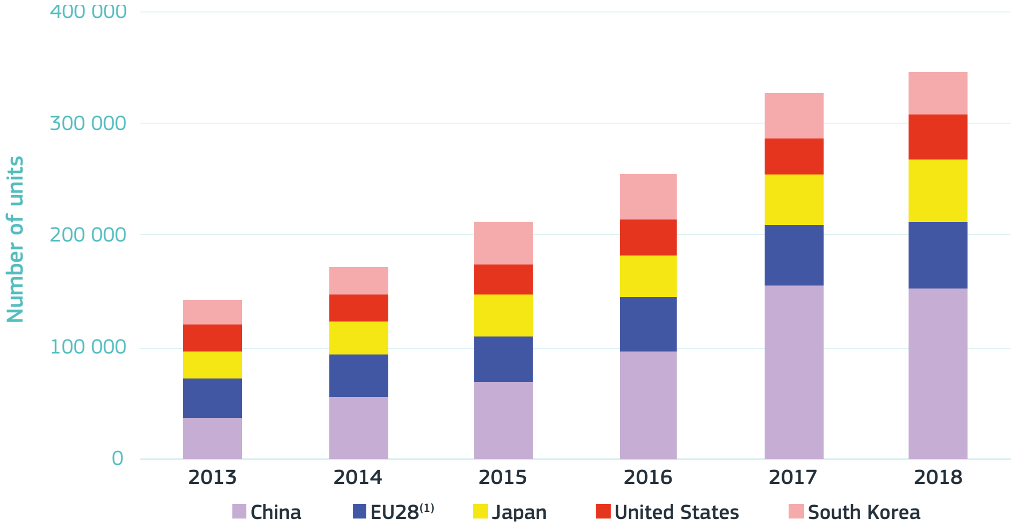
[22] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52018DC0109

Finally, in 2019, the European Commission supported the launch of the International Association for Trusted Blockchain Applications (INATBA)[23]. This public- private sector association, with members from around the world, is working on issues relating to interoperability, sector deployment guidelines and governance of blockchain technologies.

9. ‘Digital meets physical’: AI and advanced manufacturing

Two of the top 10 industrial robot manufacturers are in the EU. Worldwide, the number of industrial robots keeps growing. China has the largest market, followed by the EU and Japan. a German company (KUKA) and the Italian company Comau are in the world’s top 10 robot manufacturers[24]. The World Robotics Report shows that a record number of 422 271 industrial robots were shipped globally in 2018, a steady increase of 6 % compared to 2017 (IFR, 2019). As mentioned in Chapter 4.1 - Innovation, the future of work and inequality, worldwide robot density is highest in South Korea, followed by Japan, the United States and then the EU. In absolute terms, the Chinese market is by far the largest, followed by the EU, and it has been growing rapidly (Figure 7-39).

Figure 7-39 Annual installations of industrial robots - number of units, key world players, 2013-2018



Science, research and innovation performance of the EU 2020

Source: International Federation of Robotics (2019)

Note: (1)The EU28 values were obtained by subtracting from Europe's total the number of non-EU countries, 'others not specified' and 'other European countries'.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter7/figure-7-39.xlsx

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[23] https://inatba.org/

[24] https://www.marketresearchreports.com/blog/2019/05/08/world’s-top-10-industrial-robot-manufacturers

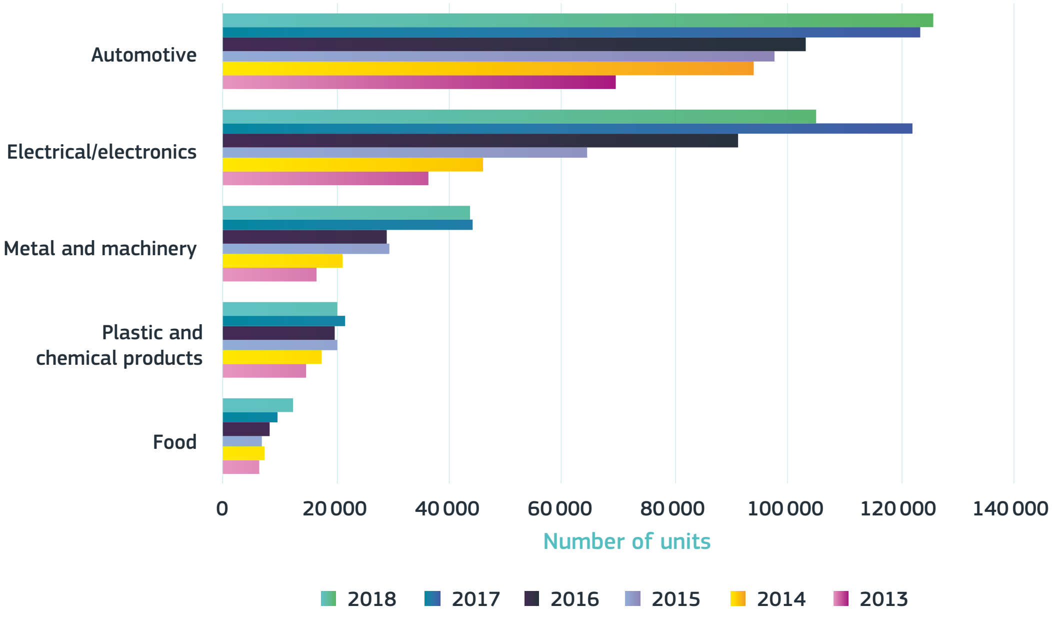
The automotive and electronics sectors are still the drivers although they are no longer growing. The food sector has registered a 32 % increase in robot deployment (Figure 7-40).

There are a number of examples of AI in current and potential application areas in manufacturing, such as cognitive automation, learning machines and robotics, intelligence monitoring (for anomaly detection and inspection) and predictive maintenance, process optimisation, sensors development, production ramp-up commissioning, task planning and scheduling, energy management, and logistics and value chains. **Overall, AI will have a major impact on how a factory will be run and which tasks workers will have to carry out**[25].

Another example where AI is expected to make a significant impact concerns the capabilities of industrial robots, making them smarter and enabling their deployment in tough and unstructured environments. Eurofound (2019) identifies advanced industrial robotics as *one of the five game-changing technologies in manufacturing*.

Factories of the future will feature advanced robots that will be able to roam around a site autonomously, recognise objects and humans, predict their movements and intentions, inspect products and assess quality. Robots will be able to learn from gestures and voice commands. All of these features will enable a true human-robot collaboration.

Figure 7-40 Annual installations of industrial robots at year-end worldwide by industries, 2016-2018



Science, research and innovation performance of the EU 2020

Source: International Federation of Robotics (2019)

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter7/figure-7-40.xlsx

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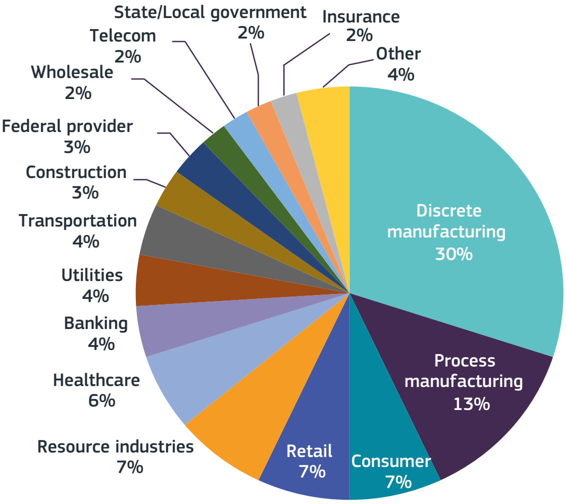
[25] See JRC, The changing nature of work and skills in the digital age, September 2019.

In 2018, *Science Robotics* listed the 10 grand challenges in robotics[26]. They identified the need for further research on new materials and fabrication schemes, new batteries and power sources for mobile robots, robot swarms, new navigation systems, AI technologies, social interaction and security. For example, further research is needed to overcome the limitations of techniques such as SLAM (Simultaneous localisation and mapping) to allow for the navigation and exploration of unmapped, time-varying and dynamic environments. This would enable an effective deployment in unstructured environments, such as construction sites. AI is still far from giving robots the capability to learn on-the-fly, adapt to dynamic settings or recover from failure. Despite great advances in sensing technologies, robots have underdeveloped social abilities. Today, robots are not able to interpret social clues such as gaze direction, facial expression or vocal intonations, which are key to unlocking the full potential of human-robot collaboration.

Europe is leading the way in collaborative robots. According to the International Data Corporation (IDC), discrete manufacturing and process manufacturing are expected to attract 30 % and 13 %, respectively, of global investment in AI estimated at EUR 32.7 billion in the world and EUR 4.6 billion in Europe (Figure 7-41).

AI in manufacturing, which relies mainly on a B2B business model, is fundamentally different from AI in the B2C world as it utilises less, but very heterogeneous, data from a variety of sources often implemented on edge devices rather than in the cloud. Manufacturing also has higher requirements regarding reliability, while the adoption of autonomy comes with safety, security and ethical issues. For business-to-business applications, Europe is still a champion.

Figure 7-41 Expected distribution of financial investments in AI systems, robotics and drones in Western Europe, 2019



Science, research and innovation performance of the EU 2020

Source: https://www.eu-robotics.net/cms/upload/downloads/ppp-documents/AI_PPP_SRIDA-Consultation_Version-June_2019_-_Online_version.pdf

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter7/figure-7-41.xlsx

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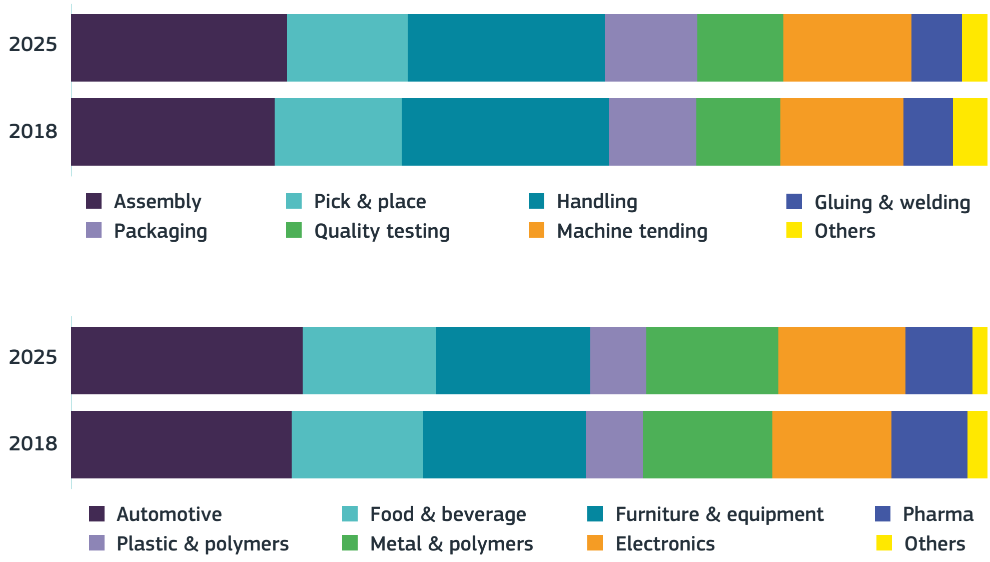
[26] Yang et al., Science Robotics 3, eaar7965 (2018).

Three of the world's largest producers of industrial robots are European and 20 % of industrial robots are produced in Europe.

Industrial robots were introduced decades ago to carry out repetitive, dull and tedious tasks better and faster than humans. Normally, such robots are caged behind fences for safety reasons and need to be carefully pre-programmed to do a specific task. Reconfiguration and flexibility are minimal. Factories of the future will feature advanced robots that will be able to roam around the site autonomously, recognise objects and humans, predict their movements and intentions, inspect products and assess quality. Robots will be able to learn from gestures and voice commands. All these features will enable a true human-robot collaboration. Nevertheless, although several advances have been achieved on smart grippers, connectivity and programming, in order to make advanced industrial robotics a reality on the shop floor the further development and integration of AI technologies, such as machine learning, computer vision, connected automatic vehicles, speech recognition and neural networks is required.

Currently, Europe as a whole is the key market for collaborative robotics, accounting for a significant share of around 37 % in 2018 (Grand View Research, 2019). The material handling and assembly application segments are currently the strongest in the collaborative robot market with end use in the automotive, plastic and polymers, metal and machine, electronics, pharma food beverage and furniture and equipment industries. As illustrated in the figure below, assembly application is expected to undergo steady growth over the forecast period thanks to the ability of combining both repetitive and easy work along with more complex assembly processes in industries such as inspection, logistics and electronics.

Figure 7-42 Collaborative robots: market size and growth prospects

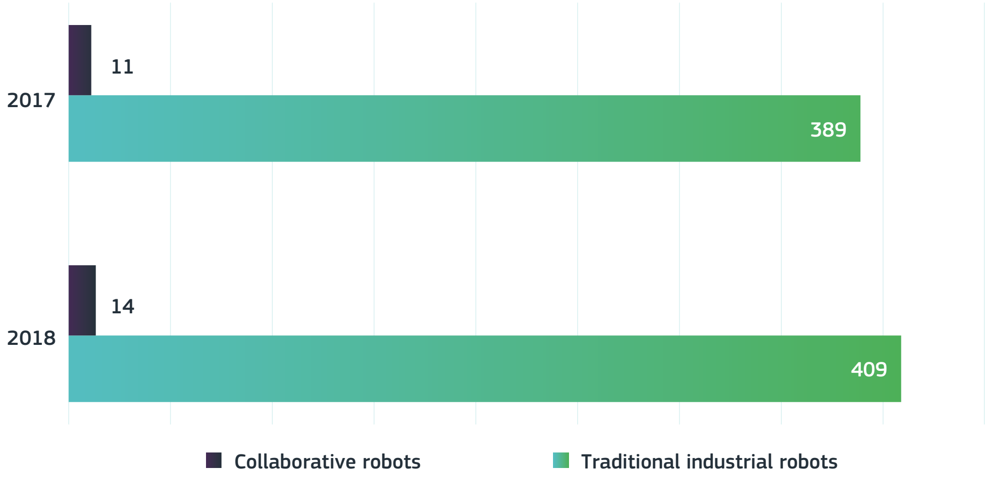


Source: Grand View Research (2019) based on RIA, IFR, Factor-tech and Discover Magazine. Hoover's, Primary interviews, Company Annual reports

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter7/figure-7-42.xlsx

Despite the constant growth of the robotics market, market-advanced collaborative robots can be still be considered as being relatively small, as only 14 000 collaborative robots were sold in 2018 worldwide (Figure 7-43) as against 409 000 traditional models.

Figure 7-43 Collaborative and traditional industrial robots, 2017 and 2018



Science, research and innovation performance of the EU 2020

Source: International Federation of Robotics (2019)

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter7/figure-7-43.xlsx

On the other hand, the global market share for collaborative robots is on the rise supported by investments in Industry 4.0, showing a 23 % increase from 2017 to 2018, with the overall market for robotics increasing by 6 % during the same period. China is expected to grow at a faster pace in the coming years, becoming the largest market for collaborative robots by 2025 (Figure 7-44).

Figure 7-44 Regional market place for collaborative robots

Region	Revenue 2018 (USD mn)	Revenue 2025 (USD mn)	Notable markets
Europe	241	241	UK, Germany
North America	193	193	United States, Canada
South America	23	23	Brazil, Mexico
Asia-Pacific	183	183	China, India

Science, research and innovation performance of the EU 2020

Source: Grand View Research (2019) based on RIA, IFR, Factor-tech and Discover Magazine. Hoover's, Primary interviews, Company Annual reports

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter7/figure-7-44.xlsx

Box 7-6 Supporting human-robot collaboration in manufacturing within Horizon 2020

Under Horizon 2020, the EU has invested more than EUR 220 million in human-robot collaboration in manufacturing and related technologies. In 2018, 5 new collaborative projects on human-robot collaboration were funded, for around EUR 37 million, under the contractual public and private partnership Factories-of-the-Future. a large number of sectors are being targeted, from aeronautics to white goods production, and from electronic-waste recycling to food packaging.

The EU-funded THOMAS project is developing a new reconfigurable industrial shop floor where AI provides mobile robots with cognitive abilities that enable them to detect other robots and thereby to calculate collision-free trajectories, share and reallocate work in case of unexpected events, whilst also detecting people in the work space and understanding their intentions. THOMAS is validating its new concept with end-users in the automotive and aeronautics sectors, estimating a market potential of at least 300 factories in Europe.

AI and material discoveries

AI is providing ways to speed up discoveries in materials science. 'From the Stone Age through the Bronze and Iron Ages to today's Silicon Age, every major advance in human civilisation has been driven by a fundamental development in materials science.' Professor Spaldin from ETH Zürich quotes and argues that without new materials we are stuck with our existing concepts for information technology and have an energy bottleneck in human progress.

The traditional pipeline through which new materials are discovered, designed, developed, manufactured, and deployed remains slow, costly, and highly inefficient (Himanen et al., 2019). AI applications (computational data science and machine learning) are significantly speeding up both fundamental and applied materials research (Schmidt et al., 2019). Current machine learning applications in materials science are rich and diverse, ranging from catalyst design, exploring the mechanisms of high-temperature superconductivity to predicting excitation spectra. Researchers are using computer modelling and machine-learning techniques to generate libraries of candidate materials by the tens of thousands to shortlist, for example, how well they will work as a conductor or an insulator, whether they will act as a magnet, and how much heat and pressure they can withstand (Nosengo, 2016).

It takes a lot of trial and error as well as lab experimentation to identify new materials, particularly high-performance materials for next-generation applications. Researchers are combining AI and machine learning models to find the optimal material to fit any given criteria in order to reduce the time and cost spent moving from lab to market. The use of machine learning and ab initio calculations are presented to guide strain engineering whereby material properties and performance could be designed (Shi et al., 2019).

Nanomedicine design also benefits from the application of AI by optimising material properties according to predicted interactions with the target drug, biological fluids, immune system, vasculature, and cell membranes, all affecting therapeutic efficacy (Adir et al., 2019). Such machine learning tools are increasingly being incorporated directly into material data infrastructures (Himanen et al., 2019).

Box 7-7 Snapshot of EU-funded projects using AI to accelerate material discoveries for green solutions

The large-scale **Battery 2030 project**, with 17 partners from academia and industry, wants to design batteries of the future by using ultra-high-performance materials and structures from the atomic level up, using advanced approaches like density functional theory calculations in combination with AI.

The **Moldesign project** uses computational material design by combining material simulation methods with AI to enable large-scale material screening for the next generation of organic solar cells.

The **CoMManD project** is developing a computational approach using AI to accelerate the discovery of molecular materials targeting applications in molecular separations, sensing, (photo) catalysis and photovoltaics.

The **DYNAPOL project** is studying bio-inspired properties such as the ability of various supramolecular materials to self-heal, adapt or reconfigure dynamically by using AI and massive multi-scale modelling.

Accelerating the discovery of new materials, and the associated research required for real deployment, will require a radical departure from traditional forms of discovery and a multidisciplinary and international effort. Computation and design are simply the first step in bringing novel materials to market. Materials synthesis and characterisation have yet to benefit from automation and accelerated learning on a large scale[27]. Even if the use of AI in materials science is still in its early days in Europe, it will enable unforeseeable and revolutionary impacts across nearly the entire spectrum of materials and structures, processes, and multi-scale modelling and simulation over the next two decades (Dimiduk et al., 2018). To establish data-driven materials science as a true paradigm in materials research, joint eco-system efforts are necessary between research, industry and public and governmental organisations (Himanen et al., 2019).

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[27] http://mission-innovation.net/wp-content/uploads/2018/01/Mission-Innovation-IC6-Report-Materials-Acceleration-Platform-Jan-2018.pdf

10. Conclusions

The EU ranks among global leaders when it comes to AI science. However, there is an AI innovation gap when compared to the United States and China. This includes, for instance, the number of AI firms and the share of firms active in AI patenting. Most unicorn companies in the AI field are also based in the United States and China.

In terms of 'AI dynamics', worldwide academia-business and cross-country collaborations have intensified over time. The EU collaborates strongly with the United States, then China, in research and patenting in the AI domain. Likewise, **AI science is no longer confined to fields such as computer science. In the EU, AI research is more oriented towards humanities and social sciences**. Moreover, in the global AI race, top companies are investing highly in AI. This is illustrated by the **rapid pace of acquisitions of AI startups (notably by tech giants)**, especially in recent years, **in order to access data and top AI knowledge**, with implications for the EU's future positioning in AI, market-concentration dynamics, data protection and competition policy.

Worldwide, major economies have put forward ambitious AI strategies. China was first to launch a comprehensive AI strategy in 2017 with the 'Next Generation Artificial Intelligence Development Plan' followed by the industry-targeted 'Three-Year Action Plan for Promoting Development of a New Generation Artificial Intelligence Industry (2017)'[28] with the aim of becoming the global AI leading nation by 2030. With the **Declaration on Cooperation on Artificial Intelligence** (2018) and the **Coordinated Plan on Artificial Intelligence 'Made in Europe'** (2018)[29], the EU and the Member States demonstrated their ambition to align priorities and maximise the impact of public and private investments in AI to enable innovation and collectively ensure that the EU as a whole can compete globally. The EU **Digital Strategy**[30] wants to ensure not only that Europe is a global digital player but also that the EU leads in making sure that technology works for all, and that we live in an open, democratic and sustainable digital society. The United States followed with a national strategy for AI, the American AI Initiative (2019)[31] which identifies R&D as a top priority for maintaining global leadership in AI.

AI can play a big role in the economic, social and ecological transition that Europe is undergoing. In the context of the current productivity slowdown, AI can be a powerful tool to improve the efficiency of operations throughout the economy. As a result, the EU should capitalise on its industrial strengths to lead in AI development. This includes, for instance, manufacturing as well as new areas of early application such as material science. In order to achieve **technology sovereignty in the field of AI as well as to diffuse it** across sectors and regions, the combination of efforts at the EU and Member State level is paramount.

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[28] http://www.gov.cn/zhengce/content/2017-07/20/content_5211996.htm, http://www.miit.gov.cn/n1146295/n1652858/n1652930/n3757016/c5960820/content.html

[29] https://ec.europa.eu/digital-single-market/en/artificial-intelligence

[30] https://ec.europa.eu/digital-single-market/en/content/european-digital-strategy

[31] https://www.whitehouse.gov/ai/

Although AI, like any technology, does not automatically make the world a better place, it can. In the fight against climate change, AI can make a significant contribution across different fields. By enabling automatic monitoring through remote sensing (e.g. pinpointing deforestation, and assessing damage after disasters), accelerating the process of scientific discovery (e.g. by suggesting new materials for batteries and carbon capture) and optimising systems to improve efficiency (e.g. by consolidating freight, designing carbon markets, and reducing food waste)[32]. In addition, AI can also help to improve public services (e.g. traffic management, healthcare delivery and processing tax forms). While some EU Member States have a high international ranking in 'government AI readiness', more efforts to roll-out AI capabilities are needed in other countries.

AI and other digital technologies have reached a stage of technological maturity that makes them important tools to help in the fight against a pandemic such as COVID-19. All over the world, ambitious R&I projects and collaborations to track, monitor and contain the COVID-19 pandemic are increasingly being carried out, including AI-powered solutions. AI-related applications have enabled population screening, tracking the spread of the infection, and the detection and diagnosis of COVID-19. Openly accessible, machine-readable, interoperable data is needed to track, monitor and forecast the spread of COVID-19. At the EU level, the Action Plan - Research data-sharing platform for the SARS-CoV-2 and COVID-19 diseases launched by the EMBL's European Bioinformatics Institute (EMBL-EBI) and the European Open Science Cloud intends to speed up and improve the sharing, storage, processing of and access to research data and metadata on the SARS-CoV-2 and COVID-19 diseases. At the same time, the use of AI tracking and surveillance tools in the context of this pandemic has clearly shown the **need for the global ethical governance of AI.**

AI also requires investing in a set of complementary assets. These include fostering talent production and retention in the EU (while attracting foreign talent from other parts of the globe), investments and **capacity-building in related digital technologies**, such as high-performance computing, European cloud and micro-electronics, and **research and digital infrastructure**, notably 5G networks, for Europe to remain competitive and ensure technological sovereignty. Both the EC's **Horizon Europe and Digital Europe Programmes** will be instrumental in achieving this. Furthermore, **advancing market integration** in Europe with a complete Digital Single Market is vital for AI startups and scale-ups to succeed, including simpler and quicker patent rights.

In addition, one of the most important considerations is to ensure that the economic and social benefits of AI are broadly shared across society. Thus, building 'trust in tech' and social acceptance around AI is essential. For example, open source and open data have important implications for boosting innovation, although there are also concerns relating to privacy and cybersecurity. In the EU, the General Data Protection Regulation (GDPR) is a major step towards building trust and ensuring legal clarity in AI-based applications. Also, AI predictions and decision-making capabilities are only as good as the quality of the underlying data. Concerns over AI bias based on gender, race and other factors due to 'inherited' bias in historical data or missing observations may lead to discriminatory decisions.

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[32] Tackling climate change with machine learning: https://arxiv.org/abs/1906.05433

All in all, although Europe has a rich history in AI research and continues to lead in that area, it is clear that the early implementers of recent breakthroughs in machine learning, big data analytics, and cloud computing are situated mainly in the United States and China, predominantly in the B2C market. In years to come, the application of AI will increasingly be the subject of concerns about its long-term impacts on privacy, technological sovereignty and the future of work. Europe is currently carving out a position to lead in a more thoughtful, ethical approach to AI with a clear and adequate legal and ethical framework to build an AI ecosystem that spurs innovation: **Europe is designing its own way**. By seeking out opportunities in the business-to-business market, investing in the development of privacy-preserving and transparent AI, rethinking existing paradigms (e.g. edge vs. cloud-based AI), putting an emphasis on the environmental impact of information technologies, and by introducing targeted regulation (of which GDPR could be seen as an onset), **Europe is positioning itself for a self-designed, AI-infused future**.

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CHAPTER
8

FRAMEWORK CONDITIONS

KEY FIGURES

8x
more venture capital funds raised in the US than in the EU

22 %
share of public sources in total venture capital funds in the EU in 2018

2.5 x
higher institutional performance of the top 10 % of regions than the bottom 10 %

What can we learn?

- The top-performing EU Member States have a very **efficient product and labour market** although on average the EU lags behind the United States and Japan on these aspects.
- **Institutional quality is high** in the core of the EU and in capitals, with a **high degree of regional variation and heterogeneity** within and across countries.
- **Europe is rich in ideas and talent but lower access to risk capital is constraining scaling-up**. In the United States, eight times more venture capital funds are raised for innovation.
- The **public sector has been an important actor in the recovery of venture capital** in the EU.
- When it comes to R&I-related activities, **three main barriers to the internal market** can be identified, namely limited knowledge circulation, limited innovation diffusion, and gaps in the quality and efficiency of R&I systems.
- There is a positive correlation between countries' **regulatory quality and innovation performance**. However, China does not follow this pattern, showing strong R&I performance but a very low score in terms of regulatory quality.

What does it mean for policy?

- These results call for policies **ensuring efficient framework conditions and improving institutional quality** across and within Member States, in particular peripheral economies in the south and east.
- **Foster the access to risk capital and other alternative sources of financing** to improve the scaling-up performance of European innovative companies.
- Europe needs a fit-for-purpose and forward-looking **regulatory framework encouraging innovation to support social, economic and environmental transitions**.
- **Completing the Single Market for research, education and innovation** can foster knowledge diffusion across the continent.

Investing in innovation activities is a risky process characterised by high uncertainty concerning the returns and their appropriability. Because of this, and the related difficulties in getting access to appropriate sources of finance, private investment in R&D and innovation tends to be lower than what would be socially desirable. Such underinvestment has been investigated by analysts and policymakers as it brings a social loss due to missed positive spillovers from R&I activities in terms of both technological opportunities and economic impacts (Arrow, 1962; David et al., 2000). On the one hand, such a 'market failure' justifies direct public support for business R&D and innovative activities in order to increase investment and the associated benefits for society as a whole. On the other hand, this suggests that the overall framework conditions in which companies operate are fundamental as they set business incentives and shape the innovation capacity of economies.

'Good' framework conditions positively affect business-investment decisions, ease access to markets for new and innovative companies, and contribute to reallocating resources towards more productive and innovative activities. This chapter investigates how fit-for-purpose framework conditions are in Europe and peer economies, along several dimensions: i) the efficiency of product markets and the functioning of the labour market; ii) the availability of sources of finance for innovative investments; iii) the quality of the institutional frameworks; and iv) the regulatory framework for innovation. These factors contribute to determining the opportunities and costs businesses face when operating in a market and, as such, affect their decisions. In particular, a higher number of bureaucratic and often redundant requirements (red tape) to engage in economic activities and exchanges pose additional, often unnecessary, burdens on companies. These are normally known as transaction costs and act as a deterrent to firms' investment and growth prospects as they affect business activities in terms of both time and monetary costs. Therefore, while they hinder investment and economic performance horizontally across sectors, their impact is specifically relevant for companies in the domain of R&I, characterised by higher risk and uncertainty over the outcomes.

Framework conditions for engaging in business activities in the EU have been improving over the last decade and a positive trend can be observed in most Member States. Europe has made substantial progress in improving the conditions for firms to operate in the markets, reducing bureaucratic requirements and other costs related to running a business. This trend is shown in Figure 8-1 which plots the ease of doing business indicator produced by the World Bank for 2010 and 2019. It is an encompassing index summarising information drawn from 10 indicators describing how easy it is to start a business or leave the market, dealing with bureaucratic procedures, getting credit and going through legal procedures[1]. An overall improvement for the EU has been driven by increases in the index for the Member States with the lowest values in 2010, suggesting that an upward convergence trend is in place. The reforms implemented by Member States and the deepening of the Single Market have been two key driving factors.

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[1] See https://www.doingbusiness.org/en/methodology and the methodological Annex for more details.

Figure 8-1 Ease of doing business - distance to frontier (0 = lowest performance to 100 = frontier)[(1)], 2010 and 2019

Science, research and innovation performance of the EU 2020

Source: World Bank data, Ease of Doing Business Index

Notes: [(1)]The distance to frontier score illustrates the distance of an economy to the 'frontier' which represents the best performance observed across all economies. The highest scores represent the friendliest regulatory environments for doing business. [(2)]EU is the unweighted average of the available data for Member States and does not include Malta for 2010. [(3)]MT: 2012; US, JP, CN: 2014.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter8/figure-8-1.xlsx

1. Efficiency of the product and labour markets is heterogeneous among Member States, with a persisting gap vis-à-vis peer economies

The structure of the product market determines the conditions under which businesses operate, shaping their incentives and opportunities to invest. Efficient product markets allow companies to compete equally, rewarding innovative investments and incentivising the entry of new firms and startup creation. Conversely, inefficient product markets that do not provide a levelling field for private activities contribute to the misallocation of resources towards less-productive uses, eventually hindering aggregate productivity.

The European product market performs better than in China or South Korea, but there is still a gap with the United States and Japan, while differences between Member States are still relevant. Figure 8-2 presents an index of the efficiency of the product market developed by the World Economic Forum (WEF), which accounts for the above factors by drawing data from different sources, including surveys to business representatives. The index is an aggregate measure that includes information on the distortive effects of taxes and subsidies on competition across several sectors, the extent of market concentration and barriers to economic exchanges, including trade[2]. International benchmarking places the EU in an intermediate position compared to its main peer economies. While the product market is more efficient in the United States and Japan, it performs better in the EU compared to South Korea and China. There is substantial heterogeneity between Member States, with central and eastern economies having less-performing goods markets while countries in the west and north of Europe have the most efficient ones. Countries in the south of Europe are in-between, with the notable exception of Greece which is at the bottom of the distribution.

Competition is one of the key elements defining the efficiency of the goods market. Indeed, while from a theoretical perspective the relationship between competition and innovation is not straightforward[3], the underperforming productivity dynamics of recent decades have raised concerns on the impact of competition on innovative investment and growth. In particular, the rise of 'superstar' firms has led to an unprecedented concentration of investment, innovation activities and the associated benefits. While these companies are more productive and invest more in intangible assets[4] than the rest, recent evidence from the International Monetary Fund suggests that their increasing market shares and mark-ups may eventually create negative effects on overall investment, productivity growth, labour shares and innovation rates. This relationship becomes more pronounced the more industries are concentrated and the closer they are to the technological frontier (Diez et al., 2018). Furthermore, in a global context in which knowledge diffusion has been slowing down, the larger the negative effects of reduced competition on innovation performance are, the less efficient the product markets are. Fair and competitive markets make more efficient and innovative industries easier to emerge (EPSC, 2019). Notwithstanding the relevance of large established companies for innovative investments, competition promotes equal opportunities for all businesses, providing new entrants with incentives to invest because of higher expected returns, while inducing incumbents to innovate and adopt technologies in order to 'escape competition' induced by new competitors.

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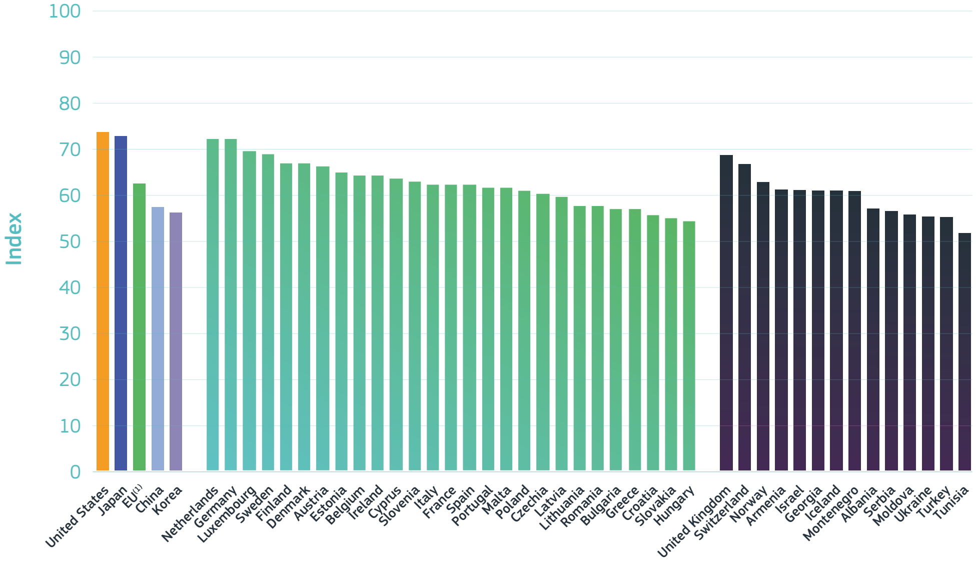
[2] The Index corresponds to the 7th pillar of the Global Competitive Index which, in turn, is the summary measure of eight sub-indicators. See reports: weforum.org/global-competitiveness-report-2018/appendix-c-the-global-competitiveness-index-4-0-methodology-and-technical-notes/ for further information on this and the other WEF indicators reported in this chapter.

[3] Higher competition may open the markets to new entrants bringing disruptive innovation while putting pressure on incumbents. However, the Schumpeterian argument states that larger firms with market power are more likely to innovate because they can benefit from innovation rents. Empirical evidence suggests that the relationship is not linear and depends on the initial level of competition and economy-wide factors, such as the characteristics of industry and firms and the technology opportunity provided by the structure of the economy. See, for instance, the review in Cohen (2010).

[4] According to data reported in The 2019 European Industrial R&D Investment Scoreboard, the world top 2 500 R&D investors account for approximately 90 % of the global business R&D investment.

Figure 8-2 Global Competitiveness Index - product market, 2018
values are on a scale of 0 to 100 (best)



Science, research and innovation performance of the EU 2020

Source: Word Economic Forum - The Global Competitiveness Index dataset 2018

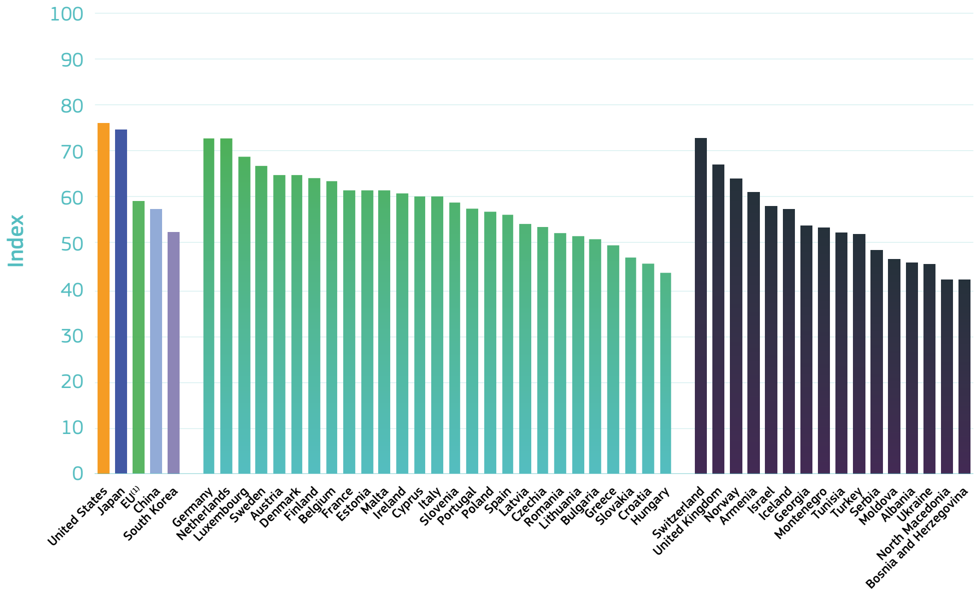
Note: $^{(1)}$EU is the unweighted average of the values for the EU Member States.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter8/figure-8-2.xlsx

The degree of competition is diverse across EU Member States and heterogeneity can be observed between peripheral and core countries. From an international perspective, the markets in the United States and Japan are significantly more competitive than the EU. Figure 8-3 shows the degree of (domestic) competition in the domestic market, drawing from a sub-sample of the indicators composing the WEF index on product market efficiency. The measure reflects the distortive effects of taxes and subsidies on competition, the extent of market dominance by a few 'take-all' firms and how competitive market services are. While the degree of competition in Germany, the Netherlands and Luxembourg is comparable to the levels observed in the best-performing economies, such as the United States, Japan and Switzerland, the aggregate EU performance is just above the Chinese and Korean standards. This is due to significant differences across Member States, in particular because of the low degree of competition in most of the peripheral economies in the east and south of Europe.

The rate of entry of new and innovative companies is affected by barriers to access, including the procedures an entrepreneur is required to undergo to be able to start up and operate a business. Barriers to entry contribute to higher transaction costs, both in terms of time and sunk costs, hampering the innovation potential of economies through the distortion of business decisions and the exclusion of innovative projects. These factors become more relevant when financial markets are not sufficiently developed and cannot provide alternative financing to young and new companies, especially those based on intangible assets that have greater constraints on their capacity to provide collateral (see below). Based

Figure 8-3 Global Competitiveness Index - domestic competition, 2018
values are on a scale of 0 to 100 (best)



Source: Word Economic Forum - The Global Competitiveness Index dataset 2018
Note: (1)EU is the unweighted average of the values for the EU Member States.
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter8/figure-8-3.xlsx

on the information on the time needed and the cost of complying with regulations in each country, Figure 8-4 shows how easy it is to start a business in Europe and its peer economies. The World Bank's Doing Business indicators[5] are used as a proxy for entry barriers[6]. A generalised positive trend has emerged since 2010 for most of Member States, with the exception of Romania and Hungary, without any regional divide. From an international perspective, South Korea and China have achieved a significant improvement in entry conditions, overtaking the United States and the EU. However, despite this progress, business dynamism is declining in Europe compared to the United States (see Chapter 3.3 - Business dynamics and its contribution to structural change), suggesting that other factors affect companies' entry (and exit) rates, such as, for instance, the lack of capital for risky innovative investments.

While more competition and improved conditions for new innovative companies to enter the market are crucial factors for investment, innovation performance and productivity growth, the uncertainty and risk associated with R&D and innovative activities require adequate protection of the returns on investment. This is also due to the non-excludability and potential externalities

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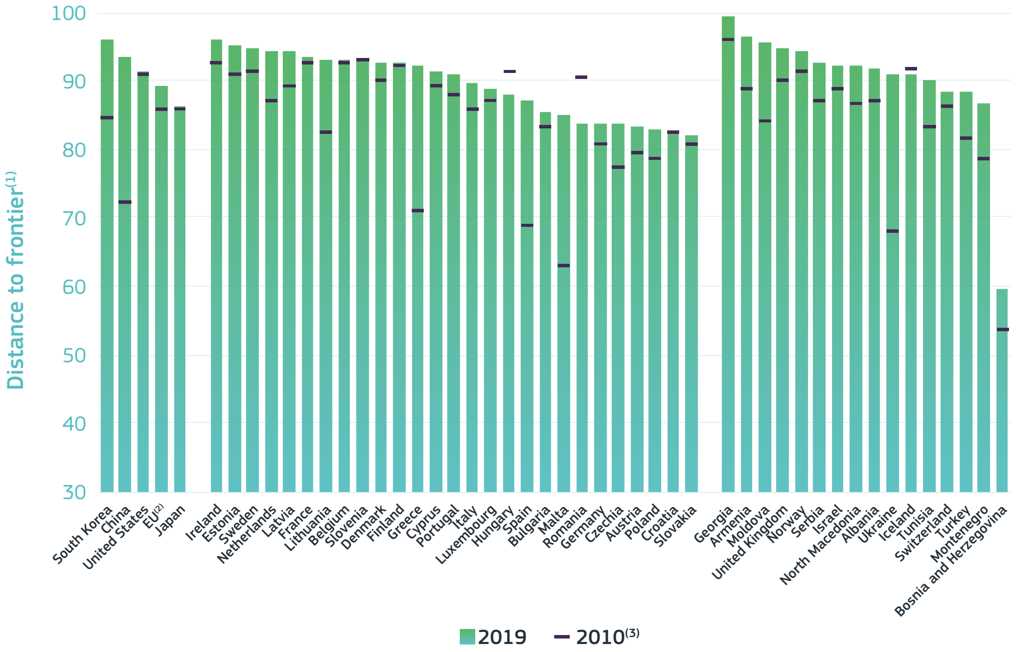
[5] See https://www.doingbusiness.org/en/data/exploretopics/starting-a-business/what-measured

[6] Different proxies can be used for the scope, such as, for instance, the OECD's Product Market Regulation indicator in either its sectoral or country-based specification. See for instance Chapter 13.

of R&D activities, which allow competitors to benefit from the positive spillover effects stemming from the efforts made by investing companies. Therefore, adequate protection of intellectual property rights gives business proper incentives for investment, while policy faces the challenge of finding the right balance with a competitive environment.

Figure 8-4 Ease of starting a business - distance to frontier (0 = lowest performance to 100 = frontier)(1), 2010 and 2019



Science, research and innovation performance of the EU 2020

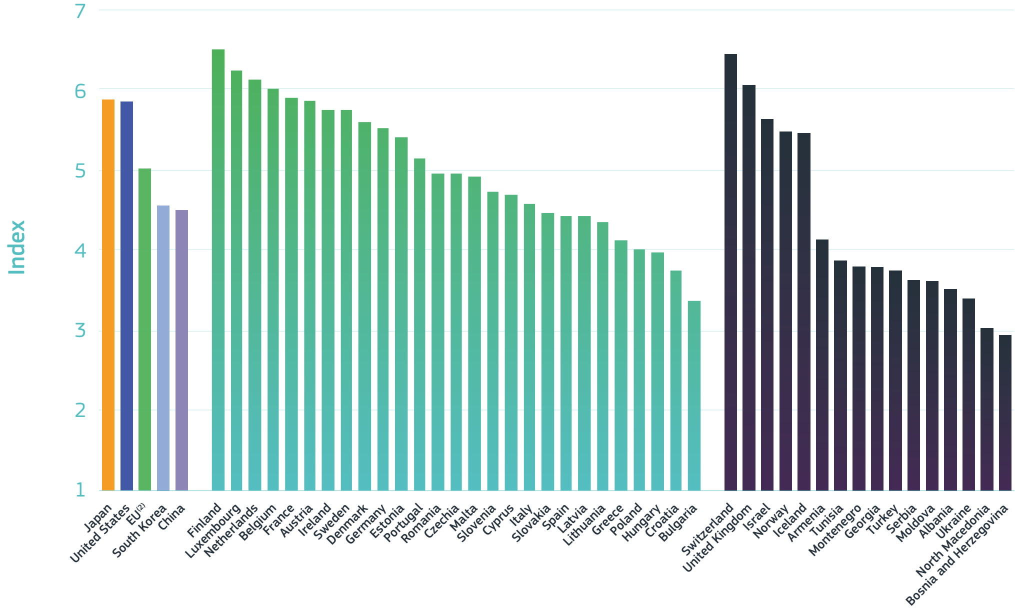
Source: World Bank data, Ease of Doing Business Index

Notes: (1)The distance to frontier score illustrates the distance of an economy to the 'frontier' which represents the best performance observed across all economies. The highest scores represent the friendliest regulatory environments for incorporating and formally operating a business. (2)EU is the unweighted average of the available data for Member States and does not include Malta for 2010. (3)MT: 2012; US, JP, CN: 2014.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter8/figure-8-4.xlsx

The protection of intellectual property rights is very heterogeneous across EU Member States, being weaker in peripheral economies compared to central and northern Member States. Figure 8-5 reports effective intellectual property rights protection, using an indicator drawn from the WEF Global Competitiveness Index dataset based on surveys among business representatives. Overall, the EU has weaker intellectual property rights protection compared to its peer economies, while still keeping ahead of South Korea and China. The gap between central-eastern and southern economies and the best-performing Member States drives the aggregate performance. However, the degree of intellectual property rights protection in some countries, such as Finland, Luxembourg, the Netherlands and Belgium, is among the highest in the world.

Figure 8-5 Global Competitiveness Index - intellectual property protection[1], 2018
values are on a scale of 1 to 7 (best)



Science, research and innovation performance of the EU 2020

Source: Word Economic Forum - The Global Competitiveness Index dataset 2018

Notes: [1]Weighted average 2017-2018. MK, TR: 2018. [2]EU is the unweighted average of the values for the EU Member States.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter8/figure-8-5.xlsx

An efficient labour market, facilitating hiring and reducing the burden on companies in case of failure, provides firms with incentives to hire workers and invest, especially when engaging in innovative activities with highly uncertain outcomes. The common view on labour market efficiency suggests that the excessive regulation of hiring and firing relationships has negative impacts on employment trends, and eventually on productivity growth (Bassanini and Ernst, 2002). In particular, rigidities in determining salaries together with high labour costs have negative bearings on firms' investments and may discourage the adoption of innovation. As a result, industry productivity is hindered, with long-term implications for industries' competitiveness and growth prospects (Tressel and Scarpetta, 2004; Thum-Thysen et al., 2017). Flexible employment relationships may increase the capacity of young and small companies to adapt to changes in market conditions and demand fluctuations while reducing expected dismissal costs and encouraging medium-long term investments. Overall, alignment between (real) wages and productivity growth, together with adequate labour taxation, are favourably associated with innovation and investment.

At the same time, an efficient labour market should incentivise firms' investment in high-skilled workers, favouring the transition towards knowledge-intensive activities, while active labour market policies need to support the retraining and upskilling of displaced workers. While increased flexibility may lead to higher productivity gains, there is some evidence that loose regulation in hiring and firing could affect companies' incentives to invest in workers' skills and increase the quality of human capital (Égert, 2016). Such a risk is higher in economies characterised by relatively low shares of knowledge-intensive sectors, where less employment protection may create unintended incentives for firms to opt for cost-competitiveness solutions, rather than scaling up the technological content of their activities (Lucidi, 2012; Pyke, 2018). As such, higher labour market flexibility could have an unintended 'protecting' effect on less-innovative firms which will be able to engage in cost-based competition and have a greater chance of survival (Kleinknecht, 1998). Within this perspective, the Schumpeterian 'creative destruction' process would be hampered, allowing less-competitive and innovative firms to survive rather than being 'competed away' by innovating firms, which are less likely to benefit from looser labour market flexibility, due to higher profits and market dominance[7] (Kleinknecht et al., 2014). Furthermore, the impact of technological change on job losses may have harmful and costly effects on displaced workers with obsolete skills. Active labour market policies promoting lifelong learning, up- and reskilling are crucial, especially in the context of the unprecedented speed of technological change and to ensure inclusive growth is achieved (Pyke, 2018)[8].

Given the above framework, Figure 8-6 reports a labour market efficiency index developed by the WEF. This is an aggregate index encompassing different dimensions of employment relationships. On the one hand, it accounts for regulation and flexibility, including redundancy costs, flexibility in hiring and firing and in wage determination, mobility of labour, the labour tax rate and the extent to which wage is related to employee productivity. On the other hand, it accounts for worker rights, the presence of active labour market policies for reskilling, female participation in the labour force and management[9].

The efficiency of labour markets is heterogeneous among Member States, with a divide emerging between most peripheral countries and the core. While the best-performing Member States have very efficient labour markets in a global perspective, on average the EU lags behind the United States, Japan and several third countries. Rigidities in hiring and firing practices are among the drivers of the low efficiency recorded for most of the south and central-eastern Member States[10], together with France and Belgium. The lack of adequate active labour market policies is also a relevant factor for southern economies like Spain, Italy and Greece.

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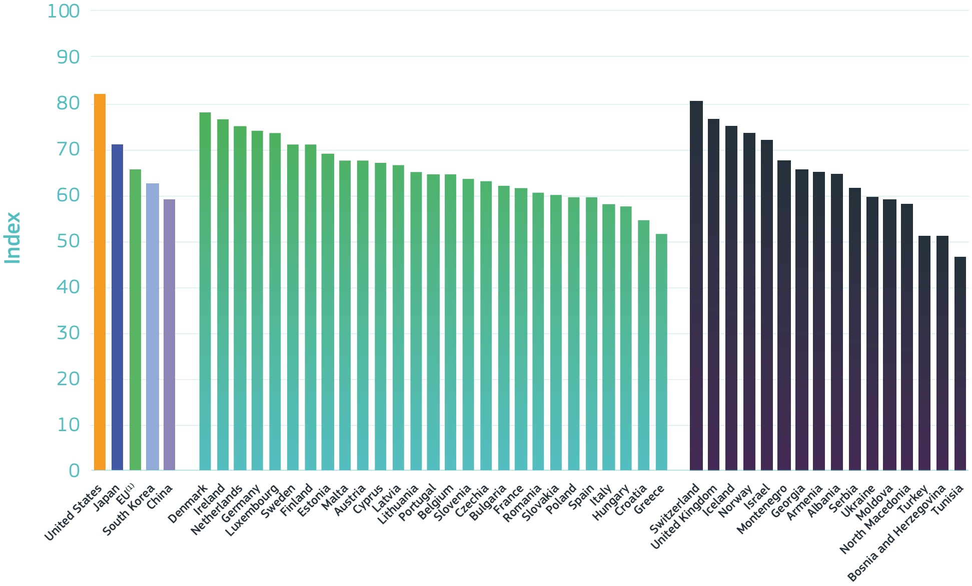
[7] The existing empirical evidence is inconclusive and varies with the data and indicators used as, for instance, reported in De Spiegelaere et al. (2014). Among others, Kleinknecht et al. (2014) report that labour market flexibility negatively affects innovation in sectors where innovation output depends on large R&D investment based on accumulated and specific knowledge, with monopolistic competition or oligopolies. See also Chapter 13 - Regulations and technology diffusion in Europe: the role of Industry dynamics.

[8] See also Chapter 2 - Changing innovation dynamics in the age of digital transformation, and Chapter 5.2 - Investment in education, human capital and skills.

[9] While the index is predominantly a measure of labour market flexibility (8 out of 12 indicators are related to it), it allows for the inclusion of different factors that are relevant for both the definition of framework conditions conducive to innovation and, partially, to the implication of technological change on employment dynamics. See also: weforum.org/global-competitiveness-report-2018/appendix-c-the-global-competitiveness-index-4-0-methodology-and-technical-notes/ for more details.

[10] Some of the measures are based on surveys among business representatives. Therefore, while European Member States have undertaken several reforms in recent years, some time lag may be needed for the reforms to be perceived as effective.

Figure 8-6 Global Competitiveness Index - labour market, 2018
values are on a scale of 0 to 100 (best)



Science, research and innovation performance of the EU 2020

Source: Word Economic Forum - The Global Competitiveness Index dataset 2018

Note: (1)EU is the unweighted average of the values for the EU Member States.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter8/figure-8-6.xlsx

2. Regional and within-countries institutional quality differences persist across the EU

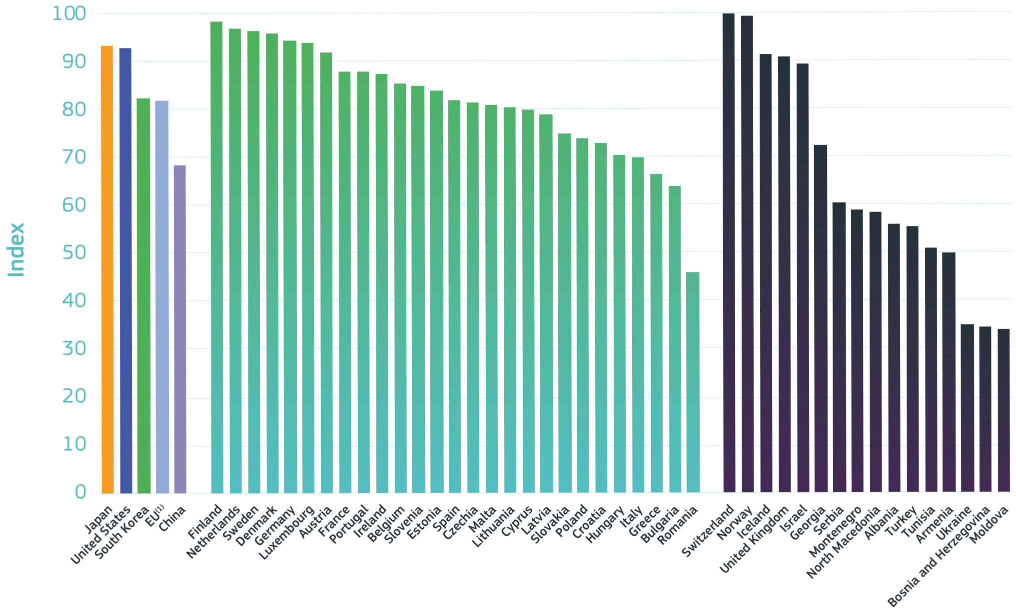
While the regulatory constraints and red tape faced by companies constitute a relevant barrier affecting overall business investment and the innovation potential of economies, the quality of the local institutional framework is a key determinant of economic and innovative performance. Indeed, the role that institutions play in shaping countries' economic performance has received growing attention. Usually defined as the set of rules setting the possible options individuals and companies have when making economic and social choices, they are devised to reduce transaction costs and favour productive investments at a lower total cost and to discourage rent-seeking behaviour (North, 1991; Williamson, 2000; Acemoglu et al., 2001). The definition of a good institution is linked to how effective it is in meeting these objectives and, consequently, improving economic and innovation performance. Empirical analyses usually measure the 'goodness' of (public) institutions by the extent to which they efficiently and effectively deliver public goods and services, and they guarantee all actors the protection and enforcement of property rights (Acemoglu et al., 2001; Ogilvie and Carus, 2014).

Good institutional frameworks improve economic and innovation prospects as they reduce uncertainty on the appro-priability of the returns on investment, which is

already higher in the context of R&D and innovative activities. Good institutions are characterised by an effective and generalised protection of property rights, effective control of corruption within a reliable legal framework, and efficient delivery of public goods and services, including education at all levels and the public infrastructure needed for the diffusion and use of technology. All these factors give companies a clear and definite framework, reducing their costs and enabling investment decisions, most notably those conducive to the adoption of new technologies. As such, existing evidence clearly supports the positive relationship between the quality of institutions and innovation performance (Rodriguez-Pose and Di Cataldo, 2014).

Institutional quality varies significantly across countries, with the EU below the standards observed in the United States and Japan. Heterogeneity among Member States drives the lower European performance, due to lower institutional quality in peripheral economies in the south and east. Figure 8-7 shows the performance of institutions using the World Bank indicator on government effectiveness, drawn from the Worldwide Governance Indicators. It reflects the perception of the quality of public services, policy implementation and its credibility, as well as the independence of the civil service from political pressures. As such, it encompasses some of the characteristics of good institutions outlined above. Government effectiveness among the best EU performers, i.e. Finland, the Netherlands, Sweden, Denmark, Germany, Luxembourg and Austria, is as high as in the leading countries worldwide, just below Switzerland and Norway. Conversely, southern and central-eastern Member States lag behind, with a few

Figure 8-7 Worldwide Governance Indicators - government effectiveness, 2017
values are on a scale of 0 to 100 (best)



Source: World Bank data

Note: (1)EU is the unweighted average of the values for the EU Member States.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter8/figure-8-7.xlsx

exceptions, suggesting that institutional quality undermines countries' performance in several dimensions, including economic and innovation (Rodríguez-Pose and Di Cataldo, 2014).

Within the above national scenario, regional disparities are a key factor to be considered when analysing differences in institutional quality and their relationship with innovation (and economic) performance. While the general framework is set at the national level, regional and local authorities are ultimately responsible for policy implementation and public goods and services delivery, which become more crucial the more autonomy lower levels of government have. This is particularly relevant in the European case, both because of the organisation of governments in Member States, which favours decentralisation in several instances, and to the principle of subsidiarity establishing that decisions must be taken as closely as possible to the citizen. For instance, Member States and their regions implement EU Cohesion Policy in partnership with the European Commission, including the selection, monitoring and evaluation of projects financed by the European Structural and Investment Funds[11].

Therefore, the quality of regional and local institutions affects regional performance and contributes to explaining the economic and innovation divide both within and between countries. Figure 8-8 represents the structure of the composite index used to measure institutional quality in EU regions, proposed by Bianchini et al. (2019) and drawing on the data and methodology of the European Social Progress Index (EU SPI) developed by the European Commission[12]. While the EU SPI develops its aggregate index on a broad set of measures, the focus here is on two main dimensions. On the one hand, the index uses some sub-indicators to measure the provision of public services, the accountability and impartiality of regional governments and the degree of corruption. This (government effectiveness) dimension highlights the quality and effectiveness of public service delivery as well as the generalised protection of property rights, which provide a level playing field for all businesses and individuals to reduce their costs and risk while engaging in economic and innovation activities. On the other hand, the Institutional Index also accounts for those public goods and services relevant for increasing the capacity of regional ecosystems to create, diffuse and absorb knowledge. This (absorption capacity) dimension includes information on education attainment and access to basic knowledge, to advanced education and to information and communication infrastructure[13]. Therefore, the Institutional Index is consistent with the concept of institutional quality, whilst also accounting for measures of absorption capacity and generalised opportunity, directly linked to innovation performance (Bianchini et al., 2019)[14].

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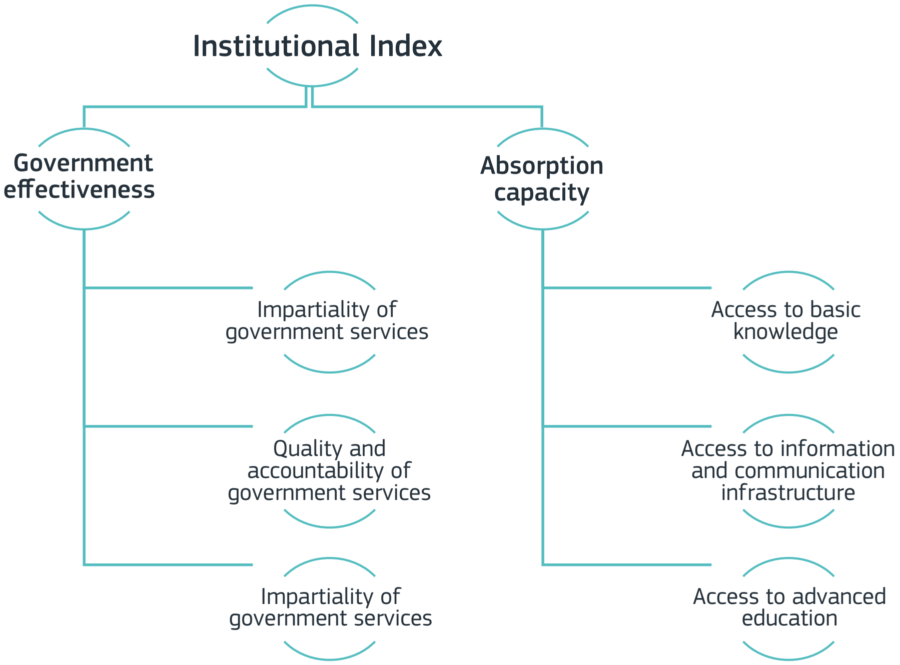
[11] See, for instance: https://ec.europa.eu/regional_policy/en/policy/how/stages-step-by-step/

[12] See https://ec.europa.eu/regional_policy/sources/information/maps/methodological_note_eu_spi_2016.pdf for further details on the EU SPI data. See Annoni et al. (2016) for additional information on the EU SPI data and the aggregation methodology.

[13] See Bianchini et al. (2019) for further details on the methodology and construction of the index.

[14] The available data cover the period 2011-2013. Given the slow changing nature of institutions, this information is still relevant for the institutional frameworks in Europe today.

Figure 8-8 The Institutional Index



Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Uni based on Bianchini et al. (2019)

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter8/figure-8-8.xlsx

EU regions differ significantly in terms of institutional quality, confirming the overall low performance of Europe's periphery while also revealing considerable heterogeneity within countries, such as, for instance, in Italy and Spain. Figure 8-9 maps European regions according to the quality of their institutions[15], classifying them by quantile and the bottom 10% of the distribution. A very heterogeneous scenario emerges, with the best institutional frameworks located mainly in regions the north of Europe, the Netherlands, Southern Germany and around London. For instance, the average performance of the regions in the top 10% of the distribution is around 2.5 times higher than that of the bottom 10%. Overall, regions in central and western Europe have better institutional quality, while peripheral regions are characterised by lower performance, with different degree of within-country heterogeneity. In particular, Spain, Italy and Czechia have the highest regional variation in institutional quality, the south of Italy in the bottom 10% of the distribution within an underperforming national institutional system.

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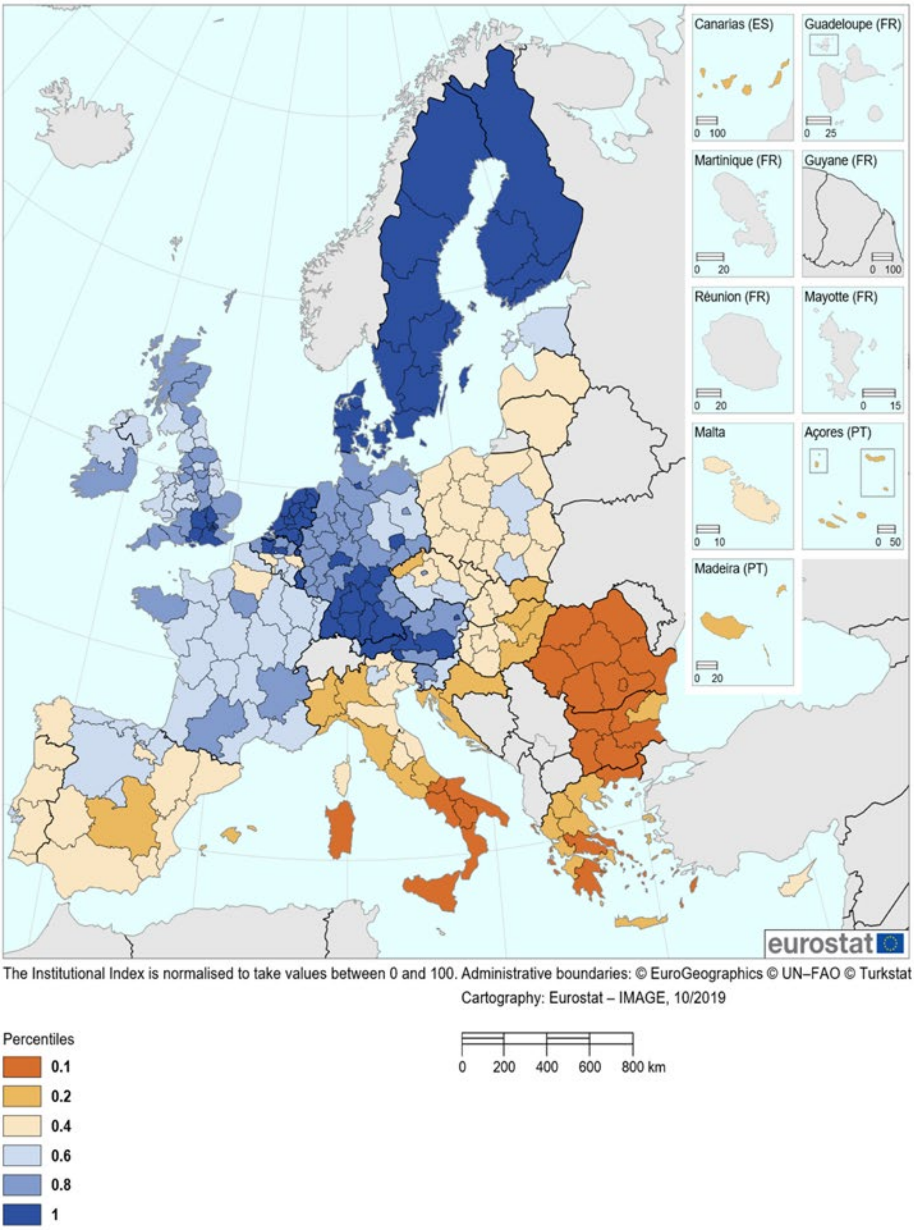
[15] Similar results are obtained using the EU SPI aggregate index, with some variation due to a larger set of indicators being considered.

Figure 8-9 Institutional quality: regional disparities[1]



The Institutional Index is normalised to take values between 0 and 100. Administrative boundaries: © EuroGeographics © UN–FAO © Turkstat

Cartography: Eurostat – IMAGE, 10/2019

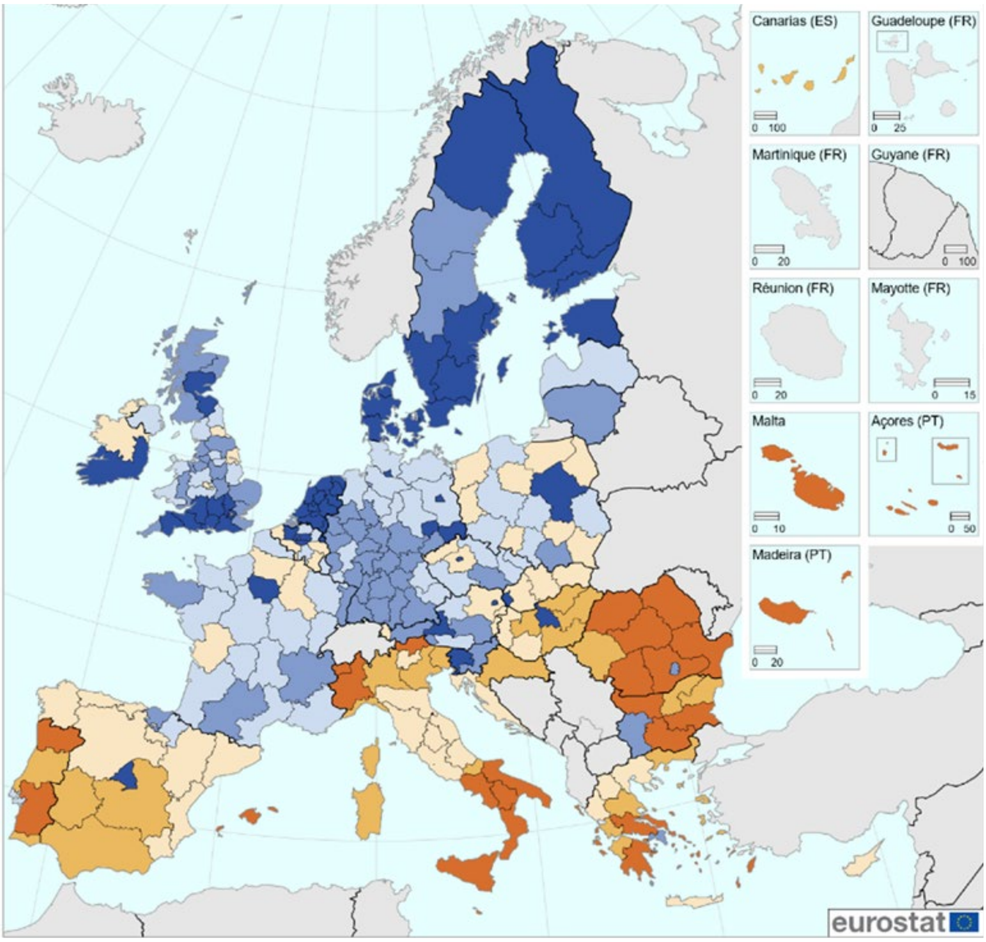
Source: European Social Progress Index, based on Bianchini, Llerena and Martino (2019), https://ec.europa.eu/regional_policy/en/information/maps/social_progress

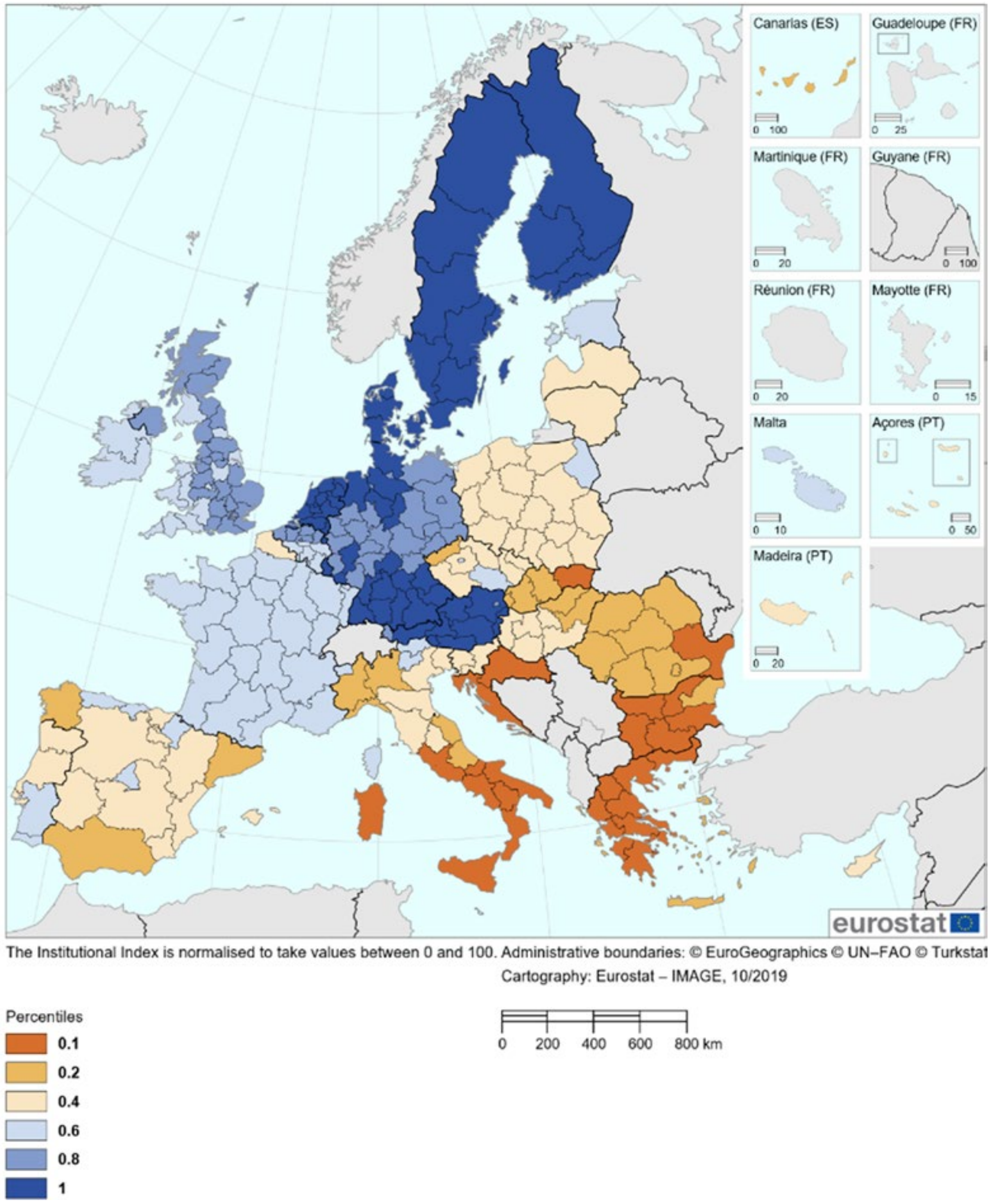
Note: [1]The indicators refer to 2013 or are built as an average over the period 2011-2013.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter8/figure-8-9.xlsx

While government effectiveness seems to follow a core-periphery pattern with different degrees of regional variation, access to information and communication infrastructure and to basic and advanced knowledge is concentrated around capitals, with a significant gap between capital regions and the rest in peripheral countries. Figure 8-10 maps European regions according to the two dimensions comprising the Institutional Index. The government effectiveness dimension (bottom panel) gives similar results compared to the aggregate figure, with a higher degree of homogeneity in central and western Europe, most notably in France, Austria and the United Kingdom. Conversely, the absorption capacity dimension (top panel) reveals an extremely heterogeneous scenario with large differences across European regions. In particular, absorption capacity is higher in capital regions, with greater variation within countries. This suggests that the availability of information and communication infrastructure and access to both basic and tertiary knowledge are still very concentrated. Furthermore, while access to education and infrastructure are comparatively high in central and northern Europe, even outside capitals, the gap between the latter and the other regions is a dominant feature of countries in the south and east, with the notable exception of Italy.

Figure 8-10 Institutional quality[(1)]: absorption capacity (top) and government effectiveness (bottom)





The Institutional Index is normalised to take values between 0 and 100. Administrative boundaries: © EuroGeographics © UN–FAO © Turkstat

Cartography: Eurostat – IMAGE, 10/2019

Source: European Social Progress Index, based on Bianchini, Llerena and Martino (2019), https://ec.europa.eu/regional_policy/en/information/maps/social_progress

Note: [1]The indicators refer to 2013 or are built as an average over the period 2011-2013.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter8/figure-8-10.xlsx

3. Despite some progress, the availability of capital and other alternative sources of financing for innovation remains limited when compared to other global players

In the EU, markets remain mainly banking-driven. Investment opportunities brought about by capital markets could be further explored. As bank finance can be of great importance to traditional businesses, a generalised contraction in SMEs' access to credit in the aftermath of the crisis affected their growth prospects (European Commission, 2018). Barriers in terms of access to finance by country are highlighted in the European Semester Country Reports[16] issued every year. Bank loans are the top source for investments in the EU, accounting for slightly more than half of investments in 2017, even though their importance varies by country (Figure 8-11). The weight of bank finance in external investments is largest in Cyprus (93 %), and lowest in Latvia (23 %). Moreover, some countries such as Malta and Bulgaria also rely significantly on other forms of bank finance, while in many countries leasing or hire purchase are also common sources of investment. Overall, grants seem to be more widely used by EU-13 countries. However, newly issued bonds are rarely used but are most popular in Malta and Finland.

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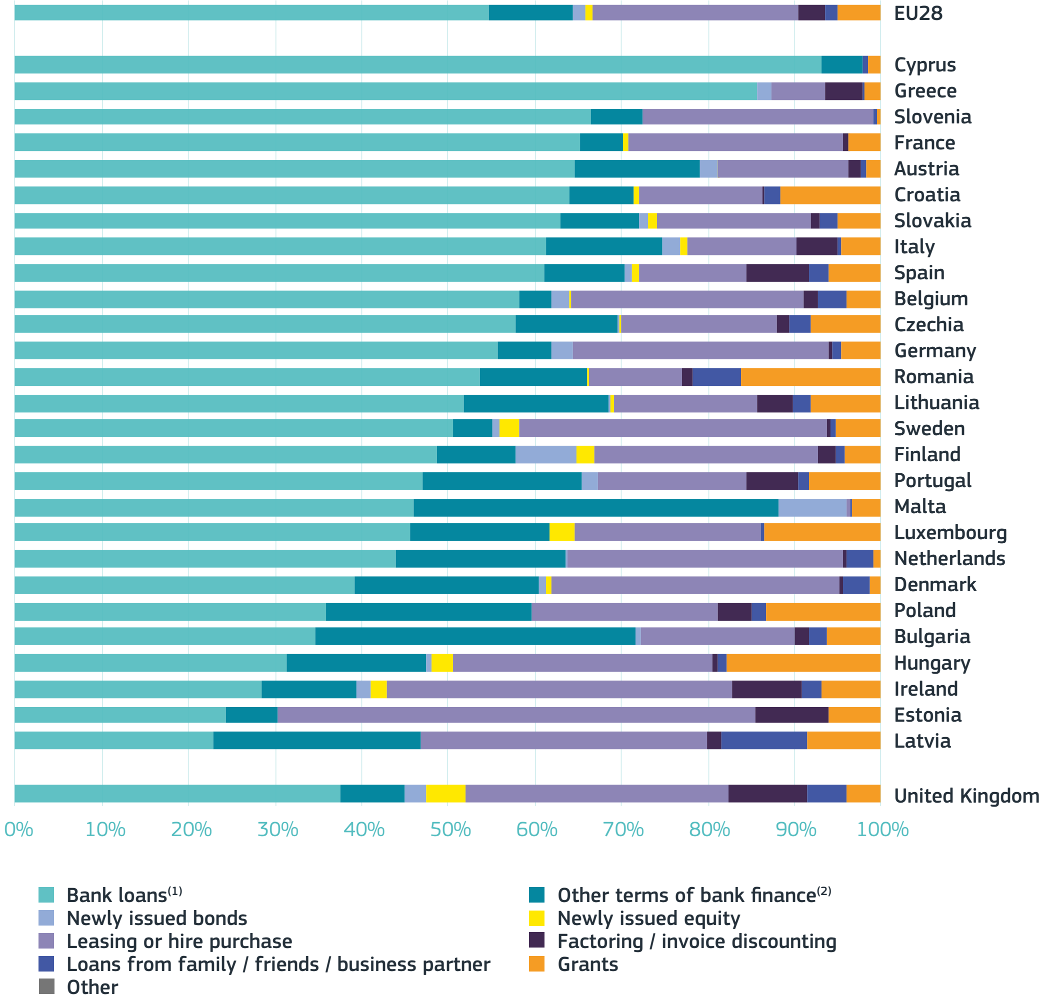
[16] https://ec.europa.eu/info/publications/2019-european-semester-country-reports_en

Figure 8-11 Composition of external investment finance by source, 2017



Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit, based on European Investment Bank

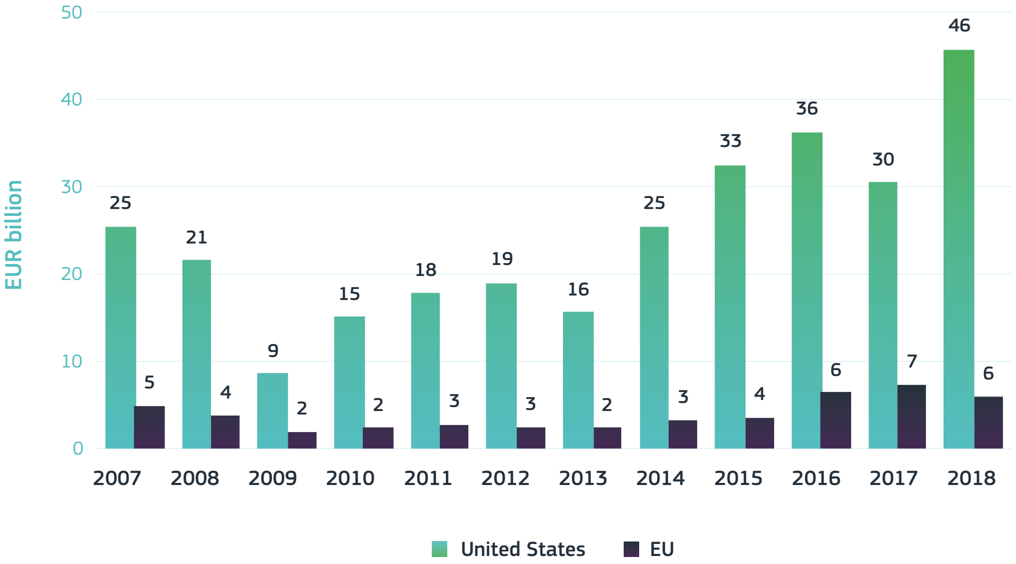
Notes: (1)Bank loans excluding subsidised bank loans, overdrafts and other credit lines. (2)Other terms of bank finance including overdrafts and other credit lines.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter8/figure-8-11.xlsx

Access to capital is fundamental for innovative European startups to be able to grow and scaleup globally. However, in the United States, eight times more venture capital funding is raised for innovation than in the EU. This may not only limit the scaling-up of 'made in EU' disruptive ideas and solutions but may also challenge the permanence of these startups in the EU. Disruptive and market-creating innovations are typically associated with a 'high risk' and degree of uncertainty which traditional finance (e.g. bank loans) is often not capable of bearing. For this reason, access to risk finance is seen as the alternative route for financing risky ideas and businesses, both at early and later stages. Indeed, venture capital investors often follow a 'high-risk'-'high-return' mindset in contrast to banks and traditional finance. As mentioned in Chapter 3.3 - Business dynamics and its contribution to structural change, the EU trails behind other major economies when it comes to transformational entrepreneurship that may lead to the 'next global technological champions'. One of the key reasons for this lies in the large gap in terms of venture capital compared to countries such as the United States. Indeed, from Figure 8-12 it is clear that the EU has not managed to close the gap in funds raised. Even though funds raised in the EU have increased since 2013 and are currently above pre-crisis levels, the venture funds raised in the United States have also risen and have almost doubled compared to 2007. Overall, the venture funds available in the EU only amount to around one-eighth of those in the United States.

Nevertheless, the availability of venture capital has increased in the EU in recent years, recovering from the aftermath of the last economic crisis. This could be partly attributed to an overall improvement in Europe's macroeconomic conditions (OECD, 2019; Pradhan et al., 2017).

Figure 8-12 Venture capital funds raised (EUR billion) in the EU and in the United States, 2007-2018



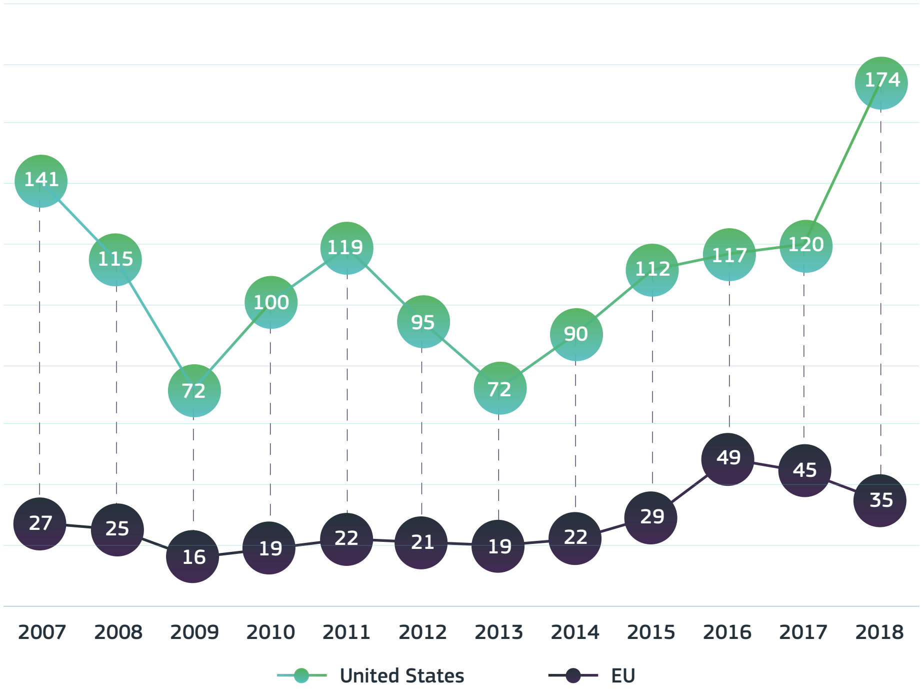
Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit, based on Invest Europe and NVCA/PitchBook data

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter8/figure-8-12.xlsx

The gap in risk capital relative to the United States can also be seen in terms of the average fund size. In 2018, the average fund size in the United States was five times that of the EU. Figure 8-13 shows that a gap in the average fund size persists between the EU and the United States. In particular, the gap in 2018 was the largest since 2007, with an average EU fund of EUR 35 million which compares with an average fund of EUR 174 million in the United States.

Figure 8-13 Venture capital average fund size (EUR million) in the EU and in the United States, 2007-2018



Science, research and innovation performance of the EU 2020

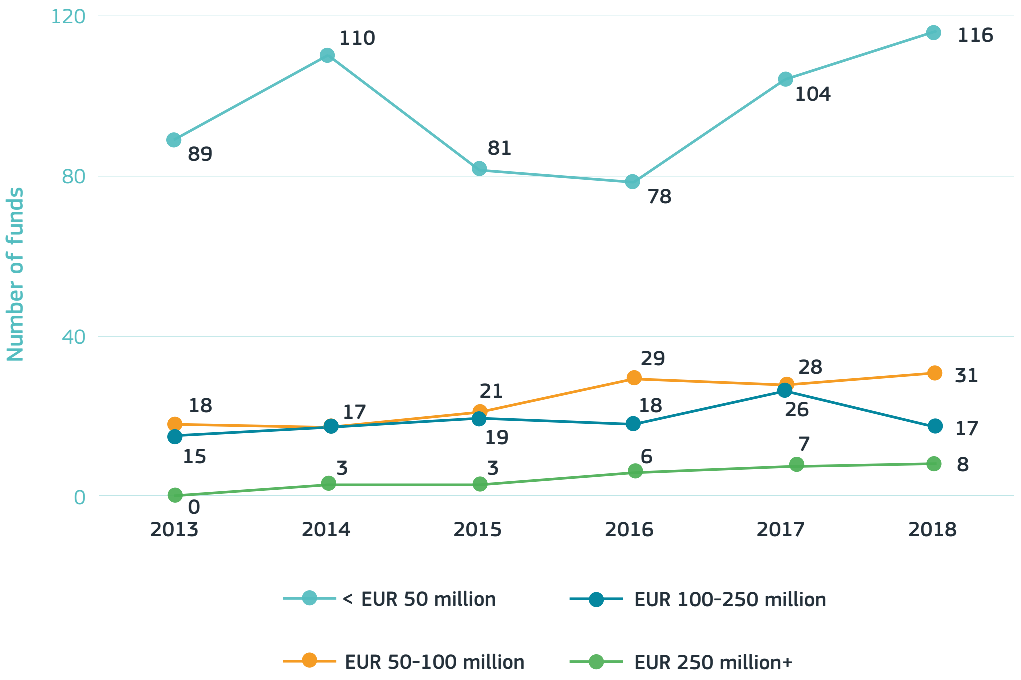
Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on Invest Europe and NVCA/PitchBook data

Note: The fund size is calculated based on the total amount raised by a fund to date; the average fund size calculation takes into account incremental amounts raised during the year and divides them by the number of funds. In other words, this calculation shows how much capital funds raise on average every year.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter8/figure-8-13.xlsx

The gap is particularly striking in late-stage financing, which can constrain scaling-up. Figures 8-14 and 8-15 show that the EU-US gap in the availability of venture capital funds is not so evident in funds of less than 50 million (euros and dollars), but rather for sums above 50 million. In particular, the difference is exacerbated when it comes to funds above 250 million. For example, in 2018, there were 8 funds in the EU above 250 million compared to 70 funds in the United States.

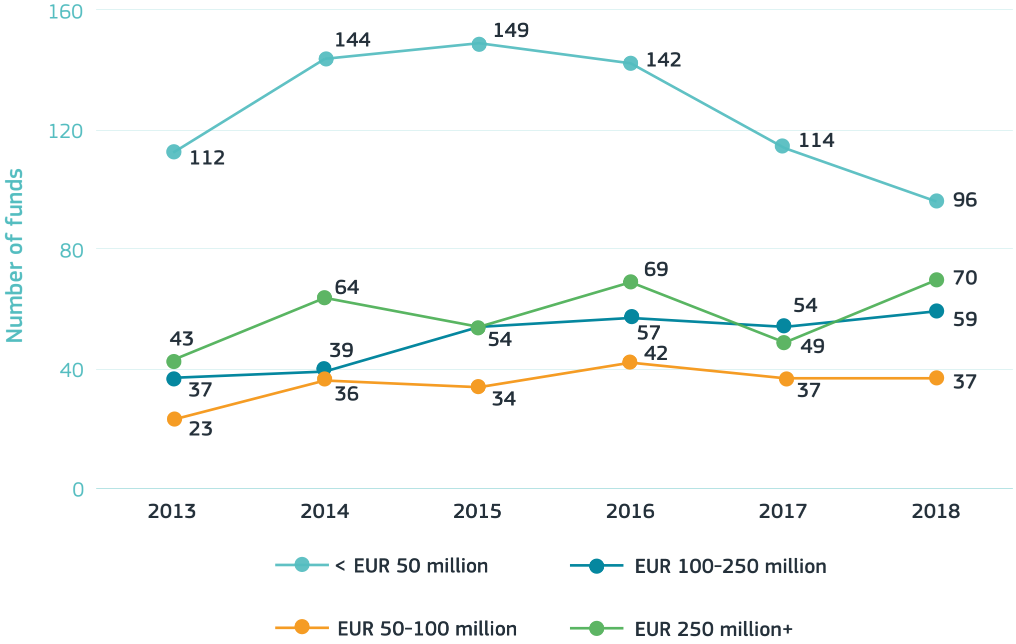
Figure 8-14 Number of venture capital funds raised by fund size (in EUR million) in the EU, 2013-2018



Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit, based on Invest Europe and EDC data
Note: The fund size is calculated based on the total amount raised by a fund to date.
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter8/figure-8-14.xlsx

Figure 8-15 Number of venture capital funds raised by fund size (in USD million) in the United States, 2013-2018



Science, research and innovation performance of the EU 2020

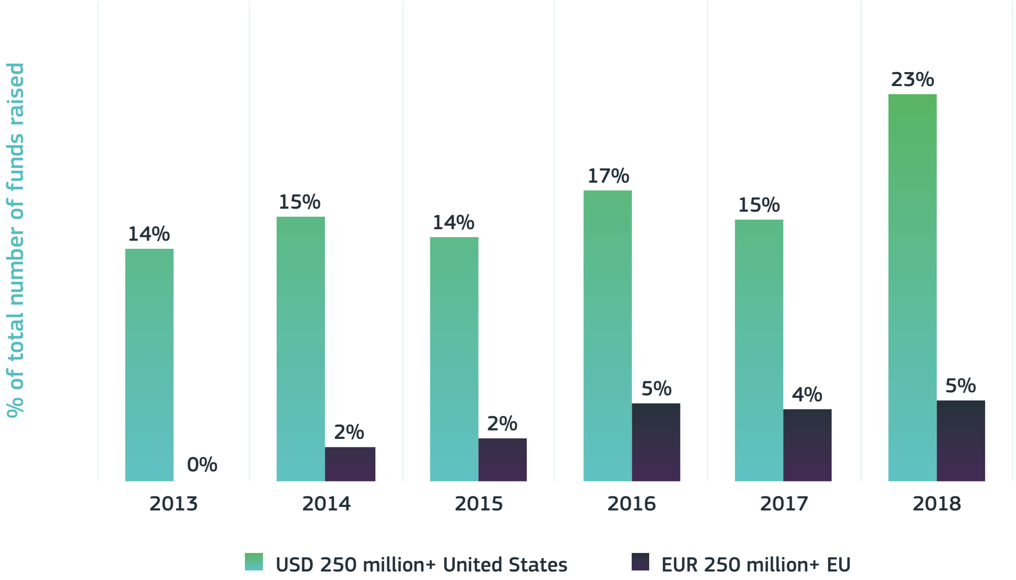
Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on Invest Europe and NVCA/PitchBook data

Note: The fund size is calculated based on the total amount raised by a fund to date.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter8/figure-8-15.xlsx

The existence of a gap in late-stage financing in the EU compared to the United States is also visible in the share of funds raised above EUR/USD 250 million (Figure 8-16). Even though the share of venture funds raised above EUR 250 million in the EU increased between 2013 and 2018, it remains significantly lower than in the United States. In 2018, 5% of the venture funds raised in the EU were above the EUR 250 million threshold, while their representation in the US funds was higher, at 23%. If, on the one hand, the differential in the shares may be justified by the different financing needs of EU and US firms, on the other hand, it is also true that in absolute terms the US also has more funds available over USD 50 million. As a result, the thesis of a gap in late-stage funding seems to hold true.

Figure 8-16 Share of venture funds raised above EUR 250 million in the EU and USD 250 million in the United States, 2013-2018



Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on Invest Europe, NVCA/PitchBook and EDC data

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter8/figure-8-16.xlsx

Each phase in the life cycle of an innovative startup has inherent different capital needs. Box 8-1 shows how the capital needs and the associated risk vary in the seed, startup and later stages of an innovative startup's life cycle.

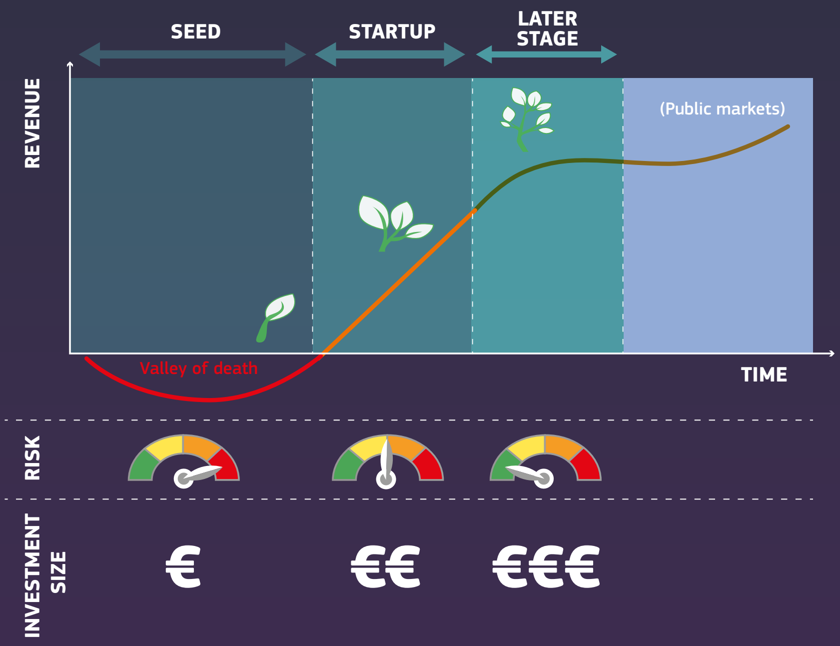
BOX 8-1 Venture capital investment stages of innovative startups

Once the concept has been created, startups may need seed capital for R&D, including prototypes and market tests, in order to achieve an initial product which may yet to become commercially viable. Seed funding rounds tend to be small. At this ‘pre-marketing’ stage, significant risk and uncertainty are involved and there are negative cash flows – the so-called ‘valley of death’.

Once the product has been developed, **startup** capital can help the company to initiate its mass production and cover expenditure with additional research to fine-tune and make the product commercially viable, which requires larger amounts of capital. The company may also be defining its marketing and advertising strategy to attract a customer base.

At this point, the company is likely to be generating sales and revenues based on the fully developed product, but not necessarily profit. This is a crucial point when **late-stage** capital may be fundamental for growth and expansion. Later, the company may consider an **Initial Public Offering** (IPO), for example. This cycle is represented in Figure 8-17[17].

Figure 8-17 Visual simplification of the startup venture capital investment cycle



Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit, based on Medium-The Startup Investment Cycle, InvestEurope and coxblue.com

Images: stock.adobe.com © csiling, #277690257; 2019. © Gstudio Group, #176944380; 2019 © Gstudio Group, #176944413; 2019. © Gstudio Group, #176944454; 2019. © Mark Stock, #196345712; 2019.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter8/figure-8-17.xlsx

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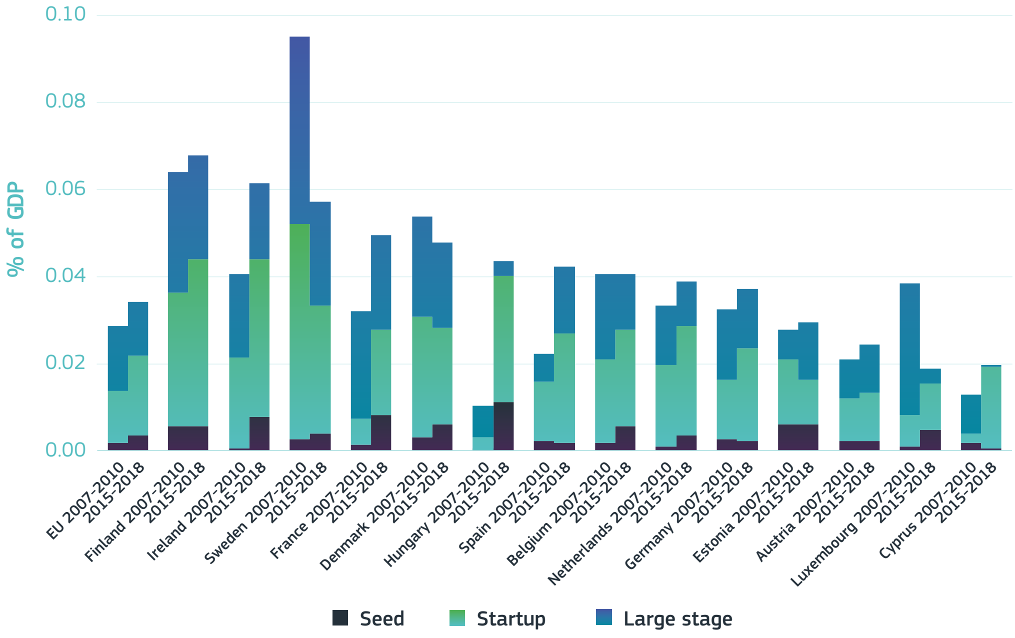
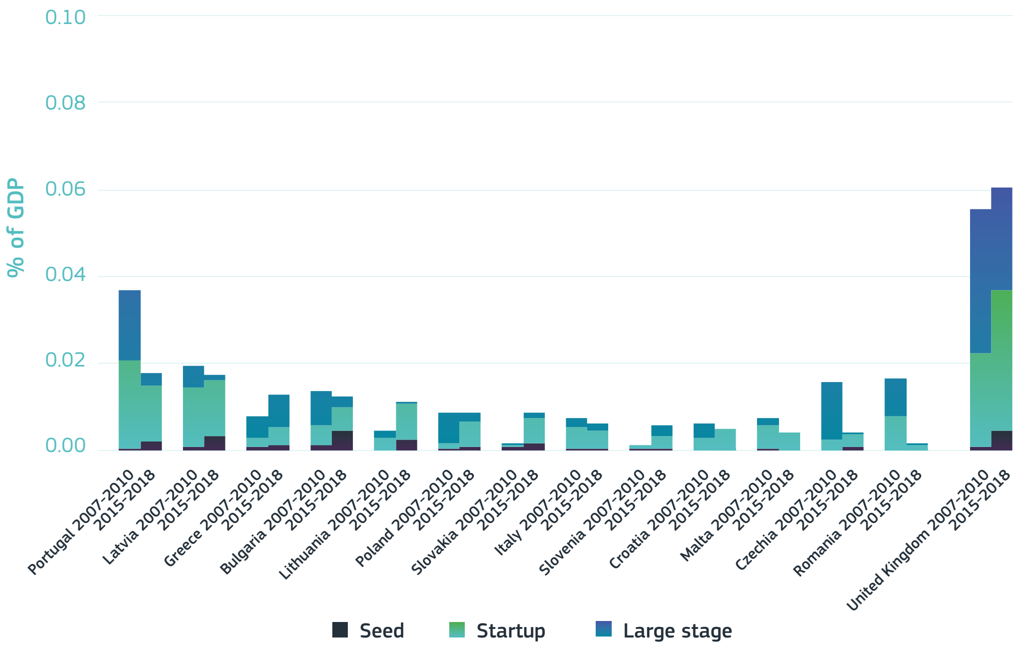
[17] The size of the stage is not related to the time each stage takes. The focus is on the sequence of the capital needs in the startup life cycle.

Overall, venture capital in the EU is mainly concentrated in a few EU Member States that are either 'innovation leaders' or 'strong innovators' as in the European Innovation Scoreboard. There are significant intra-EU differences in the availability of venture capital at each stage. Seed and startup capital have increased in the EU, while later-stage as a percentage of GDP has declined compared to 2007-2010. In recent years, when comparing the change in venture capital as a percentage of GDP between 2007-2010 and 2015-2018, Finland, Ireland, Sweden, France and Denmark stand out as the countries with the highest shares of venture capital as a percentage of GDP, while Italy, Slovenia, Croatia, Malta and Romania have the lowest shares (Figure 8-18). Most EU Member States either maintained or increased the share of venture capital in GDP. Compared to 2007-2010, there was a decline in Sweden, Denmark, Luxembourg, Portugal, Bulgaria, Italy, Croatia, Malta and Romania. There are also substantial intra-EU differences in the availability of venture capital by stage, although it seems that startup capital has the highest share in GDP in most countries. Seed capital as a share of GDP is highest in Hungary, Ireland and France but, according to the data, is practically non-existent in Croatia, Malta and Romania. Finland, Ireland and Sweden lead in terms of the relative availability of startup capital. Finland and Sweden are the Member States with the largest relative presence of late-stage capital while it appears practically absent in Cyprus, Croatia and Malta.

Figure 8-18 Venture capital (market statistics) by stage as % of GDP, periods 2007-2010 and 2015-2018





Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit, based on Invest Europe and Eurostat data

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The public sector contributes actively to a stronger innovation ecosystem. In particular, at the EU level, the European Innovation Council (EIC) will pool resources to support innovators with breakthrough ideas and market-creating innovations. The EIC intends to play a key role in tackling the financing gap for innovative and disruptive startups in Europe in a context where some degree of fragmentation of the innovation ecosystem remains. The EIC remit is represented in Figure 8-19.

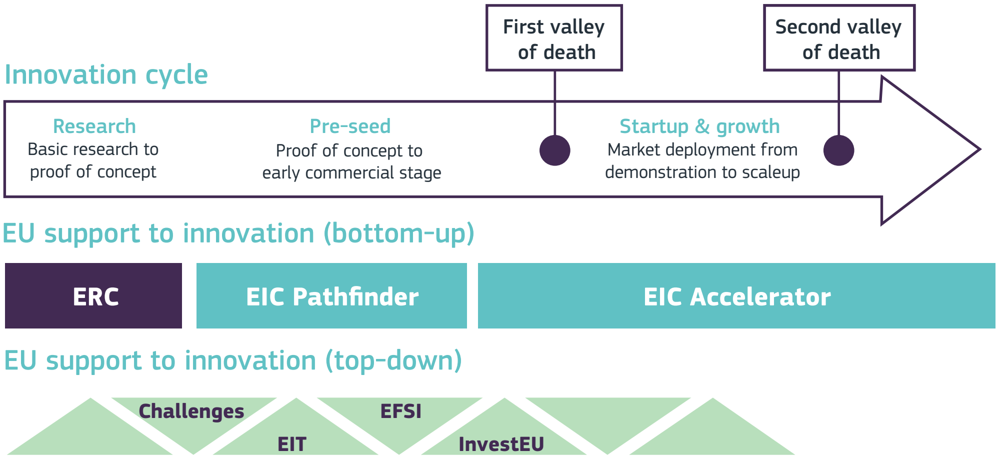
The next Framework Programme, Horizon Europe, will introduce the EIC under the Innovative pillar to support the ambition of making the EU a global leader in market-creating innovations. The EIC will integrate, reorganise and expand activities which were previously part of Horizon 2020, such as Access to Risk Finance (in synergy with the InvestEU programme), Innovation in SMEs (notably the SME instrument), Fast-track to Innovation, as well as Future and Emerging Technologies (‘FET-Open’ and ‘FET ProActive’).

The EIC will notably implement two complementary instruments, namely the EIC Pathfinder and the EIC Accelerator: it will focus on detecting, nurturing, supporting and scaling-up breakthrough market-creating and disruptive innovation, from the idea (‘Pathfinder’ scheme) down to market deployment and scaleup (‘Accelerator’ scheme). The EIC Pathfinder for advanced research will provide grants for high-risk, cutting-edge projects implemented mainly by consortia exploring new territories aimed at developing radical and innovative technologies (i.e. early-stage research on technological ideas that can be transformational, to support spin-offs and market-creating innovations). The EIC Accelerator will provide single startups, SMEs and, in very rare cases, small midcaps carrying out disruptive innovation which are still too risky to attract private investments with the necessary means to scale up through a mix of grant and finance (notably equity support, but also debt financing/guarantees) with the ultimate objective of incentivising and subsequently attracting ideally immediately) co-investments from private (or other public) investments.

Moreover, as funding is not enough, the EIC will provide its beneficiaries with a complete set of business-acceleration services (such as mentoring, coaching, access to large corporates, investors, international fairs, etc.).

The EIC will develop complementarities with the European Institute of Innovation and Technology (EIT) which is also enabling innovation to flourish in Europe through an active knowledge-triangle integration (i.e. education, research and innovation) that empowers innovators and entrepreneurs to solve global challenges through knowledge and innovation communities (KICS) in the fields of digital, environment, health, food, etc.

Figure 8-19 EU support to innovation (bottom-up and top-down)



Science, research and innovation performance of the EU 2020

Source: European Commission (2018), 'A New Horizon for Europe - Impact Assessment of the 9th Framework Programme for Research and Innovation'

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter8/figure-8-19.xlsx

Indeed, targeted 'R&D grants for scaleups'[18] can play an important role in the scaling-up phase of innovative companies. For example, Testa et al. (2019) studied aspects linked to the access to finance for young innovative enterprises with growth potential and found that R&D grants not only 'stimulate and prepare companies for the growth phase', but also have an important 'signalling' effect in obtaining follow-up funding.

Furthermore, strategic public procurement is also an important tool at governments' disposal to create new markets to support

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[18] Scaleups are classified as companies with a technological competence, well-defined project milestones, top management commitment, strategically-oriented R&D and high risk-taking behaviour.

the green transition, to induce suppliers to be more innovative, and to improve the efficiency of public services, among others. Box 8-2 discusses the potential of public procurement for innovation, reflecting on the opportunities and challenges it provides.

BOX 8-2 The role of public procurement for innovation

As noted by the European Commission, public procurement refers to the process by which public authorities, such as government departments or local authorities, purchase work, goods or services from companies[19]. Indeed, with the right framework in place, public procurement can boost innovation and potentially lead to efficiency gains and greater inclusiveness, both at the national and local levels[20].

The EU 2020 Strategy recommends using public procurement not only to drive innovation but also to achieve high-quality public services in Europe. In the EU, almost 14% of GDP is spent every year on public procurement. Two of the main findings by the OECD (2017) were that 81% of OECD countries[21] have developed strategies or policies to support innovative goods and services through public procurement, but only 39.4% of OECD countries are measuring the results of their support to innovative goods and services through public procurement. The report also notes that demand-side-driven procurement policies have led to breakthroughs key to the 'green and social economy', such as liquid light-emitting diodes (LEDs), electric cars and robotic bed-washing facilities in hospitals. Hence, public procurement can be an important channel for market-creation and directionality.

The RISE group (2019) refers to the 'triple rationale' for the **application of public procurement of goods and services to innovation** as follows:

- the **improvement of public services**;
- the **inducement of supplier firms** (and eventually other firms) to be more innovative;
- the **pursuit of broader societal goals or missions**.

As regards the challenges for public procurement for innovation, the OECD (2017) highlights the need to decrease risk aversion, set up more effective coordination mechanisms, boost skills and capacity-building, encourage public purchasers to dialogue with suppliers, and enhance data collection and the monitoring of results. These are consistent with the lessons learned from the mutual learning exercise on innovation-related public procurement under the Horizon 2020 Policy Support Facility. The final report[22] puts forward three main lessons learned, grouped as: i) developing a strategic framework; b) capacity-building; and c) financial support mechanisms.

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[19] https://ec.europa.eu/growth/single-market/public-procurement_en

[20] https://www.oecd.org/gov/public-procurement-for-innovation-9789264265820-en.htm

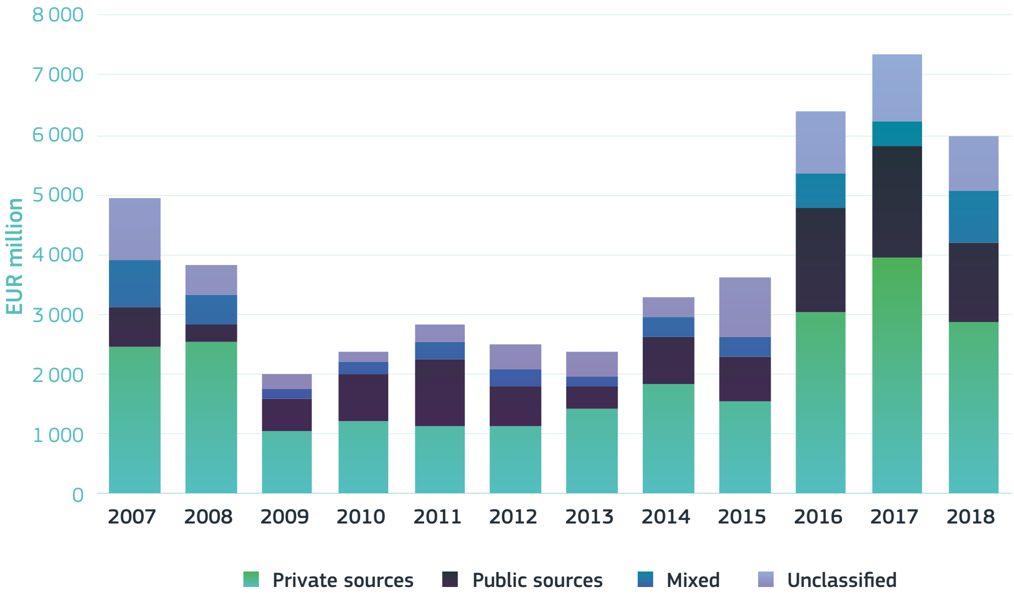
[21] Analysis covers 35 OECD countries.

[22] https://rio.jrc.ec.europa.eu/en/policy-support-facility/mle-innovation-related-public-procurement

The public sector has been an important actor in the recovery of venture capital in the EU, both in the years immediately after the financial crisis at a time when private sources were contracting, and in stimulating the availability of capital in recent years. Public funding sources, including governmental agencies and institutions such as the European Investment Fund (EIF), seem to play an important role in ensuring the availability of venture capital in the EU, which was particularly crucial in the aftermath of the crisis when private sources declined dramatically (Figure 8-20). Moreover, its weight increased from 13 % in 2007 to around 22 % of total venture funds raised in 2018. In contrast, the share of private funding has been more vulnerable to macroeconomic conditions and external shocks.

Nevertheless, in recent years, private sources have recovered and regained their prominent role, accounting for around 50 % of new funds raised. In absolute terms, private funds have even surpassed pre-crisis levels since 2016. The 'mixed' category includes, for instance, capital made available under the so-called 'fund-of-funds', which combines public and private efforts to mobilise venture capital.

Figure 8-20 Venture capital in the EU - new funds raised by source (in EUR million), 2007-2018



Science, research and innovation performance of the EU 2020

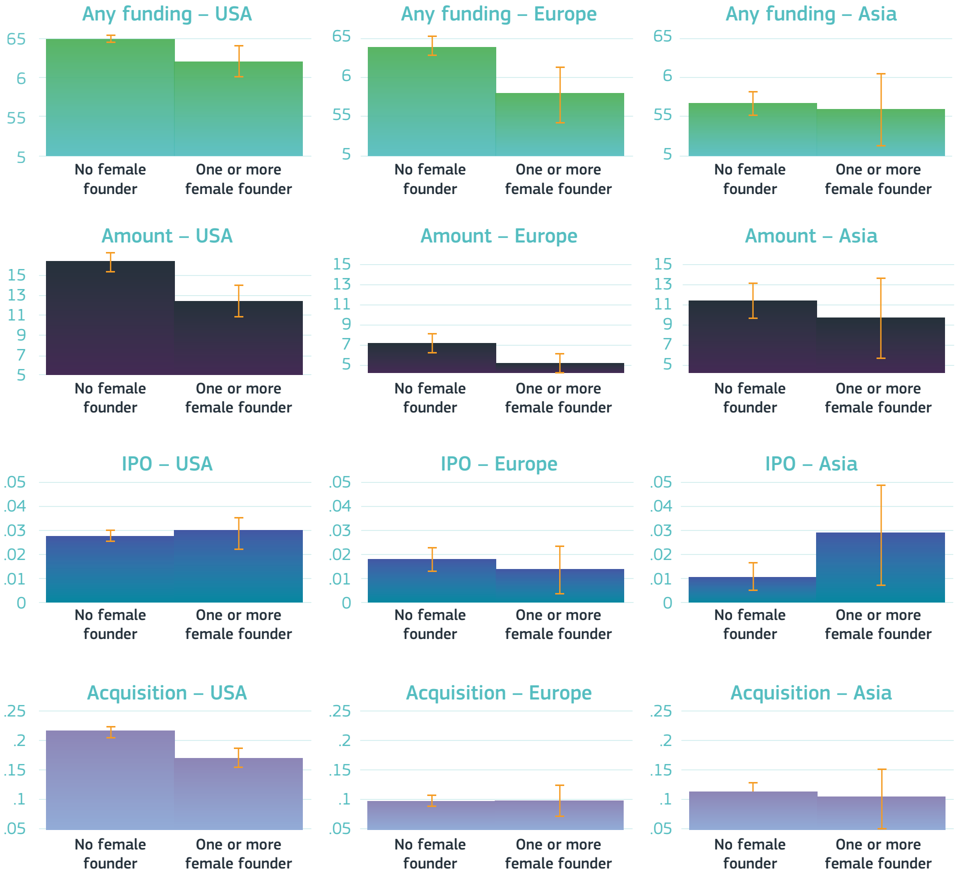
Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit, based on Invest Europe data

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter8/figure-8-20.xlsx

Overall, there seems to be a gender gap in startup funding as well as in achieving successful exit strategies, namely IPOs and acquisitions. Gender differences in the likelihood of accessing funding opportunities appear more striking in Europe than in other regions. Lassébie et al. (2019) used Crunchbase data to detect any potential gender gaps in terms of access to funding and the likelihood of going public or being acquired in Europe, Asia and the United States. The results are reported in Figure 8-21.

Gender differences in the probability of receiving funding seem more pronounced in Europe than in the United States or Asia. However, accordingly, *the difference between gender in the probability to go public via an IPO is not significant in the three regions*. As regards acquisitions, it would seem the gender gap is only present in the United States. In general, acquisition as an exit strategy is used less in Europe and Asia, *where companies are on average only less than 12% likely to be acquired*.

Figure 8-21 Differences in funding and exit between male-founded companies and those with at least one female founder, by region



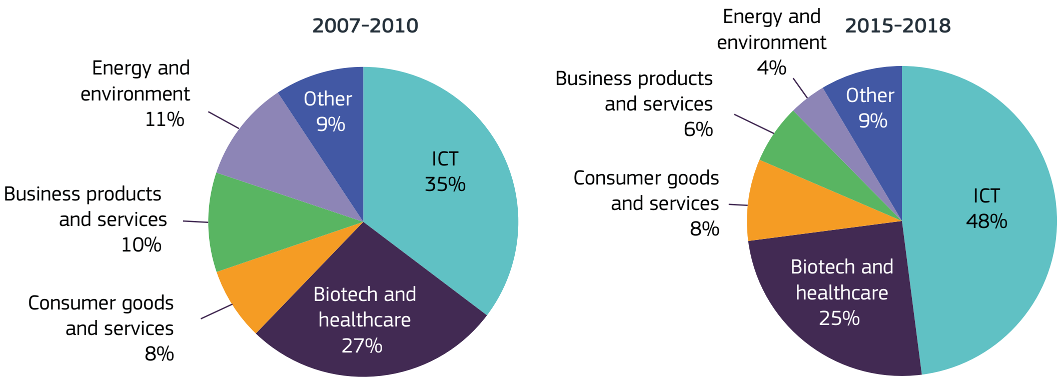
Source: Lassébie et al. (2019)

Note: The sample is restricted to companies located in OECD, Colombia and BRICS countries, created after 2000, and for which founders' demographic variables are not missing.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter8/figure-8-21.xlsx

The ICT sector is the EU's top recipient of venture capital, representing close to half of the total venture capital. The 'energy and environment' sector has seen the largest drop compared to compared to 2007-2010. Figure 8-22 depicts the evolution of the average shares of venture capital across sectors between 2007-2010 and 2015-2018. Companies in the ICT sector appear to have received the highest share in the EU. Moreover, the ICT sector's share has grown from 35 % over 2007-2010 to 48 % over 2015-2018. The 'consumer goods and services' sector also registered a relatively slight increase in venture capital, while the other sectors, most notably 'energy and environment', have registered relative declines compared to 2007-2010.

Figure 8-22 Venture capital in the EU - market statistics by sector (%), periods 2007-2010 and 2015-2018



Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit, based on Invest Europe data
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter8/figure-8-22.xlsx

Deep-tech, science-based innovations may take years or even decades to materialise into commercially viable applications, unlike some ICT-enabled innovations. In this context, the availability of 'patient capital' is key to enabling new breakthroughs in fields such as biotechnology, aerospace and clean-tech. Some great discoveries of our time, like DNA sequencing and the GPS, took decades to reach an advanced stage[23]. The key challenges of our era, such as addressing climate change, require new disruptive solutions in fields that include, for example, energy and mobility, which may take some time to become market-ready. As argued in Mazzucato (2016), the short-term nature of private finance may justify the role of 'public finance to nurture the parts of the innovation chain subject to long lead times and high uncertainty'.

According to the Boston Consulting Group (2019), the deep-tech landscape currently appears oriented towards seven fields, namely advanced materials, artificial intelligence, biotechnology, blockchain, drones and robotics, photonics and electronics, and quantum computing – which 'span the spectrum from very early research to market applications in full development'.

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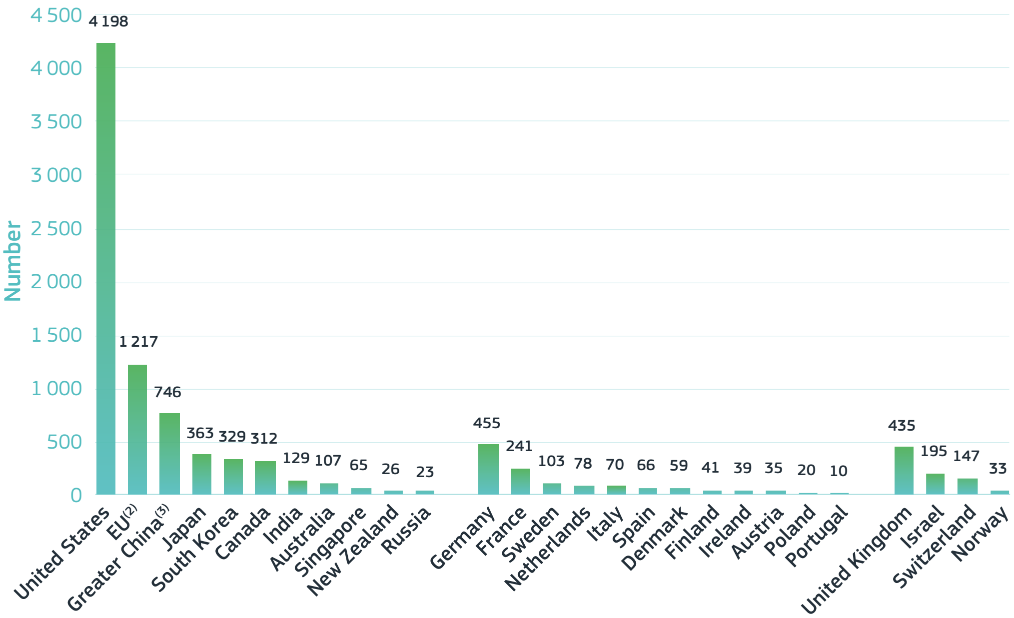
[23] See https://www.weforum.org/agenda/2018/04/patient-capital/

Within these seven domains, Hello Tomorrow and BCG (2019) identified almost 8 700 deep-tech firms. Figure 8-23 shows the geographical distribution of deep-tech firms worldwide based on Hello Tomorrow's sample. It is possible to observe that the United States leads as the main deep-tech innovation hub since US deep-tech companies make up almost 50% of the sample. The study identified 1 217 or (14% of all deep-tech startups) as being in the EU[24], with Germany, France and the Netherlands forming the largest markets. Within Europe, the United Kingdom, Israel and Switzerland also stand out in the ranking with 435, 195 and 147 deep-tech companies, respectively. This is, however, also mirroring the size of the countries.

Figure 8-23 Number of deep-tech companies identified(1), by region



Science, research and innovation performance of the EU 2020

Source: Tableau; BCG Center for Innovation Analytics; BCG and Hello Tomorrow analysis

Notes: (1)Analysis is based on 8 682 deep-tech companies related to 16 technologies across 7 categories: advanced materials, artificial intelligence, biotechnology, blockchain, drones and robotics, photonics and electronics, and quantum computing. Exhibit is missing geographic information for 199 companies. (2)EU is an aggregate of deep-tech companies identified by the study in EU Member States. (3)Greater China includes mainland China, Hong Kong, Macau, and Taiwan.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter8/figure-8-23.xlsx

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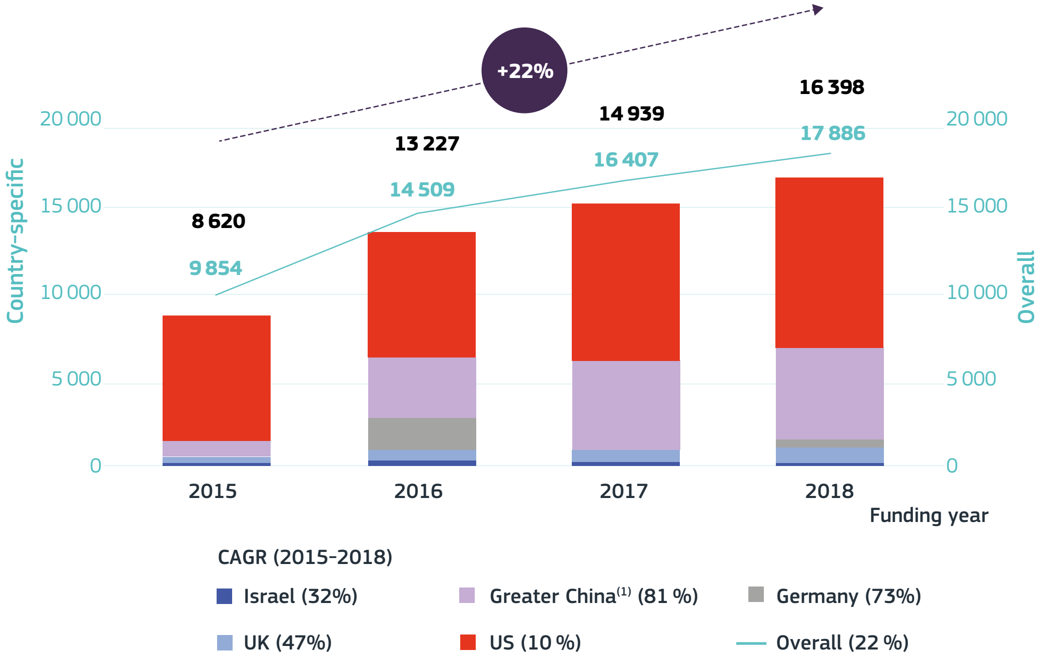
[24] The EU aggregate is merely the sum of all deep-tech startups for which there is data on EU MS.

Moreover, the study found that private investment worldwide rose by more than 20 % per year over 2015-2018, reaching close to USD 18 billion. In particular, it notes the dominant investment position of the United States and China in the deep-tech landscape as both countries alone accounted for around 81 % of global private investments in deep-tech companies between 2015 and 2018, with approximately USD 32.8 billion and USD 14.6 billion invested in each country, respectively. Germany appears to be the investment hub for deep-tech companies in the EU (Figure 8-24).

Figure 8-24 Sum of private investments in deep-tech companies (in USD million) and growth rates by top countries, 2015-2018



Source: Capital IQ; Quid; BCG Center for Innovation Analytics; BCG and Hello Tomorrow analysis

Note: (1)Greater China includes includes mainland China, Hong Kong, Macau, and Taiwan.

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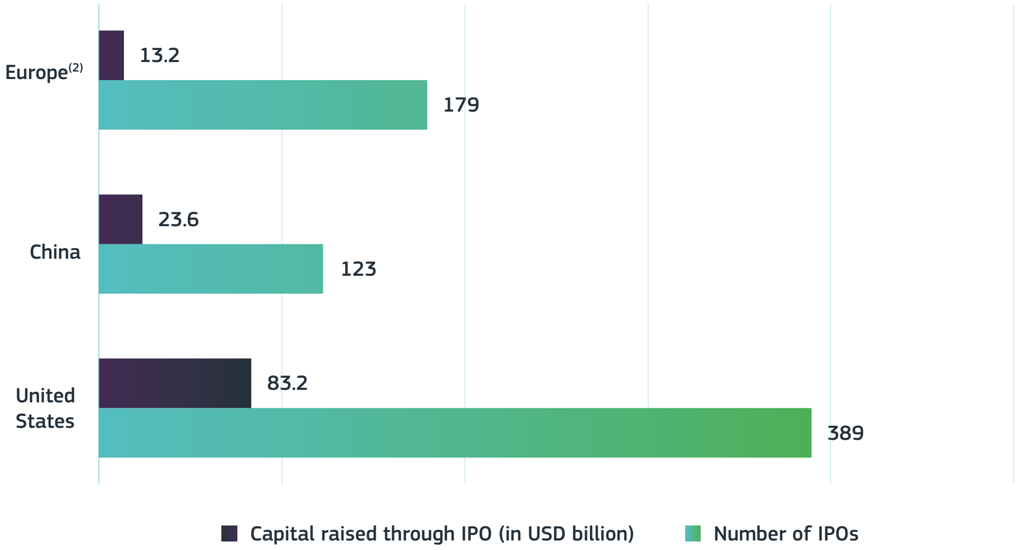
Stock markets can potentially provide exit options for scaleups and an opportunity for investors to 'cash-in'. US stock markets are the most attractive in the world for tech scaleups to go public, which indicates the need to further develop EU stock markets. According to Mind the Bridge (2019), only around 2 % of tech scaleups follow the IPO path. At the same time, the analysis also shows that there are benefits from going public: scaleups that went public had access to an amount of capital 5.5 times superior than those that did not. Over 2010-2018, US stock markets were leaders in both the number of IPOs in tech scaleups and the capital raised by going public (Figure 8-25). In particular, the

Figure 8-25 Tech scaleup[1] IPOs and capital raised by region, 2010-2018



Science, research and innovation performance of the EU 2020

Source: Mind the Bridge (2019)- Tech Scaleup IPOs, 2019 Report

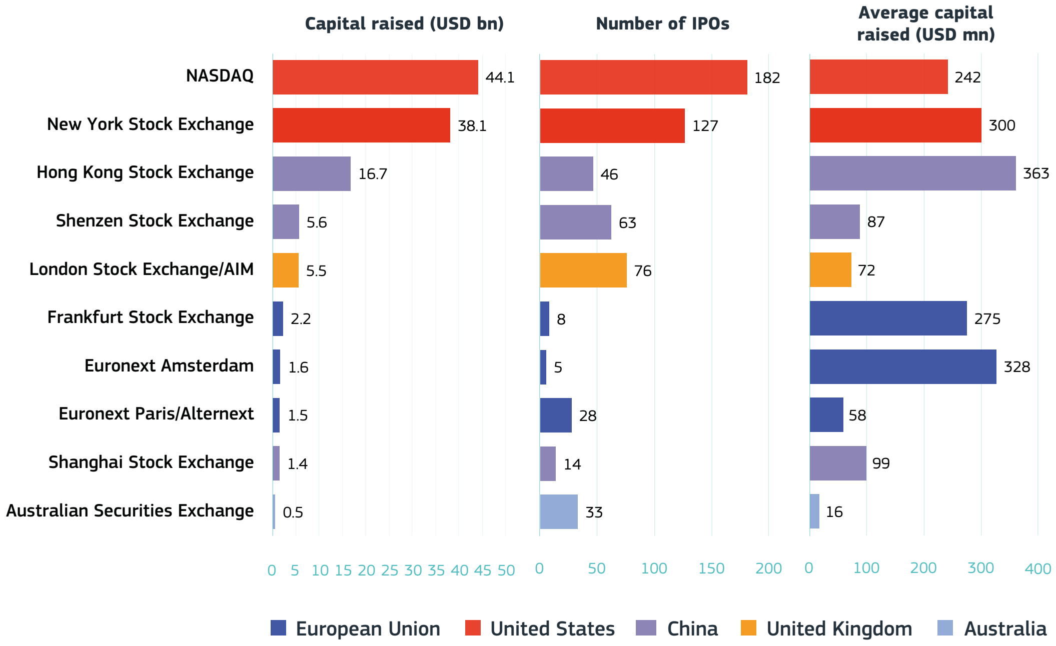
Notes: [1]A scaleup is a tech company that has raised (since inception) at least 1 million dollar in equity funding, with at least one funding event since 2010. [2]Europe includes 45 Continental European countries.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter8/figure-8-25.xlsx

United States listed slightly more than double the number of IPOs than Europe with six times more capital raised. China trails behind Europe in the number of tech scaleup IPOs, although with larger amounts of capital raised.

Three EU stock exchanges are in the world's top 10 stock exchange markets. The NASDAQ and the New York Stock Exchange, both in the United States, are the top choices of tech scaleups for going public. Figure 8-26 presents the world's top stock exchanges chosen by tech scaleups for an IPO, ranked by the amount of capital raised. The two US stock markets – NASDAQ and New York Stock Exchange – emerge as the most attractive in terms of capital raised and the number of IPOs. In fact, according to Mind the Bridge (2019), US stock markets attract in particular Chinese tech scaleups, representing 64 % or 47 of foreign scaleups' IPOs in the United States; Europe accounted for 15 % or 11. The Frankfurt Stock Exchange, Euronext Amsterdam and Euronext Paris/Alternext appear to be the top choices in the EU for scaleup exits. Finally, it should be noted that the tech scaleups that went public on the Frankfurt and Amsterdam stock markets raised on average a relatively similar amount of capital as on the Hong Kong or New York Stock Exchange.

Figure 8-26 Top 10 tech scaleup IPOs by stock exchange, ranked by capital raised, 2010-2018



Science, research and innovation performance of the EU 2020

Source: Mind the Bridge (2019) - Tech Scaleup IPOs, 2019 Report
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter8/figure-8-26.xlsx

The acquisition of startups is used as a company strategy not only to reach higher rates of innovation but also to access data and a talented team of engineers and researchers. Acquisitions of innovative startups by larger companies provide the latter with the opportunity to access a product that is already well established on the market and could be complementary (or even central) to the company's innovation activities. For the startup investors, just like the IPO exit strategy, this can also be a chance to secure returns on the capital invested. However, in a period when the competition for talent in specific STEM fields, such as artificial intelligence, is fierce (see Chapter 7 - R&I enabling artificial intelligence), the acquisition of startups is increasingly being used as a way to absorb a pool of talent, e.g. in fields such as ICT and life sciences. In addition, mergers and acquisitions seem to be on the rise (Bajgar et al., 2018).

US companies are the top acquirers of startups[25] worldwide. Figure 8-27 provides evidence of the dominance of US companies in startup acquisitions worldwide. In particular, there are 22 US companies in the 'top 30' global acquirers of startups between 2010

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[25] Startups are defined here according to Mind the Bridge (2018), i.e. companies founded after 1999 which operate in innovative industries (e.g. ICT, life sciences, etc.) and/or introduce radical (disruptive) innovations in traditional industries (e.g. drones in agriculture).

and 2018. In particular, right at the top of the list are the so-called 'tech giants' – Google, Facebook, Apple and Microsoft. These four multinationals together account for almost 25 % of the acquisitions of the top 30. The EU is represented by only three companies – Publicis Groupe (France), Siemens AG (Germany) and Essilor-Luxottica (France/Italy).

Figure 8-27 Top 30 world acquirers of startups$^{(1)}$, 2010-2018

#	HQ	Name	Acquisitions
1	🇺🇸	Google	150
2	🇺🇸	Facebook	68
3	🇺🇸	Apple	68
4	🇺🇸	Microsoft	67
5	🇺🇸	Accenture	61
6	🇺🇸	Cisco	60
7	🇺🇸	Yahoo	56
8	🇺🇸	Oracle	51
9	🇺🇸	IBM	49
10	🇺🇸	Salesforce	46
11	🇺🇸	Twitter	46
12	🇺🇸	Amazon	45
13	🇺🇸	Dell EMC	45
14	🇯🇵	Dentsu	42
15	🇺🇸	Groupon	39
16	🇺🇸	Intel	36
17	🇺🇸	eBay	33
18	🇺🇸	Autodesk	29
19	🇺🇸	Zynga	27
20	🇫🇷	Publicis Groupe	25
21	🇺🇸	Boston Scientific	24
22	🇺🇸	Citrix Systems	24
23	🇺🇸	AOL	24
24	🇬🇧	Capita	24
25	🇳🇴	Visma	24
26	🇩🇪	Siemens AG	23
27	🇰🇷	Samsung Electronics	23
28	🇫🇷🇮🇹	Luxottica-Essilor	23
29	🇺🇸	Dropbox	22
30	🇨🇭	Roche	21

Science, research and innovation performance of the EU 2020

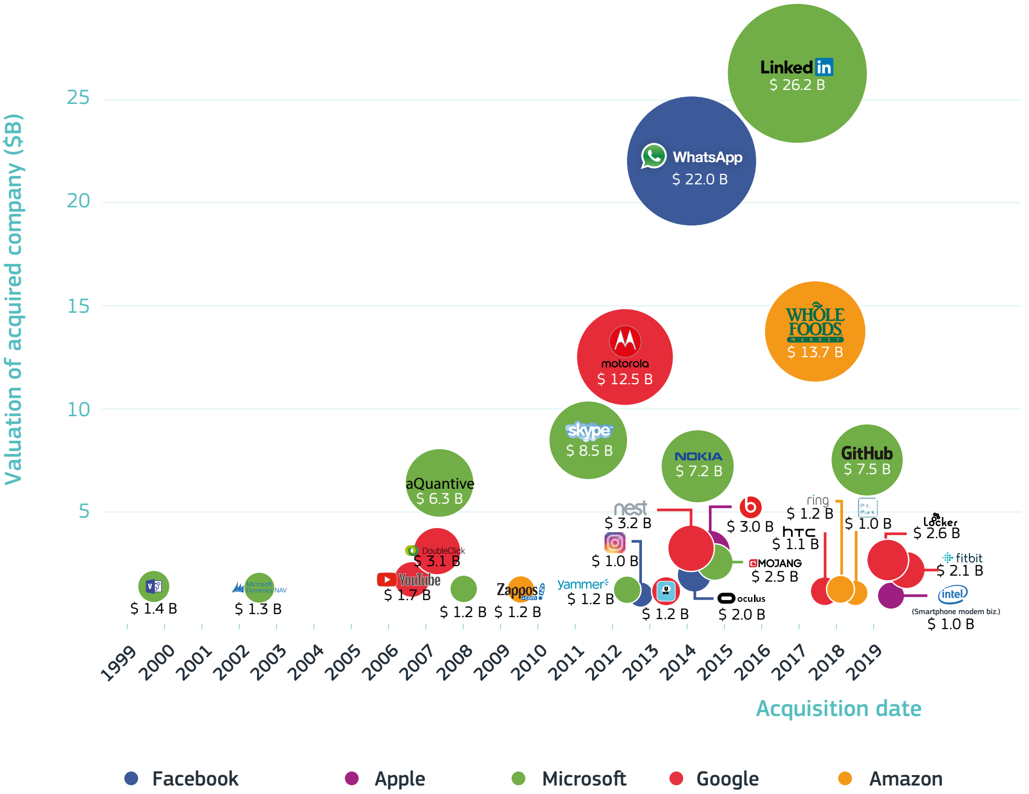
Source: Mind the Bridge (2018), TECH STARTUP M&As

Note: The studies included only startups that are defined as: companies founded after 1999, and companies that operate in innovative industries (e.g. ICT, life sciences, etc.) and/or introduce radical (disruptive) innovations in traditional industries (e.g. drones in agriculture).

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter8/figure-8-27.xlsx

Over the past 20 years, US tech giants have acquired 750 companies. In particular, since 1999, they have accounted collectively for 27 billion-dollar acquisitions that included popular companies such as LinkedIn, WhatsApp, Skype, GitHub and Nokia's mobile phone business[26]. The billion-dollar acquisitions of Facebook, Amazon, Microsoft, Google and Apple are depicted in Figure 8-28. While some of these acquisitions reflected strategies to access new markets (e.g. Google's acquisition of Fitbit to penetrate the wearables market, or Microsoft's acquisition of Skype to position itself in the video chat and internet communications service), others intended to contribute to their position in certain markets (e.g. Amazon's acquisitions of Zappos and Souq). Finally, some intended to 'absorb' big competitors that were disrupting the market and threatening their 'strong' position. For example, this was the case with Facebook's acquisitions of WhatsApp and Instagram. To date, LinkedIn (Microsoft), WhatsApp (Facebook) and Whole Foods (Amazon) are the most expensive acquisitions by US tech giants.

Figure 8-28 US tech giants' billion-dollar acquisitions over time(1), 1999-2019



Science, research and innovation performance of the EU 2020

Source: CBinsights, https://www.cbinsights.com/research/tech-giants-billion-dollar-acquisitions-infographic/

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter8/figure-8-28.xlsx

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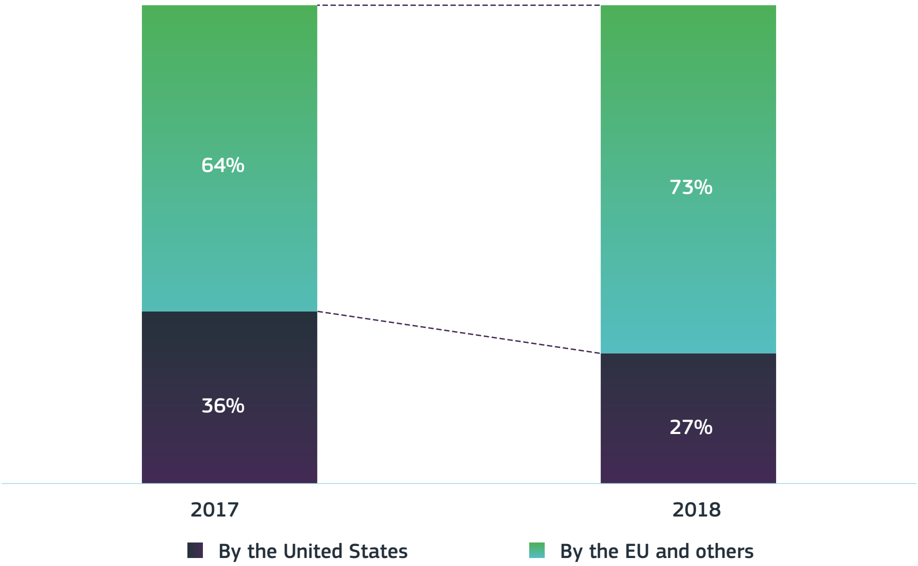
[26] Two years later, Microsoft wrote off its USD 7.2-billion deal with Nokia and laid off close to 8 000 employees in the process. See, for instance: https://thenextweb.com/microsoft/2018/09/03/five-years-ago-microsoft-bought-nokias-smart-phone-business/

US companies accounted for slightly less than a third of European start up acquisitions. Figure 8-29 shows that, despite a decline compared to 2017, US companies still represent a considerable share – of 27 % – in terms of startups acquired in Europe, including by European firms. A few of the most 'mediatic' cases include the acquisition of Skype by Microsoft in 2011 and Apple's acquisition of Shazam (UK). Mind the Bridge (2018) stressed that the 'appetite' for both European and US startups has also grown outside both regions. In particular, their analysis indicates that 'some of the most active companies acquiring US and EU startups from elsewhere are from Canada, Japan, India, Australia, China and Israel', and that their share increased from 7 % in 2017 to 14 % in 2018.

Figure 8-29 Share of European startups acquired by either US companies or EU and others, 2017 and 2018

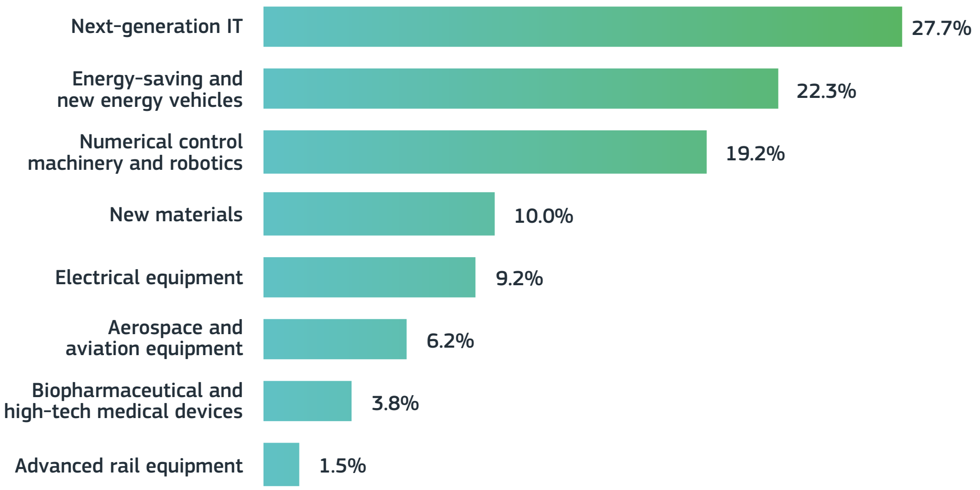


Science, research and innovation performance of the EU 2020

Source: Mind the Bridge (2018), TechStartup M&As
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter8/figure-8-29.xlsx

In recent years, Chinese acquisitions in Europe have mainly targeted companies in ‘next-generation IT’ and ‘energy-saving and new energy vehicles’ (Figure 8-30). As mentioned by the European Political Strategy Centre (EPSC) (2019), one of the ambitions of the ‘Made in China 2025’ strategy is to achieve *70% of ‘self-sufficiency’ in high-technology industries by 2023 and a ‘dominant’ global position by 2049*. Chinese acquisitions in Europe are mainly targeting companies in ‘next-generation’ IT and ‘energy-saving and new energy vehicles’. This may compromise Europe’s potential to lead in these technologies.

Figure 8-30 Share of Chinese investments in Europe related to 'Made in China 2025' by sector of the acquired firm, 2015-2018



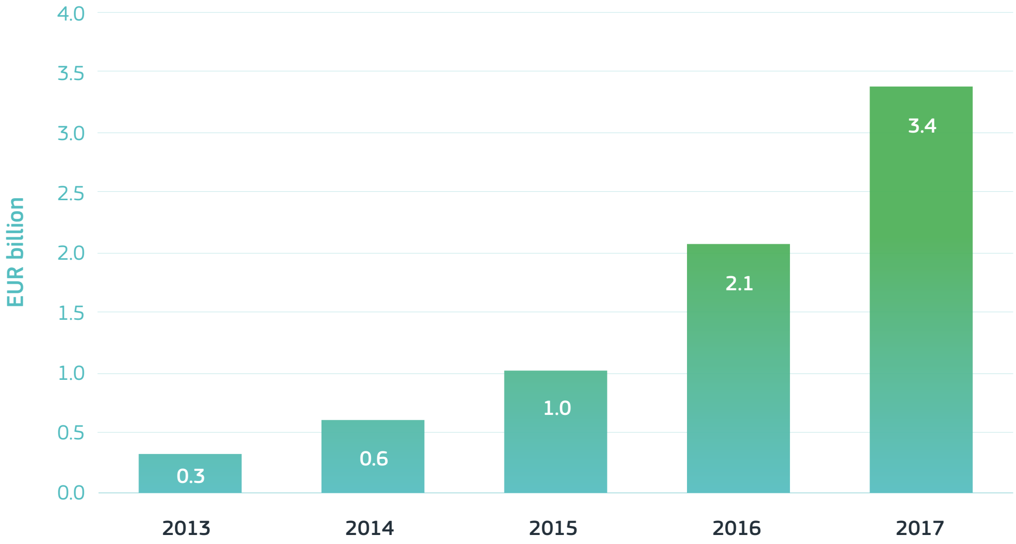
Science, research and innovation performance of the EU 2020

Source: EPSC (2019), based on JRC computations on foreign ownership database; period: January 2015-August 2018

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter8/figure-8-30.xlsx

Online alternative financing is growing as complementary to other forms of startup financing, including in Europe. China is currently the largest market providing such solutions. Alternative financing models have spread more significantly in the aftermath of the banking crisis, which has also been fostered by the digitalisation wave, including the development of online intermediate platforms that disrupted business models. The growing 'appetite' for online alternative finance is also observable in the EU (Figure 8-31). According to the Cambridge Centre for Alternative Finance (2019), online alternative finance models include a wide range of modalities that can be debt- or equity-based. These include, for example, P2P consumer lending, P2P business lending, equity-based crowdfunding, reward-based crowdfunding, donation-based crowdfunding, and profit sharing, among others. Accordingly, many platforms in Europe are positive about the regulatory framework, but a considerable number still consider the existing regulation as unsuitable. This dissatisfaction seems to be strongest regarding equity-based crowdfunding regulations.

Figure 8-31 **Online alternative finance market volumes in Europe(1) in EUR billion, 2013-2017**



Science, research and innovation performance of the EU 2020

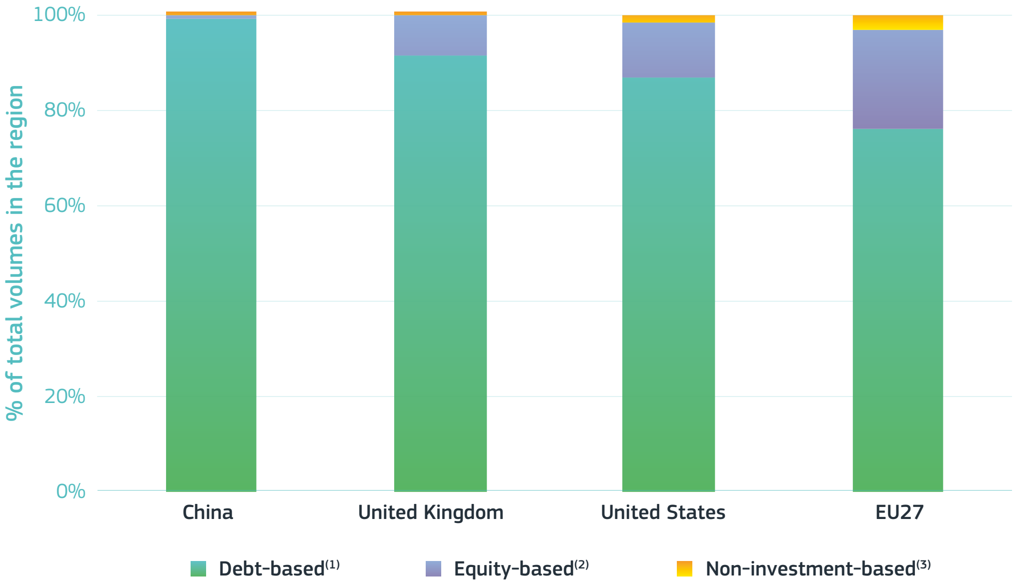
Source: Cambridge Centre for Alternative Finance (2019), 'Shifting paradigms- the 4th European Alternative Finance Benchmarking Report'

Note: (1)Europe comprises 44 countries, excluding the United Kingdom.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter8/figure-8-31.xlsx

Debt-based online activities are the most popular (Figure 8-32). Equity crowdfunding and non-investment-based crowdfunding come next but only with a marginal representation. The EU emerges as the region where the share of equity-based alternative solutions are the most common, accounting for around one fifth of all operations. This compares with only around 1 % in China, 12 % in the United States and 8 % in the United Kingdom. Non-investment-based solutions are also relatively more common in the EU.

Figure 8-32 Breakdown of the online alternative finance market for businesses by type, 2017



Science, research and innovation performance of the EU 2020

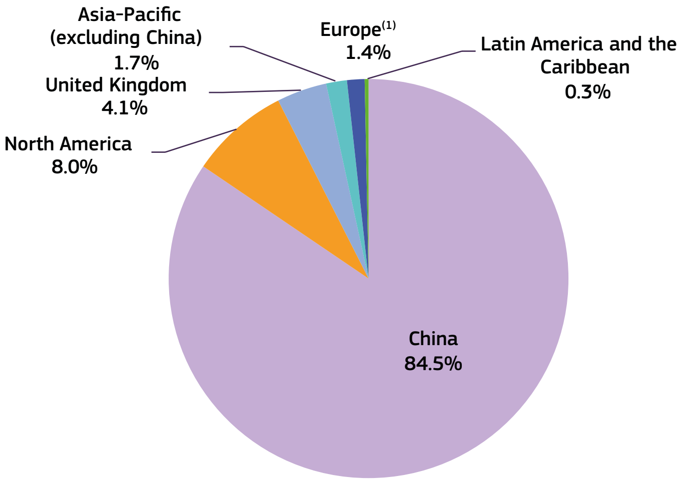
Source: OECD (2019), 'Financing SMEs and Entrepreneurs 2019: An OECD Scoreboard'

Notes: (1)Debt-based activities encompass business, property and consumer (when applicable for SMEs) loans from peer-to-peer activities, from institutional funders, or directly from the platform. This also includes invoice trading and debt-based securities. (2)Equity-based activities include equity-based, revenue-sharing, reward-based, donation-based and real estate crowdfunding. (3)Includes reward-based crowdfunding.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter8/figure-8-32.xlsx

China stands out as the nation with the largest market for online alternative finance worldwide, accounting for close to 85 % of global volumes in 2017. North America represents 8 % of the market, while the EU only covers slightly more than 1 % of the volumes (Figure 8-33).

Figure 8-33 The online alternative finance market for businesses by region, as a share of global volumes, 2017



Science, research and innovation performance of the EU 2020

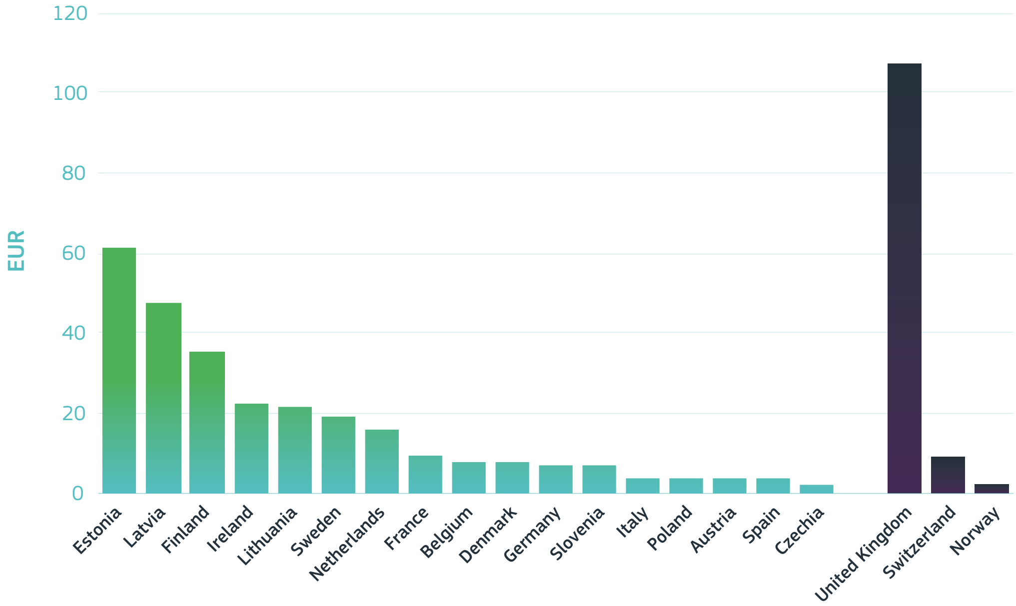
Source: OECD (2019), 'Financing SMEs and Entrepreneurs 2019: An OECD Scoreboard.

Note: (1)Europe comprises 44 countries, excluding the United Kingdom.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter8/figure-8-33.xlsx

At the EU level, considering the size of the market for alternative finance per capita, the Baltic and Nordic nations emerge at the top, while Austria, Spain and Czechia seem to have the smallest markets in relative terms. Moreover, online alternative finance models seem quite relevant in the United Kingdom while being almost absent in Norway (Figure 8-34).

Figure 8-34 Market volume of online alternative finance per capita, by country (in EUR), 2017



Science, research and innovation performance of the EU 2020

Source: Cambridge Centre for Alternative Finance (2019), 'Shifting paradigms- the 4th European Alternative Finance Benchmarking Report'

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter8/figure-8-34.xlsx

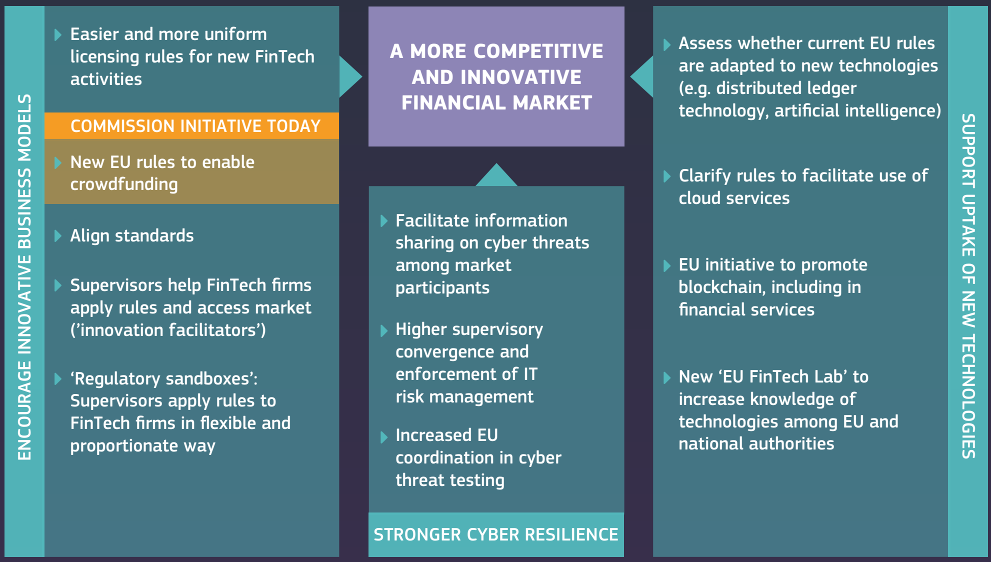
Acknowledging the importance of crowdfunding to diversify the funding available to startups and innovators at the inception of the business and part of its growth stage, the Commission has put forward Fintech action plan, including a focus on crowdfunding. Box 8-3 summarises the ambitions of this plan 'for a more competitive and innovative European financial sector'. Among the main initiatives is an **'EU-wide passport' for crowdfunding** activities. This is a key initiative that has the potential to better connect innovators' needs with the capital available from crowdfunding services. As a result, it could serve as inspiration for improving the regulatory framework in other strategic sectors, such as green tech or quantum computing, to name but a few.

BOX 8-3 Commission's FinTech action plan, including an EU-wide passport for crowdfunding

Based on European Commission FinTech action plan, 2018 - 'Creating a more competitive and innovative financial market'[27]

The FinTech action plan presented in 2018 lists 19 steps to 'enable innovative business models to scale up, support the uptake of new technologies, increase cybersecurity and the integrity of the financial system', as summarised in Figure 8-35.

Figure 8-35 **The Commission's Action Plan to promote FinTech in the EU**



Science, research and innovation performance of the EU 2020

Source: https://ec.europa.eu/info/sites/info/files/180308-action-plan-fintech-factsheet_en.pdf

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter8/figure-8-35.xlsx

New rules to expand crowdfunding in Europe were also an important part of the Fintech action plan. Overall, these rules intend to address cross-border differences in crowdfunding regimes as well as to tackle the lack of information and transparency in some cases. The solutions presented include an EU-wide passport, a common investor protection regime, and finally a simplified version of the template disclosing the main aspects related to the project and the financial product (Figure 8-36).

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[27] https://ec.europa.eu/info/publications/180308-action-plan-fintech_en

Figure 8-36 Addressing the problems limiting an EU-wide expansion of crowdfunding

PROBLEM	SOLUTION
Diverging national rules hinder cross-border crowdfunding services	EU-wide passport enables European crowfunding service providers to operate under same rules
Lack of information leads to low investor trust	Developing a common investor protection regime
Lack of transparency on project and financial product sold (e.g. loans, shares) leads to uninformed decisions	Simple template for disclosure of key characteristics of project and financial product sold

Science, research and innovation performance of the EU 2020

Source: https://ec.europa.eu/info/sites/info/files/180308-action-plan-fintech-factsheet_en.pdf

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter8/figure-8-36.xlsx

4. Better regulation for R&I will incentivise competition and innovation in Europe

In order to ensure well-functioning markets that incentivise competition and innovation, thereby maximising the impact of EU R&I investments, Europe needs a fit-for-purpose, forward-looking and overall innovation-friendly regulatory framework. There is well-established literature demonstrating that regulation, when it features adequate levels of stringency and the appropriate timing, can steer innovation towards addressing societal needs (Pelkmans and Renda, 2014; Ashford and Renda, 2016; Peter et al., 2017). Regulation needs the flexibility to adapt to an industry and society that are evolving rapidly. Hence, regulators are key players to support R&I by creating the right conditions for it and ensuring that policies are developed with innovation in mind. Regulatory frameworks need to enable more testing, learning and adaptation, and public policies have to make better use of all existing data and analytics. This implies that regulation, at both European and Member-State levels, should strike a balance between predictability and flexibility. It should also guarantee fair competition without sanctioning failure or risk-taking.

At the EU level, the European Commission recognises the importance of regulation in stimulating innovation to support social, environmental and economic objectives. In this context, it applies an innovation principle (Box 8-4) when preparing major legislative initiatives. To clarify how existing regulatory requirements apply to innovative ideas, the Commission has also been piloting Innovation Deals to help innovators address perceived EU regulatory obstacles. Early results in pilots on batteries and water reuse suggest the experience can provide useful feedback to improve regulation and promote innovation.

BOX 8-4 The innovation principle

The **innovation principle** helps to ensure that EU legislation is analysed and designed so as to encourage innovation to deliver social, environmental and economic benefits and help protect Europeans. It supports the EU's better regulation approach to help to enact smart, future-oriented regulation.

Examples of recent experience with the innovation principle in EU rules include:

- Regulation on the minimum requirements for water reuse: implications of the different policy options for this initiative were discussed with innovators. They indicated a preference for mandatory EU minimum quality requirements which became part of the legislative proposal.

- Regulation on health technology assessment (HTA): this helps to inform policy and clinical decision-making on the introduction and use of health technologies. HTA systems in Europe used to be fragmented with different methods, different requirements regarding the type of clinical evidence, and different procedures, which impeded the take-up of innovations. Better cooperation on HTA will improve the availability of innovative products for patients and stimulate the development of innovative health technology. The Commission analysed elements such as improved innovation incentives and choices for R&D investments, a reduced administrative burden in bringing new products to the market, reduced regulatory uncertainty and better adaptability to rapid technological developments.

As part of the innovation principle, the Innovation Deals address perceived regulatory obstacles to innovative solutions, stemming from the existing EU regulatory framework. Launched in 2017, a deal on anaerobic membrane technology for reuse of wastewater in agriculture aimed to investigate the (perceived) regulatory barriers that may prevent a broader application of anaerobic membrane bioreactor technology to enable the reuse of reclaimed water and nutrients in agriculture. Recommendations from this deal include: i) changing existing rules to enable fertigation[28] in sensitive areas while ensuring environmental protection; ii) developing guidance for Member States on the integration of environmental risks relating to nutrients; and iii) reflecting on methods for water pricing and recovering costs from polluters when water is reused in agriculture.

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[28] Injection of fertilisers into an irrigation system.

While the importance of a well-designed regulation to promote innovation is being increasingly acknowledged by policymakers, there are still strong differences between EU Member States in terms of regulatory quality. The perception of government's ability to formulate and implement sound policies and regulations for promoting private-sector development is very high in strong R&I countries such as Germany and Nordic countries. On the other hand, the quality of regulation is perceived as very low in countries such as Greece, Croatia, Slovenia and Bulgaria, which are also weaker in terms of R&I performance.

Overall, there seems to be a clear correlation between how countries are positioned in terms of regulatory quality and their innovation performance[29] (Figure 8-37). This is also true for global non-EU countries, with Switzerland, the United States and the United Kingdom showing both very strong R&I performance and regulatory quality. Compared to global competitors, central and eastern EU countries tend to present lower perceived regulatory quality as well as weaker R&I performance.

Figure 8-37 Regulatory quality

Source: Global Innovation Index 2019 Indicators

Notes: The Global Innovation Index[30] provides a score by country on its capacity for, and success in, innovation. Regulatory quality is a sub-index of the Global Innovation Index which captures perceptions of the government's ability to formulate and implement sound policies and regulations that permit and promote private-sector development. (1)The EU is the unweighted average of the 27 Member State.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter8/figure-8-37.xlsx

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29 Here as measured by the Global Innovation Index.

30 This index is published by Cornell University, INSEAD, and the World Intellectual Property Organization, in partnership with other organisations and institutions.

However, China does not follow this pattern, showing strong R&I performance but a very low score in terms of regulatory quality. This may point to the idea that China is playing outside the rules, its success being the result of building a competitive edge potentially to the detriment of standards and, also based on other insights on framework conditions in this section, providing generous state subsidies, significant market protection and a lengthy track record of unfair trade practices, commercial espionage and intellectual property right infringements (EPSC, 2019). Hence, compared to China, Europe seems to enjoy substantially more trust and confidence regarding its regulations and standards. This also means that Europe should capitalise on its acquis while facing potentially unfair practices, which calls for proper agility and flexibility in its regulatory framework.

In this respect, the innovation principle applied to R&I in different sectors (e.g. health technologies, waste management, energy generation) goes beyond improving the environment for doing business and can contribute to achieving sustainable growth and desirable social and environmental benefits. Using horizon scanning and innovative regulatory approaches to harness future technological advances and steer them towards delivering on European Commission priorities, the innovation principle can provide valuable insights into other policies in the areas of climate, environment, health, food, competitiveness and industry.

By its very nature and speed, innovation may often call into question traditional approaches to regulation. This raises the broader question of how regulation could be made fit for purpose to continue to be efficient while meeting the desired policy goals in a fast-moving and increasingly complex environment. Experimental approaches to regulation, including the so-called 'regulatory sandboxes'[31] are relevant in this context. When testing new solutions and alternative business models, accountability and the involvement of those who are impacted by innovation are essential.

When designing and evaluating regulation, the growing role of digitalisation in various sectors of the economy is not always reflected; the same applies to the increasingly data-driven nature of innovation. In some instances, the opportunities offered by digitalisation can facilitate the implementation of and compliance with existing rules, by reducing administrative burdens without affecting intended policy objectives, among others. More importantly, digitalisation also matters for policy design and for identifying policy approaches that grant sufficient adaptability to accommodate innovation and fast technological change, where appropriate. Indeed, while digitalisation and technology are enablers of solutions, they may also be the sources of new risks, which also need to be assessed and understood[32].

The Finnish Presidency, in cooperation with the Commission, organised a high-level conference on the innovation principle in December 2019. It concluded that the innovation principle can promote sustainable growth while offering a novel and important approach to addressing key socio-economic transitions. Thus, it is particularly relevant to meet ambitious policy goals such as carbon-neutrality but also to respond in an agile way to

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[31] For an illustration, see Financial Conduct Authority, Regulatory sandbox lessons learned report (2017).

[32] On this point, see, for instance, the Expert Group on Regulatory Obstacles to Financial Innovation (ROFIEG), Thirty Recommendations on Regulation, Innovation and Finance, Report for the European Commission, December 2019.

rapid technological development[33]. While human creativity has an inherent value, innovation can have unintended outcomes. Therefore, a critical assessment of responsible innovation is essential. In this respect, the way forward for the innovation principle rests on convening and partnering with all stakeholder groups, including civil society. In relation to institutional quality, people's skills are key to successfully delivering regulatory innovation. Human-centric approaches, design thinking and user focus can help public organisations do better.

5. Fulfilling the European Single Market

The EU Single Market for goods and services

The EU Single Market has been one of the key pillars of Europe's competitiveness. Completing the Single Market can foster knowledge diffusion across the continent. The aim of the EU's Single Market is to create a territory *without any internal borders or other regulatory obstacles to the free movement of goods and services*[34]. A functioning single market stimulates competition and trade, helps companies to benefit from economies of scale, triggers efficiency gains, and offers consumers a wider variety of products and services at lower prices (European Commission, 2015a). However, there is room for improvement to fulfil the promise of delivering a fully functioning Single Market. The Commission (2015b) stresses that labour productivity growth could be boosted in the EU space if regulatory barriers were removed, thereby *allowing for improvements in the allocation of resources across firms and sectors*. Improving the regulatory and cross-border frameworks is of the utmost importance for innovative firms that want easier access to the EU market. Furthermore, as discussed in Chapter 3.1 - Productivity puzzle and innovation diffusion, innovation diffusion from leading to laggard firms seems to be stalling Europe's productivity. Hence, stimulating knowledge flows and the diffusion of knowledge through a well-functioning single market for knowledge is of tremendous importance. The mobility of researchers and, more generally, brain circulation can also boost collaborative innovation (see Chapter 6.2 - Knowledge flows).

Building a culture of compliance and smart enforcement will set the foundations for the complete success of the EU Single Market. Figure 8-38 shows the performance of EU Member States in relation to the transposition and conformity deficit, according to the EU Single Market Scoreboard 2019. Accordingly, seven Member States still exceeded the 1% target, which was down from 13 in 2017: Germany, Luxembourg, Romania, Austria, Belgium, Cyprus and Spain. Moreover, there is a need to verify the compliance of national measures taken pursuant to directives to ensure the proper functioning of the EU Single Market. This is reflected in the conformity deficit. In particular, only five EU Member States – Malta, Greece, Lithuania, Denmark and Luxembourg – had a compliance deficit of less than 0.5%. Eleven Member States registered a high conformity deficit, surpassing the 1% mark.

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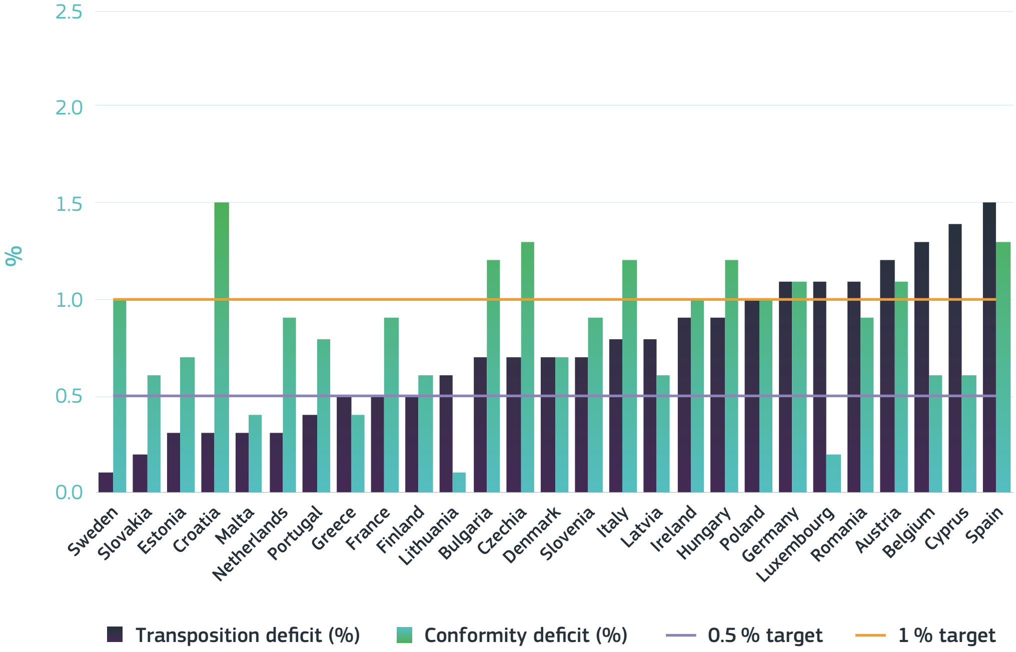
[33] Positive policy examples of innovation-friendly regulation provided during the conference included mobility as a service in Finland, and platforms to business regulation in EU rules.

[34] https://ec.europa.eu/growth/single-market_en

Figure 8-38 Transposition deficit[1] and compliance deficit[2] in EU Member States, as of December 2018



Science, research and innovation performance of the EU 2020

Source: European Commission (2019), EU Single Market Scoreboard

Notes: (1)The transposition deficit shows the percentage of Single Market directives not yet completely notified to the Commission in relation to the total number of directives that should have been notified by the deadline. It takes into account all transposition notifications made by 10 December 2018 for directives with a transposition deadline on or before 30 November 2018. (2)The conformity deficit measures the number of directives transposed where infringement proceedings for incorrect transposition have been launched by the Commission, as a percentage of the number of Single Market directives notified to the Commission as either 'transposed' or 'not requiring any further implementation measures'.

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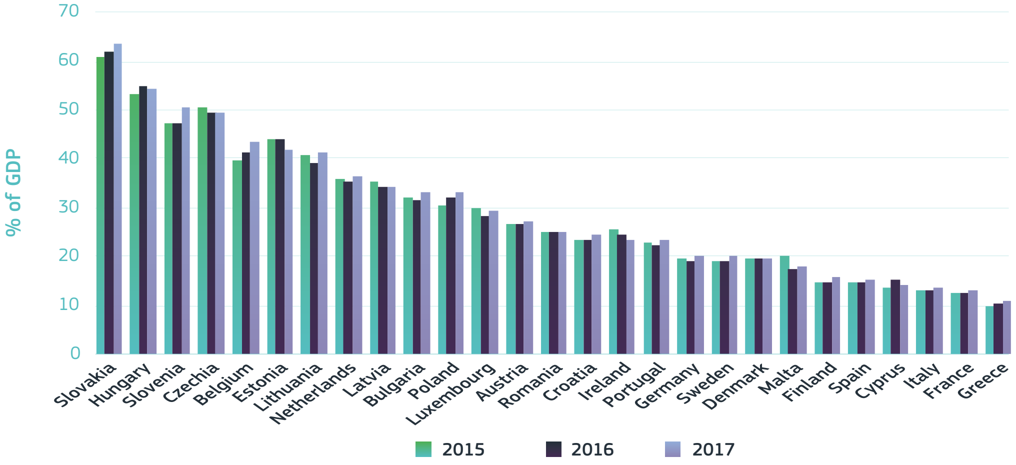
EU trade in goods and services measures the integration into European value chains and the degree of openness. Four Eastern countries – Slovakia, Hungary, Slovenia and Czechia – have the highest percentages of GDP that are accounted for by trade with EU countries (imports and exports) in goods (Figure 8-39). This is probably a reflection of the foreign direct investment (FDI)-led growth model in these countries, which has led to strong manufacturing bases, well integrated into western European production chains (Correia et al., 2018). The United Kingdom, Greece and France are at the lower spectrum of trade integration in goods.

Figure 8-40 presents the level of trade integration in services by EU Member States. It is highest in Luxembourg, Malta and Ireland while Italy, Germany and the United Kingdom register the lowest trade shares in GDP.

Figure 8-39 EU trade integration in goods (levels)(1)(2), 2015-2017



Science, research and innovation performance of the EU 2020

Source: European Commission (2019), EU Single Market Scoreboard

Notes: [1]Percentage of a country's GDP that is represented by goods trade with other EU countries (average of imports and exports). Reflects: overall import and export performance; degree of integration into European value chains and levels of openness, competitiveness and internal demand. [2]This is only a partial view of EU countries' trade integration performance and prospects. Changes in these indicators are caused not just by national implementation of Single Market policies and laws but by other factors, including general economic developments in the EU and globally.

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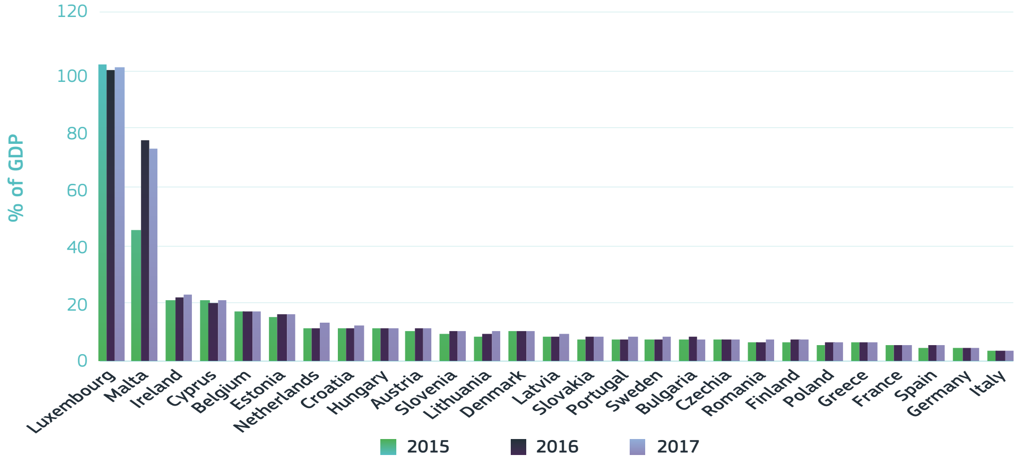
Figure 8-40 EU trade integration in services (levels)(1)(2), 2015-2017



Science, research and innovation performance of the EU 2020

Source: European Commission (2019), EU Single Market Scoreboard

Notes: [1]The percentage of a country's GDP that is represented by trade in services (financial and non-financial) with other EU countries (average of imports and exports). Reflects: overall import and export performance degree of integration into European value chains levels of openness, competitiveness and internal demand. [2]This is only a partial view of EU countries' trade integration performance and prospects. Changes in these indicators are caused not just by national implementation of Single Market policies and laws but by other factors, including general economic developments in the EU and globally.

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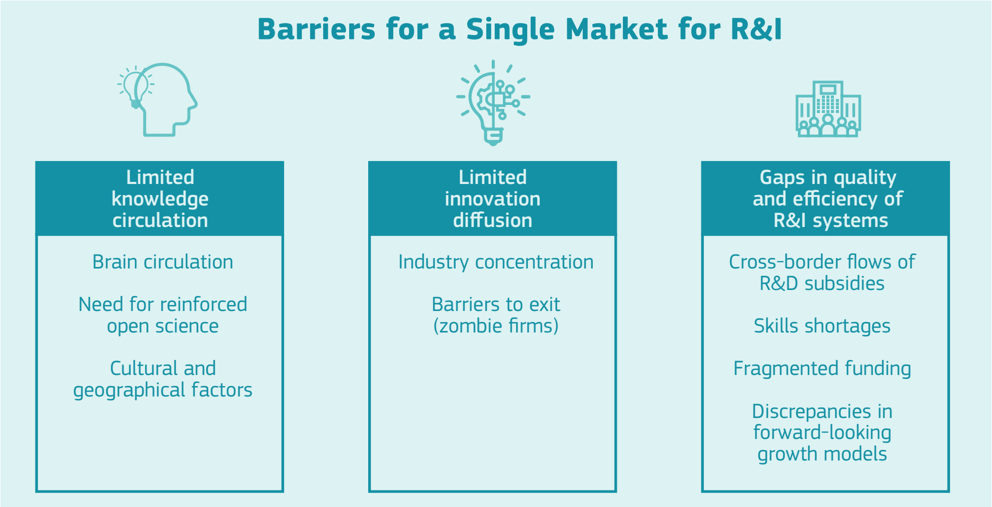
Barriers for a Single Market for R&I

When it comes to R&I-related activities, three main barriers to the internal market can be identified: i) limited knowledge circulation; ii) limited innovation diffusion; and iii) gaps in the quality and efficiency of R&I systems (Figure 8-41). When it comes to these aspects, current intra-EU disparities are creating hurdles to a fully functioning Single Market and can exacerbate inequalities among national R&I systems, hampering cross-border circulation of R&I activities. While these factors have been analysed throughout this report, this section will summarise their relevance for R&I system integration into the EU's Single Market.

Figure 8-41 Barriers for a Single Market related to R&I activities



Science, research and innovation performance of the EU 2020

Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/parti/chapter8/figure-8-41.xlsx

Barrier 1. Limited knowledge circulation

R&I increasingly happen within global networks in which interactions create value. Knowledge flows across disciplines, sectors and countries, through the geographical proximity of researchers, are crucial for fostering the higher quality and greater impact of R&I activities.

Different factors hamper knowledge flows, namely:

- **Brain circulation** is a complex and multi-directional phenomenon. International mobility is driven by research-job characteristics such as international networking, career perspectives and working with high-quality peers. Material working conditions related to remuneration, pensions and job security and other non-science-related conditions also influence job choice, and to a lesser extent mobility. Overall, the interactions of these factors contribute to explaining why brain circulation is not benefitting all countries in the EU in the same way, with an emerging core-periphery divide.

- **Open access, free flow of scientific and other data** – i.e. open science – are a way of strengthening scientific excellence, benefiting from citizen participation, achieving better reproducibility of results and increasing knowledge circulation and the reuse of research data, thereby accelerating the take-up of R&I knowledge and solutions and increasing their impact. Limited progress across these dimensions hinders the full integration of European R&I systems and the complete unleashing of spillover benefits (see Chapter 6.2 - Knowledge flows).

- **Geographical distance** still matters for international R&I collaborations and hence can hamper knowledge circulation between distant entities in the EU, despite virtual (remote) collaborations which can help to bridge the gap. Cultural differences may also have a detrimental effect on collaboration and circulation.

Overall, there are large differences between Member States in terms of knowledge flows. There is a clear divide between central and northern, and eastern and southern European countries, with the former performing considerably better. The latest European Research Area Progress Report 2018 shows that, while progress has been made, the momentum is slowing down and obstacles remain to a well-functioning single market for knowledge. In particular, these include discrepancies between Member States in application of the principles of openness, transparency and merit-based recruitment in national R&I funding schemes, and the persistence of barriers for researcher recruitment.

Barrier 2. Limited innovation diffusion

As shown in Chapter 3.1 - Productivity puzzle and innovation diffusion, the lack of innovation diffusion from leading to laggard regions and firms is stalling Europe’s productivity growth. Knowledge and innovation do not spread rapidly enough across the EU and laggard economies struggle to adopt advanced technologies and business processes from the technological frontier, raising questions about the functioning of the Single Market in these sectors.

Increasing industry concentration hinders innovation diffusion and suggests that rigidities in the product market persist. Technological change or globalisation enables the most-productive firms to expand, raising questions about the potential lack of competition and the emergence of quasi monopolies on innovation patterns in the long term. In the period 2000-2014, three quarters of European industries saw a four percentage points increase in concentration of market performance for the average European industry (Bajgar et al., 2019). Evidence shows there is a clear divergence in productivity growth performance between frontier firms, which continue to exhibit strong productivity dynamics, and laggards, whose productivity growth is stalling (Andrews et al., 2016). Chapter 2 - Changing innovation dynamics in the age of digital transformation develops these new dynamics further.

The broader effects of the Single Market should help raise the productivity levels of Europe’s ‘less-productive’ (or laggard) firms and boost their returns when they access a larger market for their products and/or services. It should also contribute to removing obstacles to innovation diffusion across Europe. However, a yet incomplete internal market is hindering Europe's ability to scale up innovations, notably in strategic areas such as digital or services. This suggests there is still room for an adequate policy mix to:

- address the incomplete market and give innovations 'born in Europe' the opportunity to scale up and become global players;
- foster EU trade integration, innovation-friendly regulation at the EU and national level, and integration into value chains for less-productive firms.

Barrier 3. Gaps in the quality and efficiency of R&I systems

The quality and efficiency of the overall R&I system and governments' longer-term commitment to investments in intangible assets play a fundamental role in boosting growth in a given country and a key role for mobility choices in the internal market (European Commission, 2017). There are significant gaps and discrepancies in the quality of R&I systems across Europe, which directly affect the cross-border circulation of R&I activities. Boosting investment and reforms to modernise R&I systems and policies across Europe remains essential to foster the cross-border circulation of R&I activities. While performance-based research funding[35] systems are becoming increasingly important as part of countries' research policy mix, there is considerable variation among countries (Arnold and Mahieu, 2018). There are also large differences in the way direct and indirect public support for R&D are used by Member States, with an increasing use of R&D tax incentives by some countries, impacting, and to some extent tilting, the EU funding landscape for R&I.

The Single Market supports the quality and efficiency of R&I systems across Europe by enabling exchanges of tangible assets through trade and FDI, but also of intangible assets which include ICT, skills, economic competences and R&D (including the positive effects stemming from the mobility of scientists, researchers and innovators). However, there are barriers to cross-border flows of R&D subsidies in many national systems and even preferential access to subsidies for local providers of R&D services. The cross-border portability of R&I funding is limited, with only a few funding schemes, such as the European Research Council or Marie Skłodowska-Curie actions, supporting such portability.

Overall, the markets for research funding and venture capital are shallow and fragmented in the EU. There is insufficient access to risk capital in Europe to support innovation and startup scaleups. Risk and patient capital, while recovering, remain very low in comparison to the United States. Although access to finance has improved significantly in Europe in recent years, risk capital (in particular for growing and scaling up businesses) continues to be scarce and significant differences persist between Member States in their access to venture capital. Venture capital raised in Europe is about one fifth of the amount raised in the United States while the EU funds are more shallow in volume.

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[35] Performance-based funding, unlike institutional funding, involves competing for money on a project or mandate basis.

6. Conclusions

Efficient and innovation-friendly framework conditions are key for business investment in innovative activities and enable new ideas and technologies to get to market. An innovation-friendly business environment includes efficient product and labour markets, national and local institutions able to provide citizens and firms with public goods and services, as well as diffused access to finance and smart regulation.

While the efficiency of framework conditions in Europe are just shy of the best performers among peer economies, significant heterogeneity across and within Member States can be observed. Different indicators of the efficiency of product markets, including ease of doing business and the degree of competition, suggest that a periphery-core gap persists, together with substantial within-countries differences for what concerns the public delivery of services and goods and overall institutional performance.

The availability of risk finance for innovative investments in Europe has improved compared to the aftermath of the crisis, but remains insufficient to meet EU ambitions in a system which is still very reliant on bank financing. A comparison with the United States reveals a significant gap in access to risk capital, late-stage financing being one of the key bottlenecks that can constrain the scaling up of European companies. Venture capital funds tend to be smaller, fewer and are mostly concentrated in a few Member States, notably among the 'innovation leaders' and the 'strong innovators'. Nevertheless, the public sector is a key player and policy initiatives at the EU level – e.g. the EIC and Horizon Europe – will contribute to leveraging resources to finance the innovation potential of European companies and innovators.

The quality of regulation shapes how innovation outcomes affect social, environmental and economic targets. In this respect, fulfilling the EU Single Market is a key pillar for Europe's competitiveness and for meeting the objectives of sustainable growth that leaves no one and no place behind, while respecting environmental boundaries. Reducing the existing barriers to completion of the Single Market (e.g. still limited knowledge circulation and innovation diffusion, together with persisting gaps in the quality and efficiency of R&I systems) will unlock the potential of EU innovation and development. Overall, while Europe is progressing towards a fit-for-purpose and forward-looking regulatory framework, there are still strong differences between EU Member States and the challenges ahead.

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PART

II

CHAPTER

9

TRANSFORMATIVE INNOVATION AND SOCIO-TECHNICAL TRANSITIONS TO ADDRESS GRAND CHALLENGES

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Summary

The aim of the chapter is to present the role of transformative innovation as a new paradigm to address many of the most pressing societal challenges we are facing, notably transition to sustainability and combatting climate change. It elaborates on what it means for research and innovation R&I) policy and attempts to 'operationalise' these transitions.

This chapter presents a broader conceptual model to benefit policies for transformative innovation and grand challenges that goes beyond the linear model and innovation system approaches. The new role for R&I is to support socio-economic transformations, but it needs to be complemented with other policies to have a stronger impact. After introducing the socio-technical transitions and potential barriers for the uptake of these niche innovations, the final analytical section gives several examples where these transformations have taken place, in both energy and mobility. The chapter closes with an extensive overview of policy conclusions.

1. Introduction

1.1 Grand challenges in a policy context: climate change, SDGs, and economic growth

Transformative innovation and systemic transitions are attracting increasing attention in the context of three policy problems. First, addressing climate change will require radical innovation and low-carbon transition in many systems, as the Commission's recent climate strategy recognises: 'The transition to a net-zero greenhouse gas emission economy by mid-century will radically transform our energy system, land and agriculture sector, modernise our industrial fabric and our transport systems and cities' (EC, 2018a: 6).

Second, addressing other grand societal challenges (such as ageing, obesity, energy security, urban quality of life, and inequality) and the Sustainable Development Goals (SDGs) will require transformative innovations in health care, agro-food and urban systems, as Vice-Presidents Timmermans and Katainen note in the foreword to the Commission's recent Reflections Paper: 'Sustainable development means that we need to modernise our economy to embrace sustainable consumption and production patterns, to correct the imbalances in our food system, and to our mobility, the way we produce and use energy, and design our buildings on to a sustainable path' (EC, 2019: 3).

Third, low-carbon and sustainability transitions offer attractive growth prospects, as the Commission's expert group on green growth and jobs concludes: 'There is a huge competitive opportunity for Europe to ride this 'green' trajectory and turn environmental problems into solutions for promoting investment and jobs. Such a green direction implies the use of technological capacities (which the EU has) in order to drastically increase the productivity of energy and material resources (which the EU only has in limited quantities). The markets of the future are bound to grow in that direction' (EC, 2016: 11). But to exploit and compete globally in this area, radical innovation should be nurtured: 'Europe is relatively strong in adding or sustaining value for existing products, services and processes, known as incremental innovation. (...) But Europe needs to do better at generating disruptive and breakthrough innovations' (EC, 2018b: 11).

1.2 Analytical challenges for innovation policy

Transformative innovation and systemic transitions pose analytical challenges for innovation policy that come in addition to traditional challenges. Schot and Steinmueller (2018) distinguish three frames for innovation policy, which respectively focus on stimulating R&D, improving knowledge flows in innovation systems, and stimulating transformation (Figure 9-1).

Figure 9-1 Three frames in innovation policy

Framing	Key features	Policy rationale	Policy approaches (examples)
Science and technology for growth (since 1950s)	Linear innovation model, driven by R&D (research and development)	Addressing market failures (firms invest insufficiently in R&D because of public good character of innovation)	State financing of R&D; subsidies or tax incentives for business R&D
National and sectoral systems of innovation for improved competitiveness (since 1980s)	Focus on knowledge flows between upstream actors (universities, firms, agencies)	Responding to system failures, e.g. improving linkages between actors, addressing institutional problems (in laws, property rights, regulations)	Promoting science hubs and science-industry collaboration; education and training; cluster policies
Transformative change to address grand challenges (since 2010s)	Nurture radical innovation and new pathways; shape directionality of innovation	Promote system transformation, which incumbent actors are slow or reluctant to do	Missions and goals (SDGs, climate targets), assisting new entrants, creating transformative coalitions, learning, experimentation

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Source: Author's elaboration based on Schot and Steinmueller, 2018

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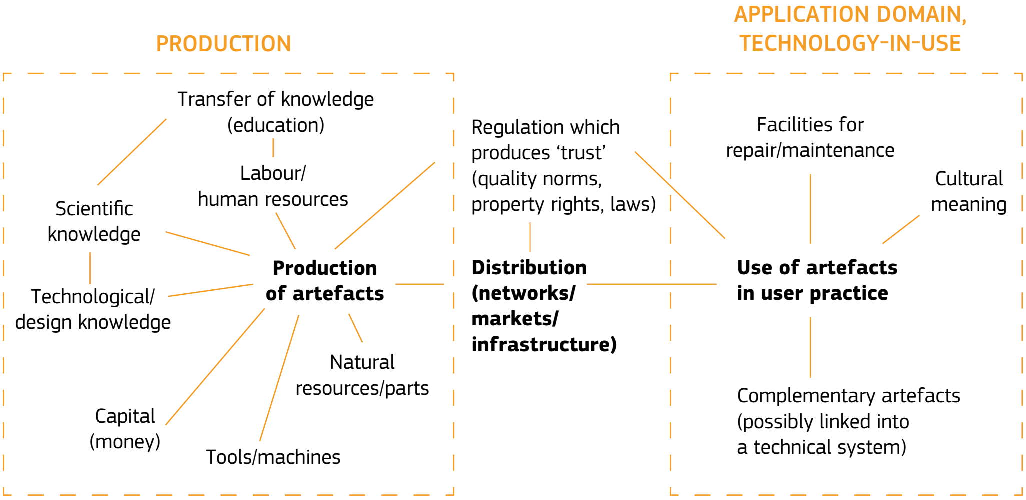
Whilst the first two frames remain relevant, transformative innovation and systemic transitions involve several new policy challenges.

Horizontal policy coordination

Systemic transitions go beyond products and technologies to involve changes in broader socio-technical systems, which refer to all the elements that make energy, mobility and agro-food systems work (Geels, 2004), as schematically represented in Figure 9-2. While innovation policy remains essential, horizontal coordination with other policy domains (e.g. labour markets, competition policy, finance, industry policy, transport/energy/agricultural policy, environmental policy) is crucial to transform entire systems.

Figure 9-2 Schematic representation of socio-technical system elements



Source: Geels, 2004: 900

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Social, business model and infrastructural innovation

While innovation policy traditionally tends to focus on science and technology, transforming entire socio-technical systems involves not just radically new technologies, but also social, business model and infrastructural innovation (Bulkeley et al., 2013; Bolton and Foxon, 2015; Bolton and Hannon, 2016; Hoppe and de Vries, 2019; Van Waes et al., 2018). Focusing on environmental sustainability, Figure 9-3 provides some examples of innovations that may create the seeds for low-carbon and sustainability transitions.

Figure 9-3 Examples of radical innovations in mobility, agro-food and the energy domain

	Mobility	**Agro-food**	**Energy (electricity, heat)**
Radical technical innovation	Battery-electric vehicles, (plug-in) hybrid electric vehicles, biofuel cars, self-driving vehicles	Permaculture, agro-ecology, artificial meat, plant-based milk, manure digestion	Renewable electricity (wind, solar, biomass, hydro), heat pumps, passive house , biomass stoves, smart meters
Grass-roots and social innovation	Car sharing, bike clubs, modal shift to bicycles and buses, tele-working, tele-conferencing	Alternative food networks, organic food, 'less meat' initiatives, urban farming	Decentralised energy production ('prosumers'), community energy, energy cafés
Business model innovation	Mobility services, car sharing, bike sharing	Alternative food networks, organic food	Energy service companies, back-up capacity for electricity provision, vehicle-to-grid electricity provision
Infra-structural innovation	Intermodal transport systems, compact cities, revamped urban transport systems (tram, light-rail, metro)	Efficient irrigation system, agro-forestry, rewilding, multi-functional land use	District heating systems, smart grids, bio-methane in reconfigured gas grid

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Source: Author's elaboration based on Bulkeley et al., 2013; Bolton and Foxon, 2015; Bolton and Hannon, 2016; Hoppe and de Vries, 2019; Van Waes et al., 2018

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/partii/chapter9/figure_9-3.xlsx

Wider set of actors and coalitions

While innovation policy traditionally has an 'upstream' focus (on knowledge flows between universities, firms, policymakers), the implication of the previous two points is that transformative innovation and transition processes require the involvement of a wider set of actors. The inclusion of new entrants, like start-up companies, cities, communities, citizens and NGOs, may help to create transformative coalitions that think out of the box and drive transitions (Diercks et al., 2019; Marletto et al., 2016; Söderholm et al., 2019; Steward, 2012).

EU policy discussions already recognise this idea, which underpins the notion of 'open innovation'. For example, the European Commission's RISE group (research, innovation and science experts) notes that: 'Traditionally, addressing societal challenges has been primarily a 'supply-pushed' concern with the research community playing a central role. (...) Implementation in terms of innovation has, however, often been disappointing. Typically, users and more broadly the demand side, has been insufficiently involved in the design and development of innovative ways to address those societal, global challenges' (EC, 2017a: 160).

The RISE group therefore recommends that: 'It will be crucial to break open the current supply-side research dominance in addressing societal challenges, which has sometimes cornered the discussion and debates to technical debates about measurement, evidence and methodologies' (EC, 2017a: 160).

The Commission's Lamy report similarly calls for wider stakeholder engagement: 'As part of a coherent innovation policy, EU policymakers should be required to regularly identify, in dialogue with stakeholders and citizens, how and what innovation can help them more easily achieve their objectives' (EC, 2017b: 12). 'Fully mobilising and involving stakeholders, end-users and citizens in the post-2020 EU R&I programme, for instance in defining its missions, will not only increase the degree of co-creation, it will also maximise its impact and stimulate a stronger demand for innovative products and services as well as a better grasp of social changes. This will bring open science and open innovation to the next level and turn Europe into a continental living innovation lab' (EC, 2017b: 19).

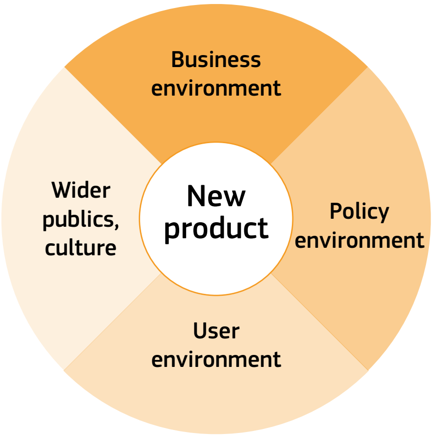
Visions and missions to create drive and directionality

While innovation policy traditionally focuses on rates of innovation, transformative innovation is also about directionality since sustainability transitions aim to solve particular problems and reach particular goals (e.g. 80-90% reduction of greenhouse gas emissions by 2050). Recent debates about mission-oriented innovation policy emphasise the importance of inspiring visions which provide long-term directionality and challenging, yet doable missions that formulate more specific targets (which enable accountability) and are accompanied by financial instruments (that enable concrete action) (Mazzucato, 2018).

Diffusion

While innovation policy tends to focus on the emergence of new ideas and innovations (R&D), transformation and system transitions only happen when radical innovations actually diffuse into markets and society, which includes embedding in business, user, civil society and policy environments (Deuten et al., 1997; Kanger et al., 2019; Mylan et al., 2019), as schematically represented in Figure 9-4.

Figure 9-4 Relevant environments for new products and practices



Source: Adapted from Deuten et al., 1997: 134
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/partii/chapter9/figure_9-4.xlsx

These five challenges suggest that policies for transformative innovation and grand challenges could benefit from a broader conceptual model that goes beyond the linear model and innovation system approaches (Figure 9-1). Section 2 describes such a conceptual model, which provides a big-picture understanding of core processes and mechanisms in systemic transitions. The so-called multi-level perspective provides a general framework, which has been tested and refined with dozens of historical case studies, including shifts from cesspools to sewer systems, from horse-drawn transport to automobiles, from sailing ships to steamships, from traditional factories to mass production (Geels and Schot, 2007). It has also been widely applied to low-carbon transitions (Geels et al., 2016, 2017; Moradi and Vagoni, 2018; Berkeley et al., 2018) and has become a core framework in studies of sustainability transitions (Smith et al., 2010; Köhler et al., 2019). Section 3 empirically illustrates this model with three case studies of sustainability transitions: the German electricity transition, Austrian biomass district heating, and French tram systems. Section 4 discusses the five policy challenges in the three cases and ends with policy messages.

2. Multi-level perspective on socio-technical transitions

2.1 Basic concepts

Drawing on evolutionary economics, the sociology of innovation, and institutional theory, the multi-level perspective (Geels, 2002; 2004; Smith et al., 2010) suggests that transitions come about through the interplay between processes at niche, regime and landscape levels.

Radical innovations tend to emerge in small niches at the periphery of existing systems, through the pioneering activities of entrepreneurs, startups, activists or other relative outsiders (Van de Poel, 2000; Schot and Geels, 2008). Niche innovations like those in Figure 9-3 are ‘radical’ because they deviate from existing systems on technical, social, business model or infrastructural dimensions, which also implies they often cannot survive mainstream selection pressures. Niches therefore act as ‘protected spaces’ that shelter radical innovations in early phases and nurture learning and development processes (Smith and Raven, 2012).

Since radical innovations are often enacted by new entrants, they may entail organisational innovation and new business models (Bolton and Hannon, 2016; Van Waes et al., 2018), implying changes in the ways that firms appropriate value from their activities. Business model innovation may be risky and challenging, as the ongoing struggles of Tesla and Uber to become profitable suggest. Niches may also nurture social innovations and grass-roots innovations, although actors, motivations, and forms of protection may be different than those for market-based innovation (Figure 9-5). Grass-roots innovations include changes in social practices and lifestyle and using technologies (see Figure 9-3 for examples), which are typically enacted by volunteers and activists (Seyfang and Smith, 2007; Hargreaves et al., 2013), foreground moral values and collective aspirations, and are highly contextual, often developed in response to local problems (Hossain, 2018). Figure 9-5 summarises some of the differences

Figure 9-5 Comparing the characteristics of market-based and grass-roots innovations

	Market-based innovations	Grass-roots innovations
Context	Market economy	Social economy
Driving force	Profit: Schumpeterian rent	Social need; ideological
Niche protection	Market rules are different: tax and subsidies temporarily shelter novelty from full market forces	Values are different: alternative social and cultural expressions enabled within the niche
Organisational form	Firms	Voluntary associations, co-ops, informal community groups
Resource base	Income from commercial activity	Grant funding, voluntary input, mutual exchanges, limited commercial activity

Source: Seyfang and Smith, 2007: 92
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/partii/chapter9/figure_9-5.xlsx

between grass-roots innovations and market-based innovations. Despite these differences, temporal developments of both types of innovation can be analysed with strategic niche management categories (learning, network building, visioning), although specific mechanisms vary (as discussed in section 2.2).

Radical niche innovations face uphill struggles against existing energy, agro-food and mobility *systems*, which are stabilised by the alignments between technologies, policies, user patterns, infrastructures and cultural discourses (Figure 9-2), that were created in previous decades. Elements of existing systems are reproduced, maintained and incrementally improved by incumbent actors, such as firms, engineers, users, policymakers and special-interest groups. The perceptions and actions of these social groups are shaped by entrenched shared rules and institutions, called *socio-technical regimes* (Geels, 2004; Fuenfschilling and Truffer, 2014). Innovation in existing systems and regimes is mostly incremental and path-dependent because of various lock-in mechanisms (Klitkou et al., 2015):

- Techno-economic lock-in mechanisms: a) sunk investments (in competencies, factories, infrastructures) that create vested interests against transitional change; b) low-cost and high-performance characteristics of existing technologies due to economies of scale and decades of learning-by-doing improvements.

- Social and cognitive lock-in mechanisms: a) routines, shared mindsets and core capabilities that 'blind' firms and other actors to developments outside their focus (Leonard-Barton, 1992; Nelson, 2008); b) 'social capital' resulting from alignments between social groups; organisations develop 'webs of interdependent relationships with buyers, suppliers, and financial backers' (Tushman and Romanelli, 1985: 177), which may be difficult to change; c) user practices and lifestyles which have been organised around particular technologies (Shove, 2003).

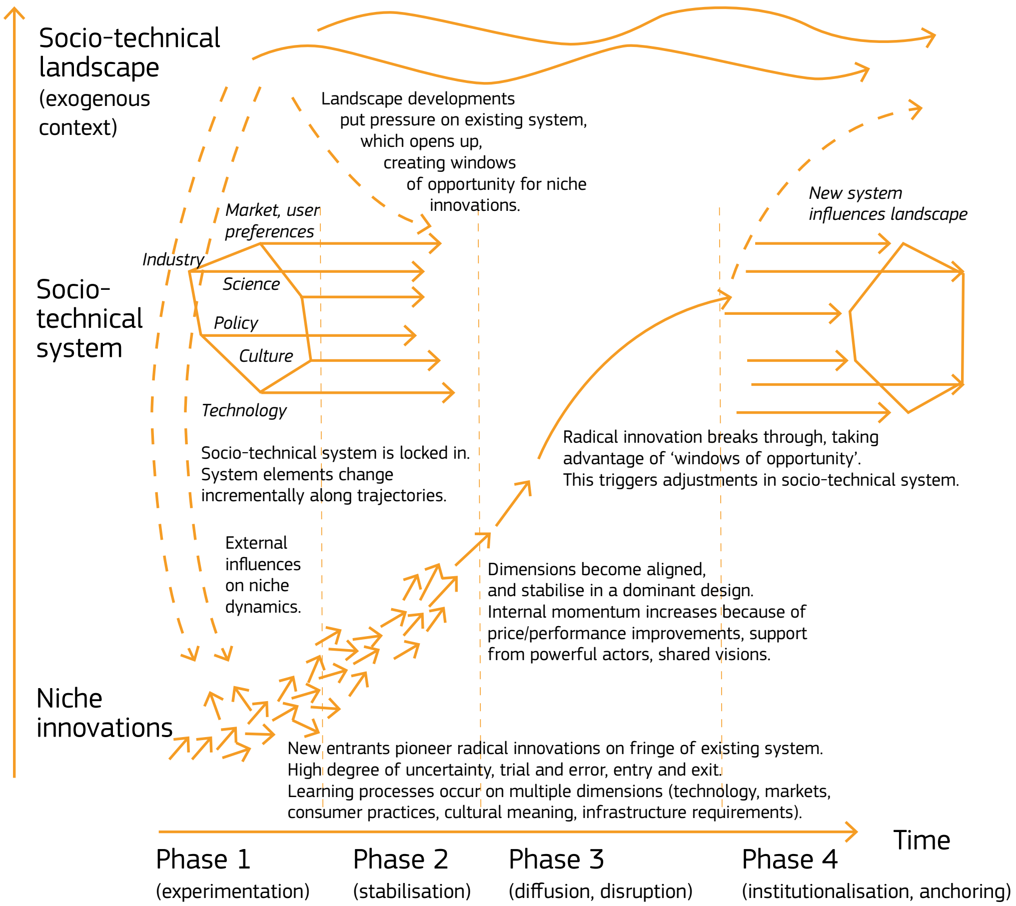
- Institutional and political lock-in mechanisms: a) existing regulations and policy networks favour incumbents and create an uneven playing field (Walker, 2000); b) vested interests use their access to policy networks to water down regulatory change and hinder radical innovation (Hess, 2016).

Because of their commitments to existing socio-technical systems and regimes, incumbent organisations (like coal, oil, and agro-food companies) tend to oppose sustainability transitions (Geels, 2014) or prefer incremental, efficiency-oriented changes (e.g. direct fuel injection in car engines or 'clean coal' power plants). Nevertheless, incumbent firms can (often gradually) reorient to address social or environmental problems (Penna and Geels, 2015) if they are stimulated by attractive financial incentives, forced by legislation or pushed by public opinion, especially when scandals (like 'Dieselgate') erode their social legitimacy.

Niche and regime actors operate in wider secular contexts (called 'socio-technical landscapes'), which accommodate both gradual changes (e.g. demographics, political ideologies, macro-economic trends) and shocks (e.g. accidents, oil crises, wars, recessions) (Van Driel and Schot, 2005).

Although transition specifics vary between domains and countries, the general dynamic is that: a) niche innovations gradually build up internal momentum; b) changes at the landscape level create pressure on the system and regime; and c) destabilisation of the regime creates windows of opportunity for niche innovations, which then diffuse and disrupt (parts of) the existing system (Figure 9-6).

Figure 9-6 Multi-level perspective on socio-technical transitions



Source: Substantially adapted from Geels, 2002: 1 263

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2.2 Core processes in different phases of socio-technical transitions

Socio-technical transitions take several decades and can be divided into four phases with different challenges and core activities. For the first phase, the niche development literature distinguishes three core processes (Kemp et al., 1998; Schot and Geels, 2008): a) experimentation and trial-and-error learning about the techno-economic performance, socio-cultural acceptance and political feasibility of radical innovations; b) building of social networks and transformative coalitions of actors who are willing to develop, nurture and protect the innovation; and c) the articulation of positive visions that provide direction for innovation processes and attract wider attention.

While there are presently many sustainability experiments (Sengers et al., 2019), urban projects (Bulkeley et al., 2016), and local grass-roots initiative projects (Pesch et al., 2019), which act as concrete carriers of niche innovations, an important challenge is to 'overcome the current fragmentation of initiatives, and their tendency to remain isolated or short-lived, which ultimately reduces their potential for lasting and wide-ranging change' (Turnheim et al., 2018: 237). In addition, niche innovations initially face other challenges such as being more expensive than existing technologies, the absence of 'ready-made' markets, and social acceptance problems due to unfamiliarity ('liability of newness').

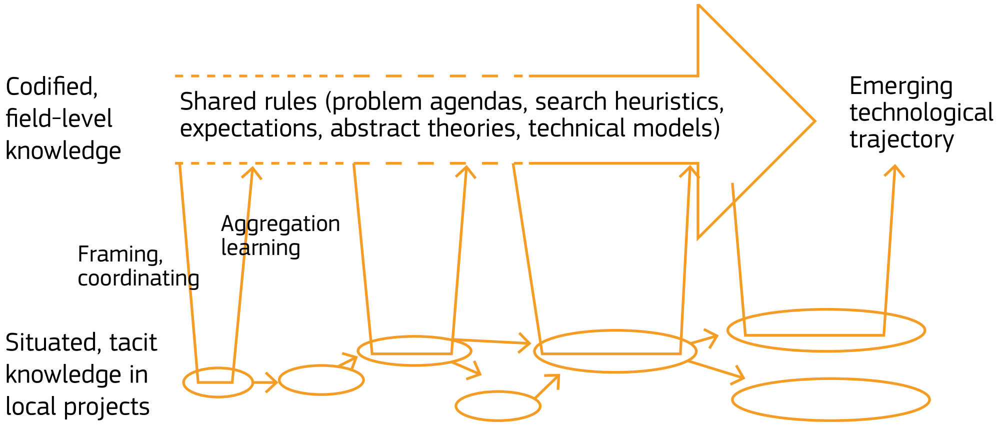
Because grass-roots innovations rely on voluntary commitments, they are also vulnerable to the departure of key champions and a high turnover of volunteers (Hargreaves et al., 2013). Grass-roots innovations may also experience difficulties in securing funding because activists may lack either the professional skills to apply for such funding (e.g. proposal writing, reporting, financial accountability) or the desire to deal with bureaucratic procedures (Hossain, 2018).

In the second phase, niche innovations begin to stabilise because: a) they establish a foothold in small market niches which creates a flow of resources for ongoing innovation activities; b) the articulation of codified design rules, technical models, standards, consumer preferences, and policies, which reduce uncertainties (Geels and Raven, 2006); and c) the creation of communities that share experiences and support dedicated aggregation activities by intermediary actors such as industry associations, engineering communities or innovation agencies (Hargreaves et al., 2013; Kivimaa et al., 2019). These socio-cognitive activities help to gradually stabilise innovation trajectories (Figure 9-7).

Aggregation and cumulative learning among projects may be more difficult for grass-roots movements (GMs) which tend to 'engage in informal learning, mainly due to a lack of intermediary actors. Most GMs do not document their tacit knowledge, such as the institutional learning, skills, and training that their members possess' (Hossain, 2018: 67). The variability and context-specificity of local projects may also complicate the articulation of 'best practice' lessons. And grass-roots activists may resist codification and mainstreaming if this involves the loss of particular values that inspired initial initiatives (Smith, 2012).

In the third phase, the radical innovation diffuses more widely, which includes embedding in various environments (Figure 9-4). *Internal* drivers of diffusion are: a) price/performance improvements, due to learning-by-doing, scale economies, and complementary innovations (Arthur, 1994); b) consumer interest and adoption; c) business investments in production facilities, supply chains, infrastructure; d) policies and institutional change which may shape markets, consumer adoption and business confidence (King and Pearce, 2010); and e) positive cultural discourses which may shape consumer preferences and political support

Figure 9-7 Innovation trajectory emerging from sequences of local projects



Source: Adapted from Geels and Raven, 2006: 379

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(Lounsbury and Glynn, 2001). But diffusion can also be facilitated by *external* landscape developments that destabilise the existing regime (Turnheim and Geels, 2012) and thus create 'windows of opportunity' for diffusing innovations (represented by diverging arrows in Figure 9-6).

The third phase is often full of struggles such as: economic competition between new and existing technologies; business struggles between new entrants and incumbents, which may lead to the downfall or reorientation of existing firms (Christensen, 1997); political conflicts and power struggles over adjustments in subsidies, taxes and regulations (Meadowcroft, 2009); and discursive struggles about problem framing and (dis)advantages of particular innovations and transition pathways (Rosenbloom et al., 2016). There is no guarantee that niche innovations inevitably win these struggles. Radical innovations may fail to build up sufficient endogenous momentum or suffer setbacks. Tensions in existing regimes may be contained, such that windows of opportunity for niche innovations do not (sufficiently) materialise. Or incumbent actors may successfully counter-mobilise and thwart niche innovations (Geels, 2014).

In the fourth phase, the new socio-technical system replaces the old one and becomes institutionalised in regulatory programmes, industry structures, habits of use, views of normality, professional standards, and training programmes. 'Whole system' transitions are not about single technologies (e.g. renewable energy) – they also involve complementary innovations (e.g. smart meters, energy storage), infrastructure adjustment (e.g. smart grids, bidirectional flows), new business models (e.g. capacity markets), and user practices (e.g. demand response, self-generation) (McMeekin et al., 2019).

3. Empirical examples

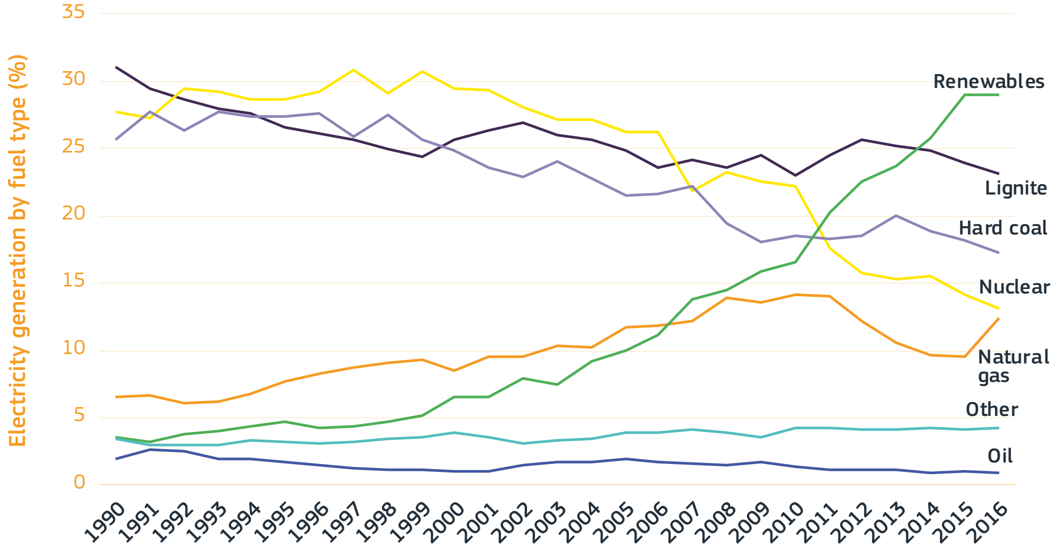
Three brief case studies aim to illustrate the socio-technical transition perspective: the German electricity transition (1986-2016), Austrian biomass district heating systems (1970-2013), and French urban tram systems (1971-2016). The three cases were chosen because they all became linked to grand challenges (e.g. climate change, urban quality of life), had economic growth and export implications, transformed entire systems, involved multiple actors, activities and dimensions (techno-economic, social, political, cultural), and are longitudinal processes that progressed through several phases. Because of their complexity, the case studies are not comprehensive but selectively emphasise parts of the theoretical perspective. The German electricity transition emphasises multi-level interactions, showcasing how niche innovations can disrupt the existing regime in the context of landscape developments and shocks. The Austrian and French cases focus more on the emergence and diffusion of niche innovations, showcasing two different kinds of niche-regime interactions. Although Austrian biomass district heating systems were initially pioneered by new entrants, incumbent regime actors reoriented in later phases and their involvement further accelerated diffusion. French tram systems, in contrast, were developed by incumbent regime actors (transport ministry and railway industry) from the start, and subsequently involved new entrants (particularly cities and entrepreneurial mayors) in local deployment. Both cases emphasise learning processes, knowledge stabilisation, changing visions and social networks.

3.1 German electricity transition (1986-2016)

Electricity from renewable energy technologies (RETs) in Germany increased from 3.6 % in 1990 to 29.0 % in 2016, while nuclear energy and hard coal declined substantially (Figure 9-8). Natural gas increased until 2010, then declined, before bouncing back in 2016, while brown coal declined between 1990-2000 and then fluctuated. This unfolding supply-side energy transition provides a good illustration of the multi-level perspective.

In the first period (1986-1998), niche innovations were nurtured in the context of a stable regime. Wind turbines and solar PV were supported by R&D programmes introduced after the 1970s' oil crises, but deployment remained limited in the 1980s because of poor performance and high costs (Jacobsson and Lauber, 2006). The 1986 Chernobyl accident was a landscape shock that stimulated some deployment of wind turbines by new entrants such as environmentally motivated citizens, farmers, and anti-nuclear activists who wanted to demonstrate the feasibility of alternatives. The accident also created negative public attitudes towards nuclear power, which was supported, however, by successive Conservative-Liberal governments.

Figure 9-8 German electricity generation by source, 1990-2016



Source: AG Energiebilanzen
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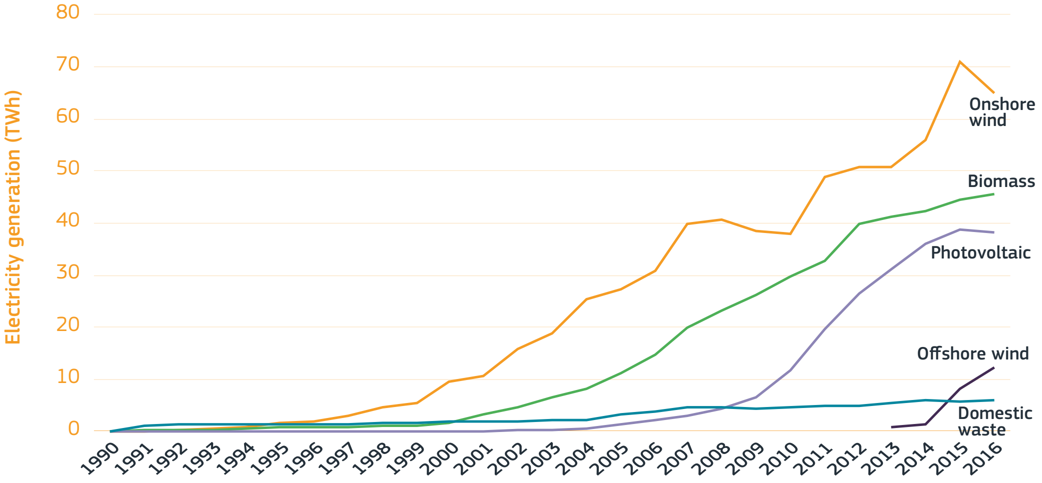
Proposals for RET market support were defeated in parliament, although the 1991 proposal succeed 'by accident' as the government was preoccupied with German reunification (Jacobsson and Lauber, 2006). It was not expected that the resulting Feed-in Law would have major effects and, in 1994, the Environment Minister Angela Merkel thought it unlikely that Germany would ever generate more than 4 % renewable electricity (Lauber and Jacobsson, 2016). However, the Feed-in Law, which obliged utilities to purchase renewable electricity at 90 % of the retail price, made onshore wind deployment economically feasible and stimulated significant deployment in the 1990s (Figure 9-9). The success of German turbine manufacturers (Enercon, Husumer Schiffswerft, Tacke) also attracted industrial policy support in the peripheral regions of Northern Germany, which expanded the RET advocacy coalition (Geels et al., 2016).

To hinder RETs, incumbent utilities lobbied the government which, in 1997, proposed to reduce feed-in tariffs. But public protests by the RET advocacy coalition (including environmental groups, solar and wind associations, metal- and machine workers, farmer groups and church groups) led to the rejection of the proposal by the German parliament and the continued protection of RETs (Jacobsson and Lauber, 2006).

Figure 9-9 Electricity generation from German renewable energy technologies, excluding hydro, 1990-2016



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Source: AG Energiebilanzen

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In the second period (1998-2009), the election of a 'Red-Green' coalition government between the Social Democratic Party and the Green Party (1998-2005) was another landscape shock, which disrupted the cosy regime-level relations between utilities and policymakers (Geels et al., 2016). The new government decided to phase out nuclear energy and support RETs with the Renewable Energy Act (EEG, 2000), which guaranteed fixed, premium payments for renewable electricity over a 20-year period, with tariffs varying with the maturity of the technology.

Renewable electricity subsequently diffused rapidly from 6.6% in 2000 to 15.9% in 2009 (Figure 9-8) because of reinforcing developments in multiple environments:

- In the policy environment, generous and stable feed-in tariffs created attractive market opportunities.
- In the business environment, new entrants (like households, farmers, municipal utilities, project developers and other industries) dominated RET deployment, while the incumbent utilities produced only 6.5% of renewable electricity in 2010 (Figure 9-10). The very rapid diffusion of solar PV after 2006 (Figure 9-9) was unforeseen and driven by feed-in tariffs that far exceeded generation cost as the price of solar PV panels fell rapidly. This stimulated strong interest from households, who deployed small-scale rooftop PV systems, and from farmers, who deployed large-scale roof- and field-mounted systems (Dewald and Truffer, 2011). Solar PV became an industrial success story as total sales for the German PV industry grew from EUR 201 million in 2000 to EUR 7 billion in 2008. Export sales grew from EUR 273 million in 2004 to approximately EUR 5 billion in 2010 (BSW-Solar, 2010).
- In the public domain, broad advocacy coalitions and positive discourses about renewable energy, ecological modernisation and green growth supported and legitimated RET diffusion and policy support (Geels et al., 2016).

Figure 9-10 Ownership of installed capacity of different renewable electricity technologies in Germany in 2010 (%)

	House-holds	Farmers	Banks, funds	Project devel-opers	Municipal utilities	Industry	Four major utilities	Others
Wind	51.5	1.8	15.5	21.3	3.4	2.3	2.1	2.2
Biogas	0.1	71.5	6.2	13.1	3.1	0.1	0.1	5.7
Biomass	2.0	0	3.0	6.9	24.3	41.5	9.6	12.7
Solar PV	39.3	21.2	8.1	8.3	2.6	19.2	0.2	1.1

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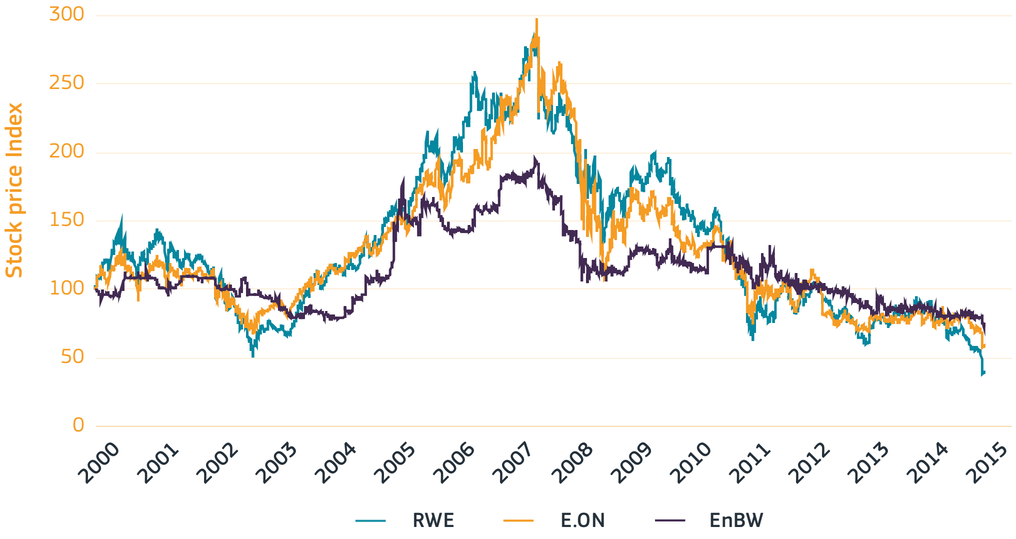
Source: Klaus Novy Institut, 2011
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/partii/chapter9/figure_9-10.xlsx

Instead of addressing renewable energy, incumbent regime actors focused on other issues. In 1998, the liberalisation of the electricity sector triggered a wave of mergers and acquisitions which resulted in the big-four utilities (RWE, E.ON, Vattenfall, EnBW) capturing 90 % of the wholesale market by 2004. By the mid-2000s, the big-4 were investing in new coal- and gas-fired power plants to meet expected growth in demand (Kungl and Geels, 2018). They also focused on European and global expansions, which boosted growth and stock prices (Figure 9-11). After years of lobbying, the utilities also scored a political victory when the newly elected (2009) Conservative-Liberal government decided to overturn the earlier nuclear phase-out decision.

Figure 9-11 Normalised stock price performance of three German utilities



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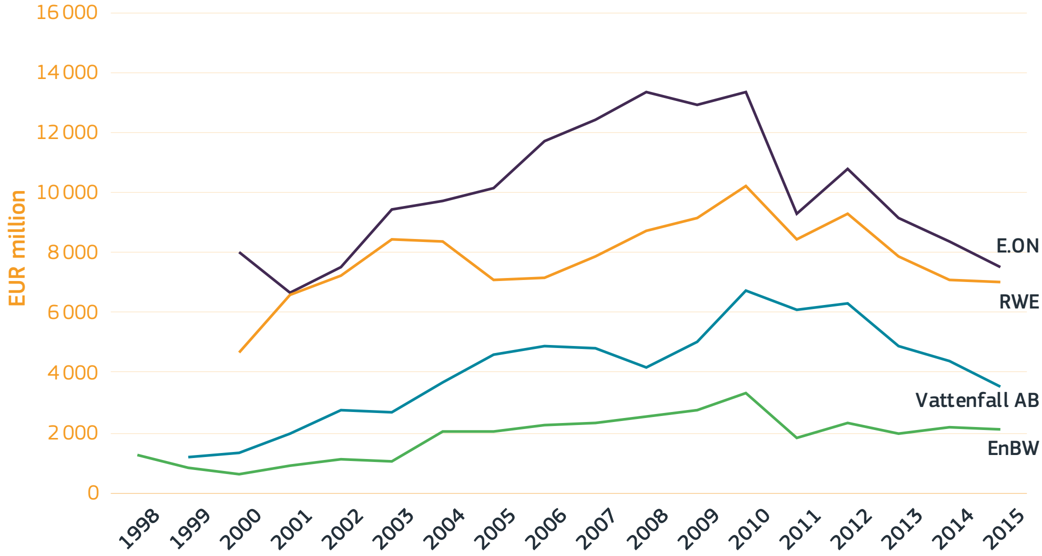
Source: Frankfurt stock exchange www.finanzen.net
Note: Vattenfall is not included in the figure because it is a Swedish state-owned company.
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/partii/chapter9/figure_9-11.xlsx

In the third period (2009-2016), RETs further diffused thanks to feed-in-tariffs, positive discourses and declining RET prices. The price of PV modules, for instance, decreased by more than 65 % between 2007 and 2011 as a result of scale economies in Chinese production, oversupply, and price dumping (Goodrich et al., 2013). RET diffusion was also facilitated by another landscape shock (the 2011 Fukushima accident) which destabilised the regime as the government performed a U-turn and reintroduced the nuclear phase-out, with a target date of 2022. The government also adopted an official energy transition policy (Energiewende) that included ambitious future targets for renewable electricity (35 % by 2020, 40-45 % by 2025, 55-60 % by 2035 and 80 % by 2050).

The existing regime destabilised and experienced various problems during this period (Geels et al., 2016): a) the expansion of renewables reduced the market share of existing fossil plants and decreased wholesale electricity prices because of the 'merit order effect' (solar PV and wind, with low marginal costs, were dispatched first in power generation); b) the aftermath of the financial crisis (another landscape shock) depressed economic activity and reduced electricity demand, which eroded the economic viability of newly built fossil plants; and c) the nuclear phase-out decision implied write-off costs. These developments reduced net incomes of the big-4 utilities after 2011 (Figure 9-12) and created doubts about the viability of traditional business models. Consequently, incumbent utilities began strategic reorientation activities (Kung and Geels, 2018). In 2014, E.ON split into two companies: one focused on renewables, distribution grids and service activities, the other holding conventional assets in large-scale electricity production and trading activities. In 2015, Vattenfall put up its German lignite activities for sale. And in 2015, RWE announced plans to separate its renewables, grid and retail business into a new sub-company.

Figure 9-12 **Net profits of the big-4 utilities in Germany, 1998-2015**



Source: Kungl and Geels, 2018: 79

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/partii/chapter9/figure_9-12.xlsx

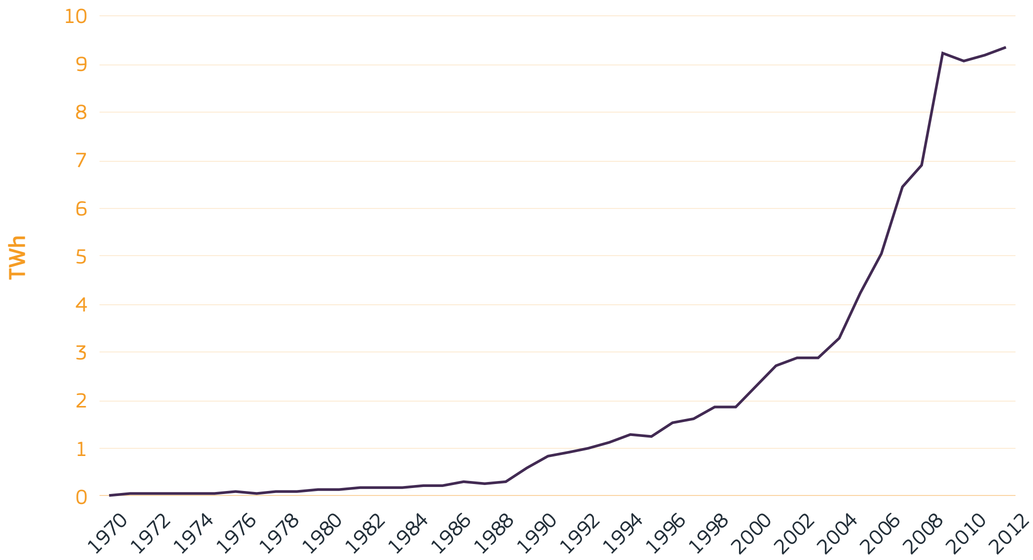
The diffusion of RETs also experienced several unforeseen problems (Geels et al., 2016): a) many German PV manufacturers went bankrupt because of Chinese competition, which eroded the salience of the green growth discourse; b) the deployment of renewables (especially solar PV) increased EEG (Renewable Energy Act) surcharges from 1.3 eurocents/kWh in 2009 to 6.24 eurocents/kWh in 2014, making German retail electricity prices the highest in Europe; c) these increasing surcharges provided ammunition for political opposition from utilities and the Economics Ministry; and d) intermittent renewables threatened grid stability and increased price volatility, leading to negative prices on sunny, windy days when supply exceeded demand.

These RET-related problems and the economic problems of utilities (which were seen as 'too big to fail') led to government efforts to slow RET expansion and increase support for the utilities: a) feed-in tariffs were reduced in several rounds (Hoppmann et al., 2014); b) from 2017 onwards, feed-in tariffs were replaced by a bidding system for target capacity (which required capabilities and resources that suited big players); and c) offshore wind deployment was stimulated, which provided attractive diversification opportunities for incumbents because of size and cost structures.

3.2 Biomass district heating systems in Austria (1970-2013)

Biomass district heating (BMDH) is a complex socio-technical system that uses pellets and waste wood from Austria's abundant forests as input for generating heat in boilers which is then disseminated through piped infrastructures and extracted by heat exchangers in target buildings (houses, schools, hospitals). Austrian BMDH systems emerged in the early 1970s, stabilised and slowly diffused between 1986-2002, and rapidly expanded after 2002 (Figure 9-13).

Figure 9-13 Annual heat production from Austrian BMDH, 1970-2013



Source: Statistik Austria, 2015
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/partii/chapter9/figure_9-13.xlsx

The first period (1970-1986) was characterised by local tinkering with BMDH systems by new entrants such as sawmill owners, carpenters, monasteries and agricultural cooperatives which utilised wood residues and imported boilers (from Sweden) to provide heat services to nearby buildings. Farmers, who often own forests in Austria, teamed up in cooperatives to address high investment costs and to pool resources such as time, skills and fuel (Seiwald, 2014). Installers, operators and local plumbers lacked engineering skills and experience, leading to design mistakes and over-dimensioning in early BMDH systems (Madlener, 2007). In this early niche development phase, plant operators shared little information and were secretive about operational problems. There was limited feedback to technology suppliers and no institutionalised learning or performance evaluation.

The second period (1986-2002) saw slow but steady growth of these small- to medium-scale, village, heat-only system (400 kWth to 1 MWth), enhanced interactions and informal knowledge exchange among BMDH innovators, and increasing interest and support from agricultural policymakers who saw BMDH as a means for regional revitalisation, providing opportunities for alternative incomes in agro-forestry. Provincial energy agencies and the newly created Austrian Biomass Association acted as intermediary organisations which collected and compared local operating experiences, formulated generic lessons and insights and organised workshops to facilitate network building and disseminate more codified knowledge (Geels and Johnson, 2018). Energy agencies in pioneering provinces (Lower Austria, Styria) also provided training and financial support for BMDH developers, assisted by heat-mapping exercises, and advised in BMDH construction via 'technology introduction managers' (Rakos, 1995). BMDH also benefitted from regional innovation policies that supported research and product development in the fields of energy efficiency and renewable energy sources. 'Research and development in energy technology has a long and strong tradition in Austria and has been successful in creating world-class industries, e.g. for small-scale biomass boilers' (IEA, 2014).

Early diffusion in this second period was driven by developments in multiple environments:

- In the business environment, learning-by-doing and dedicated aggregation activities gradually reduced operational problems and improved techno-economic performance. Dedicated supply chains for biomass, pellet boilers and prefabricated heat pipes emerged in the 1990s (Kalt and Kranzl, 2009) which, in turn, stimulated specialisation and innovation.

- In the user environment, local residents began to switch to BMDH, which was slightly more expensive than traditional stoves (that burned biomass, coal or oil) but offered greater comfort and convenience, e.g. continuous heat without smoke emissions and no need for storage space and manual handling of fuel (Seiwald, 2014). The switch to BMDH required few adjustments in user skills and routines, although consumers did experience some difficulties in understanding the bills for heat services, particularly the addition of service charges (for recovery of fixed costs, maintenance and metering) besides consumption-based charges (Metschina, 2014). To stimulate use among local farmers, municipalities also began to adopt BMDH to heat public buildings, such as schools, town halls, hospitals and swimming pools.

- In the policy environment, in the early 1990s, the federal Ministry of Agriculture started to complement provincial BMDH support which led to subsidies and capital grants that could amount to 60% of investment costs (Geels and Johnson, 2018). This reduced the commercial risks for BMDH system builders and operators. From the mid-1990s, the Environmental Promotion Fund also provided support for BMDH.

- While narratives in the public sphere initially framed BMDH as a potential response to rural problems (e.g. unemployment, declining industrial base and depopulation), these were complemented in the mid-1990s by discourses that were portrayed as a response to climate change.

In the third period (2002-2013), diffusion accelerated as two other technical configurations also gained momentum (Seiwald, 2014): a) large-scale BMDH-CHP plants (between 10-65 MWth), which produced both heat and power and were operated by incumbent organisations like energy utilities; and b) small-scale micro-grids (between 100-400 kWth), which provided heat for a limited number of closely situated buildings and were often operated by energy service companies (ESCos) that pioneered new business models like energy service contracting[1]. The following developments assisted rapid diffusion:

- In the user environment, housing associations, hotels and public-building operators became interested in micro-grids because of their operational ease and cost-effectiveness, while large-scale BMDH-CHP plants mainly focused on electricity production to the grid.

- In the business environment, incumbent actors from the electricity regime reoriented to BMDH-CHP because the Green Electricity Act (2002) established an attractive feed-in tariff for electricity generated from biomass CHP. The involvement of incumbent organisations advanced BMDH diffusion by making available greater financial resources and more profound technical and operational capabilities. BMDH diffusion stimulated complementary innovations in biomass collection and processing, prefabricated heat pipes (which reduced infrastructure installation costs and increased system efficiencies) and pellet boilers (which became easier to handle and more fuel-efficient). The creation of specialised clusters and supply chains made Austrian manufacturers world-leading exporters of pellet boilers (Geels and Johnson, 2018). Business opposition came from chimney cleaners and coal dealers whose jobs were threatened, and from natural gas suppliers who also wanted to expand into rural areas, giving rise to 'significant conflicts between agricultural lobbies and the gas industry' (Rakos, 1995: 879).

- In the policy environment, BMDH continued to benefit from support policies, such as the Green Electricity Act (2002), the CHP Law (2009), and the Law for the Expansion of District Heating and Cooling Networks (2009). From the mid-2000s, BMDH also became part of wider biomass strategies (such as the 2006 Biomass Action Plan and the 2010 Austrian Energy Strategy 2020), which emphasised energy self-sufficiency, sustainability, green growth, and export opportunities for Austria's world-leading biomass energy systems (Geels and Johnson, 2018).

- Ongoing policy support in this period was legitimated by public discourses that combined environmental benefits and economic goals through notions such as self-sufficient 'energy regions' and the inclusion of BMDH in national biomass strategies which emphasised energy autarky, green growth and exports. The Federal Minister

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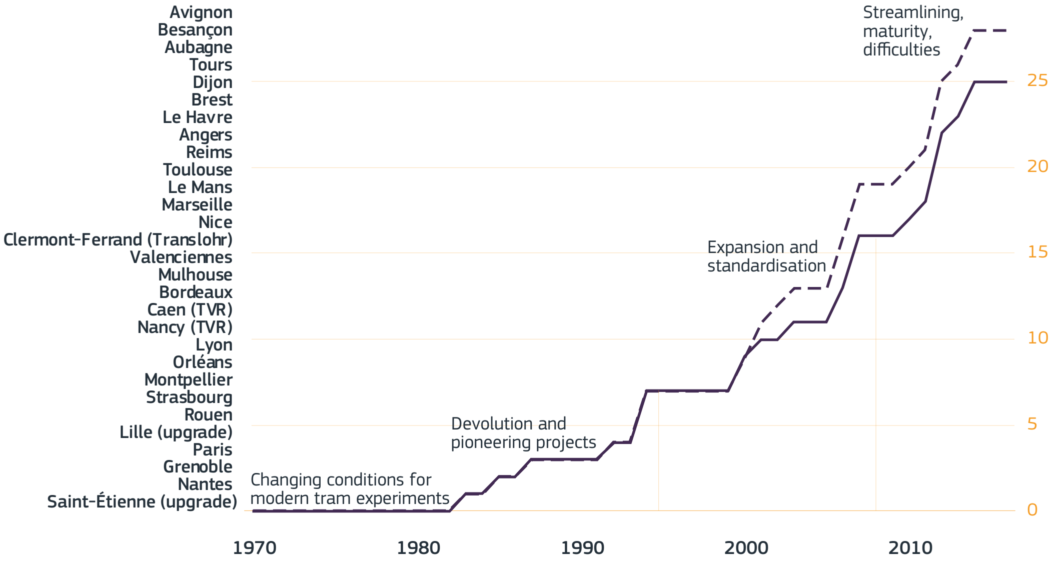
[1] In energy service contracts, customers pay a monthly rate for the provision of heat (and electricity), leaving the construction and operation of biomass plants, located on the client's premises, to ESCos.

for Agriculture, Forestry, Environment and Water Management supported this vision in the preface to a Bio-Energy Report: 'We can produce in Austria, on balance, as much energy from domestic, renewable sources as we consume by ourselves. This makes us independent from expensive, fossil energy imports such as oil and gas and brings about a boom in the economy as well as positive employment effects with new green jobs' (Austrian Energy Agency, 2012, p. 2).

3.3 Urban tram systems in France (1971-2016)

Trams were widely used in the first half of the 20th century but disappeared from many European cities in the 1950s and 1960s to make way for motorised transport. From the 1970s onwards, however, they made a comeback which was particularly strong in France where tram systems spread to 15 out of 19 cities of more than 300 000 inhabitants and, in some instances, to cities with fewer than 200 000 inhabitants (Figure 9-14). For larger cities (over 400 000 inhabitants) penetration reached 27 %, 53 % and 80 % by 1994, 2001 and 2010, respectively.

Figure 9-14 Modern tramway diffusion in French cities (solid line: tramways; dotted line: tramways and rubber-tyred tramways)

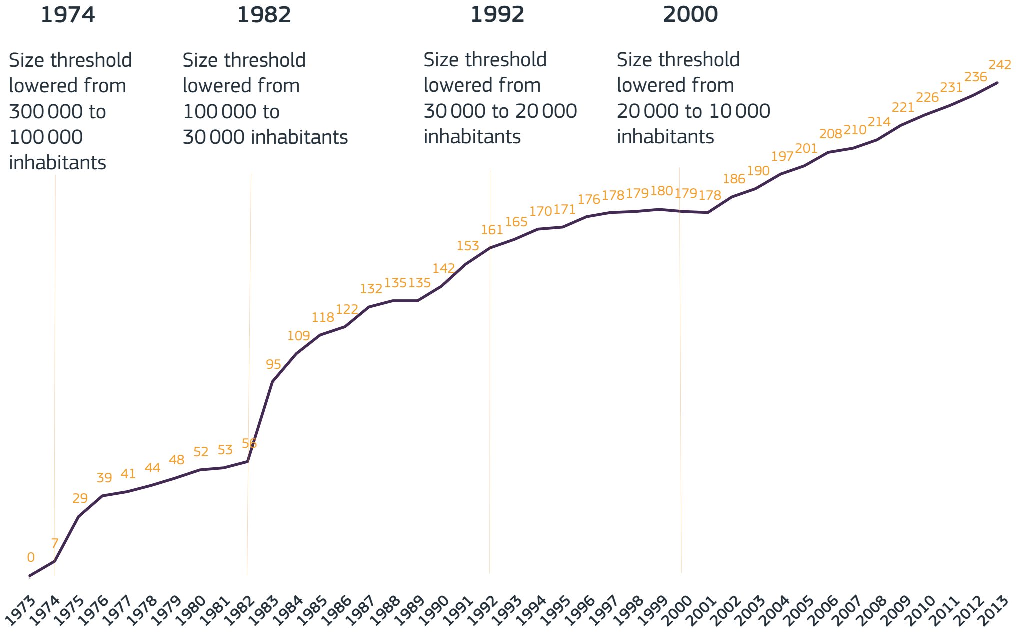


Source: CERTU, 2013

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/partii/chapter9/figure_9-14.xlsx

Because urban tram systems are expensive infrastructure projects, they often involve lengthy planning and design periods before actual construction. In the first period (1971-1983), the success of high-speed railways (TGV) and concerns about urban congestion and car accidents led policymakers to prepare the ground for tram systems. In 1971, they introduced the 'versement transport' financing instrument which raised employment tax locally to pay for large public transport schemes. First introduced in Paris as support for metro-like schemes, it was gradually extended to smaller cities (Figure 9-15) and used to support tram systems.

Figure 9-15 Evolution of French municipalities collecting local transport tax, 1973-2013



Source: GART, 2015
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/partii/chapter9/figure_9-15.xlsx

The early support coalition for trams comprised incumbent actors with congruent motivations and skills (Turnheim and Geels, 2019): a) the Transport Ministry saw trams as a means of addressing local transport problems and industrial exports; b) the railway industry (GEC Alsthom) saw trams as a diversification opportunity, using its technological skills to enter new markets; and c) the national rail operator (SNCF) wanted to use its network management skills to enter the urban public transport market. In 1974, Transport Minister Marcel Cavaillé set up a working group with members of this coalition which coordinated R&D programmes and developed a top-down vision of rail-based, public transport as a radical solution to transform urban transport systems. The 1975 Cavaillé Circulaire called on eight cities to explore this vision and test new tram technologies with on-the-ground projects, funded through versement transport. This created space for the newly elected Socialist mayors (in Nantes, Strasbourg and Grenoble) to advance radical new transport ideas for their cities which, in the late 1970s, led to more detailed design and planning studies.

In the second period (1985-1995), pioneering tram projects were stimulated by 'landscape' developments such as Mitterrand's 1981 election, which led to stronger strategic state intervention and the devolution of planning powers to cities (through the 1982 Gaston Defferre laws), including public transport responsibilities and resources (through the 1982 domestic transport guidance law, LOTI). Local tram projects promoted by city mayors were also enabled by planning and design support from technical bureaucracies and generous public funding, ranging from between 15 % and 40 % of capital costs in this period (ACUF, 2007), which was legitimated by high-level visions and a modernist and patriotic discourse about high-tech industrial achievement (Turnheim and Geels, 2019).

In 1985, Nantes opened the first modern tramway system which established technical and commercial viability of the new designs (based on adaptations of existing rail-industry knowledge). Learning from the Nantes project (which encountered some local opposition during construction), Grenoble's tramway system, opened in 1987, included compensation for local businesses, low-floor carriages for better accessibility for disabled users, and full pedestrianisation of a segment crossing the urban centre (Laisney, 2011). The Strasbourg project was designed in 1985, revoked in 1988, and reintroduced in 1989 by the incoming Socialist mayor who framed it as a civilisation battle to reconquer public space from cars (Laisney, 2011). Opened in 1994, the system had low-floor carriages, bay windows, a hyper-futurist design and was developed to act as a public transport backbone with park-and-ride facilities and buses acting as feeders/extensions.

Lessons from one project fed into the next, and knowledge gradually stabilised as technical bodies, research centres and government-affiliated technical services (including the 'technical committee for the standard French tram', established in 1982) acted as intermediary organisations that aggregated, standardised and codified technical knowledge (Hamman, 2015).

Trams spread rapidly in the third period (1995-2008) as the success of Strasbourg led to a flurry of new tram projects, both in large cities (Lyon, Bordeaux, Marseille) and smaller ones (Figure 9-16). Central government funding became more codified via 1994 and 2001 'guidance circulars' which specified evaluation criteria (including social and security objectives) and institutionalised technical expertise. CERTU (the assessment centre on networks, transport and public works) and governmental technical services delivered technical manuals, evaluation guidelines, technical notes and travel observatories that further stabilised tram design and operational features (Hamman, 2015).

Figure 9-16 Adoption of modern tramways by French cities (excluding Paris) according to urban area population

Science, research and innovation performance of the EU 2020

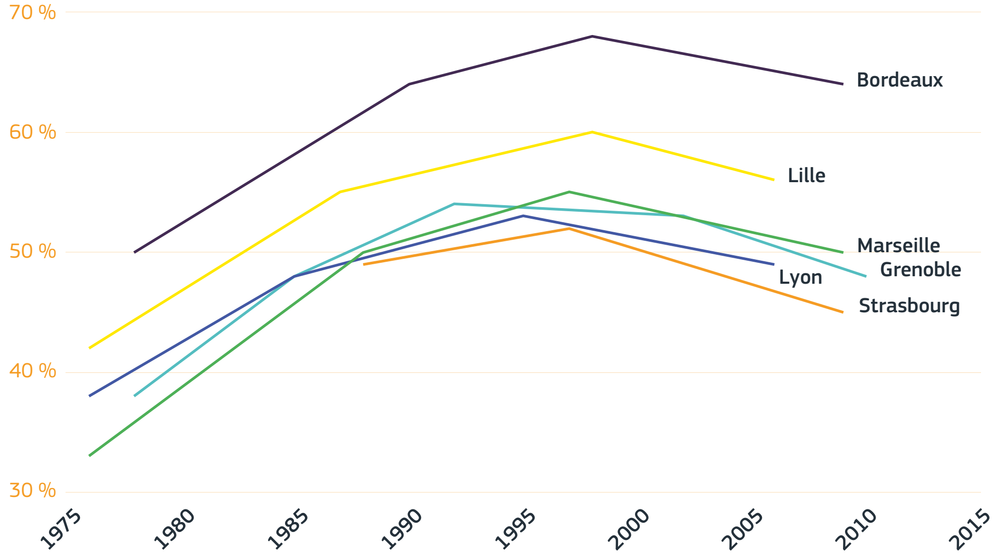
Source: CERTU, 2013
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/partii/chapter9/figure_9-16.xlsx

In the policy environment, strategic mobility plans (plans de déplacements urbains, PDU) became mandatory (requiring cities to develop alternatives to cars) and increasingly linked to energy and air-pollution measures. Local policymakers increasingly embraced trams as vehicles for urban marketing, promoting 'emerging' urban areas (often for business and tourism attractiveness) and projecting a modern city image (Kaminagai, 2014). In 2003, central government funding for light rail was reduced, which delayed several projects and increased reliance on loans and cross-financing (Turnheim and Geels, 2019).

Lighter top-down government influence (e.g. reduced funding) increased dynamics in the business environment, as Alstom faced competition from consultancy and engineering companies, while SNCF increasingly competed with other local transport service operators (Keolis, Connex/Veolia Transport, RATP).

Users also enthusiastically embraced trams, although lengthy construction projects sometimes encountered local opposition. From the late 1990s, increasing tram use led to declining car use in various French cities (Figure 9-17).

Figure 9-17 Evolution of car use (percentage of journeys) in selected French cities with tramways



Science, research and innovation performance of the EU 2020

Source: CERTU, 2013

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/partii/chapter9/figure_9-17.xlsx

The public discourse also changed during this period, as tram debates moved beyond transport-specific considerations and became linked to wider issues such as urban transformation, quality of life and environmental problems. Thus, tram visions took on new meanings that aligned with emerging norms and values (e.g. access, sustainability, liveability, urban renewal) which broadened the attractiveness of trams and helped to build a broad discourse coalition, so that trams became 'irresistible' for mayors of medium and large cities (Hamman, 2015).

In the fourth period (2008-2016), trams became further linked to environmental objectives as the 2007 'Grenelle Environment' (a multi-party debate between government, local authorities, trade unions, business and voluntary sectors) committed, amongst others, to building more urban light-rail projects. In 2008, although the government increased central funding again, the money was spread thinly over more projects, new tram designs aimed at streamlining and cost-cutting.

Motivations for tram projects became highly convergent, emphasising 'urban sustainable development and environmental preservation, renewal or requalification of urban space, mature technology, positive effects on job creation' (Pissaloux and Ducol, 2016: 183). French tram manufacturers (e.g. Alstom), operators (e.g. Keolis, Transdev, RATP) and engineering firms (Vinci, Bouygues) increasingly turned to export markets, building on earlier experiences: 'the building consultants, the transport operators and the designers intervene in response to a growing number of cities in the world, on the base of the references created in the French cities' (Kaminagai, 2014: 62).

4. Conclusions and policy recommendations

4.1 Socio-technical transitions

The three examples have demonstrated that socio-technical transitions are longitudinal processes which progress through phases with different activities and causal mechanisms. The radical innovations emerged in sheltered niches, but their transformative effects were not realised until they were diffused more widely, which (inevitably) takes time and involves embedding processes in business, policy, user and cultural environments. The German electricity transition most clearly also involved landscape developments (e.g. 1998 election, Chernobyl and Fukushima accidents, financial-economic crises) and regime disruption, which was only briefly addressed in the other two cases (e.g. disruption of Austrian chimney cleaners and coal dealers, and a decline in car use in French cities).

All three cases also involved multiple actors and dimensions, which demonstrates that socio-technical transitions are not just about universities, firms and markets (as in innovation system approaches), but are also about households, cities, communities, NGOs and the wider public. In all three cases, radical innovations became linked to grand challenges (particularly climate change and quality of life), although this alignment was often strengthened in later phases as visions became broader and combined multiple issues (a pattern called 'issue linkage'). Furthermore, the cases illustrate socio-technical transitions are non-linear processes, characterised by surprises, unintended consequences, setbacks and twists and turns, which means that transformative effects are difficult to predict correctly. All three cases also showed that environmentally oriented socio-technical transitions can have positive economic and export effects, which substantiates the suggestion from the Commission's expert group on green growth and jobs, cited in the introduction. The German case, however, shows that positive green growth effects may be eroded when competitors, such as Chinese manufacturers, successfully enter the new economic domain.

4.2 Five policy challenges in the case studies

The five policy challenges mentioned in the introduction also played out in all three cases, although in different ways.

Horizontal policy coordination. Although innovation policy (particularly R&D support, demonstration projects and knowledge aggregation) was important in all three cases, sector-specific policies (energy, agricultural, transport, environmental) were also clearly relevant, especially for deployment and diffusion:

- In the German energy transition, R&D support and demonstration projects helped to create technological niches for wind and solar PV in the 1980s and 1990s. But renewable energy policy (particularly feed-in tariffs) was crucial to create market niches and drive subsequent diffusion. Responsibility for renewable energy policy changed from the Ministry of Economic Affairs to the Ministry for Environmental Affairs in 2002 and back again in 2014, which suggests that horizontal coordination may involve turf battles between ministries.

- In the Austrian BMDH transition, innovation policy helped to generate knowledge and improve techno-economic performance in the 1980s and 1990s. But other policy domains were also important: agricultural policy provided financial support to BMDH operators, which reduced investment risks and facilitated learning-by-doing (especially in the early phases); environmental and climate policy subsidised green innovations (like BMDH); regional energy policy (especially provincial energy agencies) helped with knowledge aggregation, codification and dissemination (in the early phases), while federal energy policy stimulated the reorientation of energy utilities through the CHP feed-in tariff (in the later phases); and economic and industrial policy stimulated energy clusters, green growth and exports (in the later phases).

- Innovation policy was crucial for the development of French tram designs, by stimulating R&D, technical learning, and codification. However, transport policy, environmental policy and industrial policy also supported the development and deployment of tram systems.

Social, business model and infrastructural innovation. While technological innovation was crucial in all three cases, other forms of innovation were also important:

- Community energy (particularly collectively owned wind turbines) was an important social innovation which made citizens and communities active participants in Germany's energy transition. In the later phases, the diffusion of intermittent renewables (wind, solar PV) also required infrastructural innovations, such as grid extensions, smart grids, back-up capacity and energy storage.
- Infrastructural innovation was central to the Austrian BMDH transition involved, which policymakers stimulated by providing financial support (e.g. capital grants) that reduced investment risks. It also involved business model innovation (e.g. energy service companies) and some social innovation (shift towards heating services), which were mostly left to the market.
- French tram systems involved the building of new infrastructures, but also had wider transformative effects as cities started to close off city centres to cars and to align pedestrianised areas with tram systems. The modal shift from cars to trams (and buses) also constituted important social innovations.

Wider set of actors and coalitions. All three cases involved wider sets of actors than the 'upstream' groups (universities, research centres, firms) that are central to innovation system approaches, although their roles vary:

- The German energy transition was mainly driven by new entrants like households, farmers, municipal utilities and project developers which, together with environmental groups, solar and wind associations, metal- and machine workers, farmer groups and church groups, formed a powerful advocacy coalition lobbying for stronger support policies. In addition, the traditional regime-level coalition between utilities and the government was disrupted by the election of a Red-Green government (1998-2005) which introduced EEG support and nuclear phase-out policies that had an unfavourable effect on the big-4 utilities.
- The Austrian BMDH transition was also pioneered by new entrants (e.g. woodworkers, farmers) without dedicated policy support during the first period. In the second and third periods, these new entrants were supported by various policies that enabled the building of green clusters and energy regions. In the third period, incumbent actors like energy

utilities reoriented and also became involved, focusing particularly on large-scale BMDH-CHP systems which were supported by attractive feed-in tariffs. Over time, the actor coalition expanded to include domestic boiler manufacturers, installers, municipalities, farmers, energy service companies and various kinds of users (households, housing associations, hotels and public-building operators).

- In contrast to the other two cases, French tram systems were pioneered by incumbent regime actors (railway companies, national rail operator, the Transport Ministry, and technical services), although new entrants (cities, mayors) were also important for local implementation and on-the-ground learning, which led to cumulative design improvements. Over time, the actor coalition widened to include consultancy and engineering companies, other local transport service operators, citizens, and advocates of various societal issues (environment, climate change, air pollution, congestion and safety).

Visions and missions to create drive and directionality. Future visions were important in all three cases, but they evolved during the transitions as actors learned more about technical performance and functionalities and as more actors (with different concerns) joined the advocacy coalitions. The alignment with grand challenges often became more pertinent in the later phases of transition, rather than driving them from the start, although the cases do vary.

- In the German energy transition, visions in the 1980s and 1990s were inspired by anti-nuclear and pro-renewable sentiments, but federal policy support occurred mainly ‘by accident’. The Red-Green government coalition (1998-2005) did develop a long-term vision which anticipated that wind and solar PV innovations could become economically viable in the 2020s (through scale economies and learning-by-doing processes) if sufficiently nurtured, which led to the 2000 EEG support policy. The energy transition mission (with ambitious targets and explicitly linked to climate change) did not emerge until 2011, in the context of a landscape shock (Fukushima), the nuclear phase-out decision, strong RET-growth and a broad-based advocacy coalition.
- Visions of Austrian BMDH also evolved as the transition unfolded. In the mid-1980s, BMDH was seen as a means for local economic development and the revitalisation of rural areas. By the mid-1990s, environmental and climate change benefits were also being emphasised. And by the mid-2000s, BMDH became part of wider plans and strategies through its inclusion in the 2006 Biomass Action Plan and 2010 Austrian Energy Strategy 2020. This linking of BMDH to multiple policy goals (agricultural, environmental, economic) helped to create legitimacy and wider advocacy coalitions that underpinned continued policy support.
- French tram development was driven from the start by a dedicated, top-down vision, formulated by the Transport Ministry and railway industry, and motivated by specific concerns about local transport problems (noise, air pollution, parking, accidents) and export potential. The vision broadened over time and became linked to quality-of-life issues, climate change, and deeper urban reconfiguration (closing off city centres to cars, pedestrianisation, etc.).

Diffusion. In all three cases, the dissemination of radical innovations beyond initial niches required not only innovation policy (which remained important for performance improvement, cost reduction, knowledge development and stabilisation), but also sectoral policies (e.g. energy, agriculture, transport), as described above under horizontal policy coordination. Therefore, the cases support the suggestion in the Commission's recent BOHEMIA report: 'Conditions for uptake of new solutions (...) are often defined by sectoral policies (e.g. regulation, standards, procurement), and it is through alignment between sectoral and R&I policies that change can be accelerated' (EC, 2018c: 30). All three cases also demonstrate that diffusion involves processes in business, policy, cultural and user environments. The latter, however, was not discussed in depth, which may be due to the characteristics of the cases, two of which were about infrastructure systems and one concerned supply-side electricity generation. Diffusion in all three cases was stimulated by: a) dedicated financial instruments that reduced business investment risks; b) positive discourses and visions (discussed above) that legitimised policy support; and c) cross-ministerial alliances and high-level political support (often from ministers).

- RET-diffusion in Germany's energy transition was stimulated by: a) stable and attractive feed-in tariffs because guaranteed minimum payments for 20 years reduced investment risks for new entrants; b) positive green growth discourses; c) broad-based advocacy coalitions; and d) top-level political support (from Chancellor Merkel after 2011) which has weakened, however, in recent years because of concerns over rising costs and the disruption of incumbent utilities.

- The diffusion of Austrian BMDH was stimulated by: a) knowledge aggregation, codification and dissemination activities that stabilised the innovation and reduced uncertainties; b) capital grants that reduced investment risks, which are often substantial for infrastructure systems like BMDH; c) financial incentives (e.g. feed-in tariffs) that created attractive market conditions for company involvement; and d) broadening visions and support coalitions.

- French tram diffusion was driven by: a) new financing instruments (like versement transport) which reduced investment risks; b) planning and design support from technical bureaucracies; c) political support from local mayors (as trams demonstrated their capacity to support electoral wins) and the Transport Minister Cavaillé; d) positive visions and discourses; and e) a broad-based support coalition with growing export success.

4.3 Messages for transformative innovation policy

Instruments from all three innovation policy frames (Figure 9-1) are important for transformative innovation and socio-technical transitions and should be strengthened to address grand challenges. In addition to the well-known instruments from the first two policy frames, the following policy messages summarise important avenues for transformative innovation policy which include, and go beyond, the five policy challenges discussed above.

Emergence of radical innovations

- Support a wide range of sustainability innovations, not just technological but also social, infrastructural and business model innovations (Figure 9-3).

- Support more real-world experiments, pilots, demonstration projects and living labs, which move innovations beyond the R&D phase and enable open-ended learning with multiple stakeholders about technical performance, market uptake, social acceptance and environmental impacts.

- Build transformative innovation coalitions which not only include ‘traditional’ actors (universities, research centres, firms), but also new entrants (NGOs, cities, startups, pioneers) that are willing to challenge conventional wisdom and to think ‘out of the box’.

- Nurture new market creation (e.g. through subsidies, public procurement, feed-in tariffs) and new business models so that radical innovations can become economically viable.

Diffusion

- Insights and findings from local projects and experiments should be shared, compared, aggregated, codified and disseminated, which could be done by intermediary actors such as innovation or implementation agencies.

- Research, development and innovation policy can help improve price/performance characteristics of innovations, which stimulate diffusion.

- Adoption by consumers can be stimulated with targeted financial instruments (purchase subsidies, low-interest loans, tax exemptions), information provision (media campaigns, labels, celebrity endorsements) and adjustments in economic framework conditions.

- Uptake of innovations in businesses can be supported with financial instruments that reduce investment risks (e.g. interest-free loans, capital grants, investment subsidies), regulations (e.g. renewable energy obligations for utilities, electric-vehicle sales targets for automakers, environmental standards for home builders), and public infrastructure investment.

- Policymakers can support the social acceptance of innovations by developing positive visions and debates and by involving societal groups through public participation.

Disruption and system reconfiguration

- Reconfiguring entire systems should go beyond technological ‘silver bullets’ and promote synergies among multiple innovations.

- Since transitions are full of surprises, non-linearities and unintended consequences, adaptive governance approaches are recommended, based on iterative cycles of policymaking and planning, implementing, evaluating and learning.

- To mitigate potential resistance from incumbent firms, policymakers could assist them in strategic reorientation processes or provide compensation (e.g. sunset clauses).

Cross-cutting policy recommendations

- Horizontal coordination between policy domains (innovation, transport, energy, industry, education, skills) is important, especially in the later phases.

- Meeting the large investment needs for diffusion and infrastructure change will require policies that change market incentives, reduce risks and uncertainties, and incentivise private investment, as well as more fundamental reforms of the financial system.

- Long-term change and directing innovative trajectories towards grand challenges should be promoted through ambitious visions, missions and targets.

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CHAPTER
10

THE BOTTOM ALSO MATTERS: POLICIES FOR PRODUCTIVITY CATCH-UP IN THE DIGITAL ECONOMY

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Summary

Research into the slowdown in global productivity has brought to the forefront of the policy debate the importance of understanding the nature of firm-level productivity developments. This has become particularly relevant following evidence showing a significant increase in the productivity gap between highly productive firms and the rest of businesses within the same industries since the 2000s. This diverging trend in productivity performance would eventually lead to broader social implications in terms of wage inequality and inclusiveness.

This chapter provides an overview of recent and ongoing analysis of these issues and discusses policies that affect the catch-up by laggards in the context of the digital transformation. First, it introduces productivity divergence in the context of the global phenomenon linked to digital transformation and the knowledge economy. Later, it examines trends in productivity divergence and business dynamism, respectively, with a focus on the bottom of the productivity distribution. Beyond common trends, a few examples highlight cross-country and cross-sector heterogeneity. The descriptive sections conclude with firm and sector characteristics and discussions about possible explanations behind the documented trends at the bottom, including the role of openness. The final analytical section provides a framework and summarises the main results of the analysis of the role of policies on the speed of catch-up by laggards.

1. Introduction

The productivity gap between successful firms and the rest of businesses within the same industries has been increasing since the 2000s across OECD countries (Andrews, Criscuolo and Gal, 2016; Berlingieri, Blanchenay and Criscuolo, 2017). Productivity developments at the firm level point to impediments to technology diffusion from the productivity frontier to the rest of the distribution, with too many firms stuck at the bottom – the so-called 'laggards'. The evidence suggests that the increase in the productivity gap has come mainly from the bottom half of the distribution, where the distance in terms of performance between the very bottom and the median firm has increased more over time than at the top of the distribution (Berlingieri, Blanchenay and Criscuolo, 2017). Yet, this does not imply that the left tail of the productivity distribution only includes zombie firms that survive due to weak market selection. Rather, the evidence shows that a substantial share of low-productivity firms are businesses at an early stage of their development and operating below their efficiency level (Berlingieri, Calligaris, Criscuolo and Verlhac, 2019). While allowing for the exit of zombie firms, efficient bankruptcy legislation is key; a dynamic business environment with productivity-enhancing creative destruction is key to enabling these young, small and dynamic firms to achieve their growth potential.

Importantly, the productivity divergence seems to be larger in sectors providing information and communication technology services (e.g. computer programming, software engineering and data processing) and in industries that are intensive in intangible assets (e.g. data, proprietary software, human and organisational capital). The increasing potential of digital technologies to create global winner-takes-most dynamics might have helped frontier firms to increase their performance disproportionally more than laggards within these industries (Criscuolo, 2019) and gain larger market share (Andrews et al., 2016, and Bajgar et al., 2019). Ongoing OECD work suggests that intangible assets are associated with productivity dispersion through their complementarity with digital technologies, and that the effect arises from laggards' worsening productivity performance vis-à-vis the median firm (Berlingieri, Corrado, Criscuolo, Haskel, Himbert and Iona Lasinio, 2019). Intangible assets are also linked to increased concentration, especially in sectors that are open and digital intensive (Bajgar, Criscuolo and Timmis, 2019). The rise of the intangible economy exacerbates productivity dispersion, as laggards may not be able to afford and finance the necessary intangible investments to reap the benefits of technological change (Berlingieri et al., 2019).

This chapter provides an overview of recent and ongoing analysis on these issues and discusses policies that affect the catch-up of laggards in the context of the digital transformation. It is organised as follows: section 2 briefly puts the productivity divergence in the context of other manifestations of the same multifaceted global phenomenon linked to digital transformation and the knowledge economy. Sections 3 and 4 document trends in productivity divergence and business dynamism, respectively, with a focus on the bottom of the productivity distribution. Beyond common trends, a few examples highlight cross-country and cross-sector heterogeneity. Section 5 identifies firm and sector characteristics that may explain the documented trends at the bottom, including the role of openness. Section 6 provides a framework and summarises the main results of the analysis on the role of policies on laggards' rate of catch-up. Section 7 concludes with a policy discussion.

2. A multifaceted phenomenon

The global productivity slowdown has brought to the forefront of the policy debate the importance of understanding the nature of firm-level productivity developments. Recent OECD research has documented the significant increase in the productivity gap between successful firms and the rest of businesses within the same industries since the 2000s, both at the global level and within countries. The divergence in productivity performance has implications in terms of wage inequality and inclusiveness. Indeed, increases in wage inequality and in productivity dispersion are linked. Therefore, policy responses to the increasing productivity divergence could potentially produce a 'double dividend' in terms of both greater productivity growth and reduced income inequality (see Criscuolo, 2018 and references therein). Importantly, productivity policies need to account for local and sectoral specificities as countries and industries have experienced heterogeneous productivity and wage developments beyond well-established common trends (Box 10-1).

Productivity divergence is observed in the context of ongoing digital transformation that radically alters the way firms produce, upscale and compete. In particular, digital technologies may affect the two microeconomic processes that shape aggregate productivity trends. First, they impact within-firm productivity growth, thanks to the efficiency gain that firms can achieve by adopting digital technologies and enhancing their innovation capabilities – if they have the necessary complementary

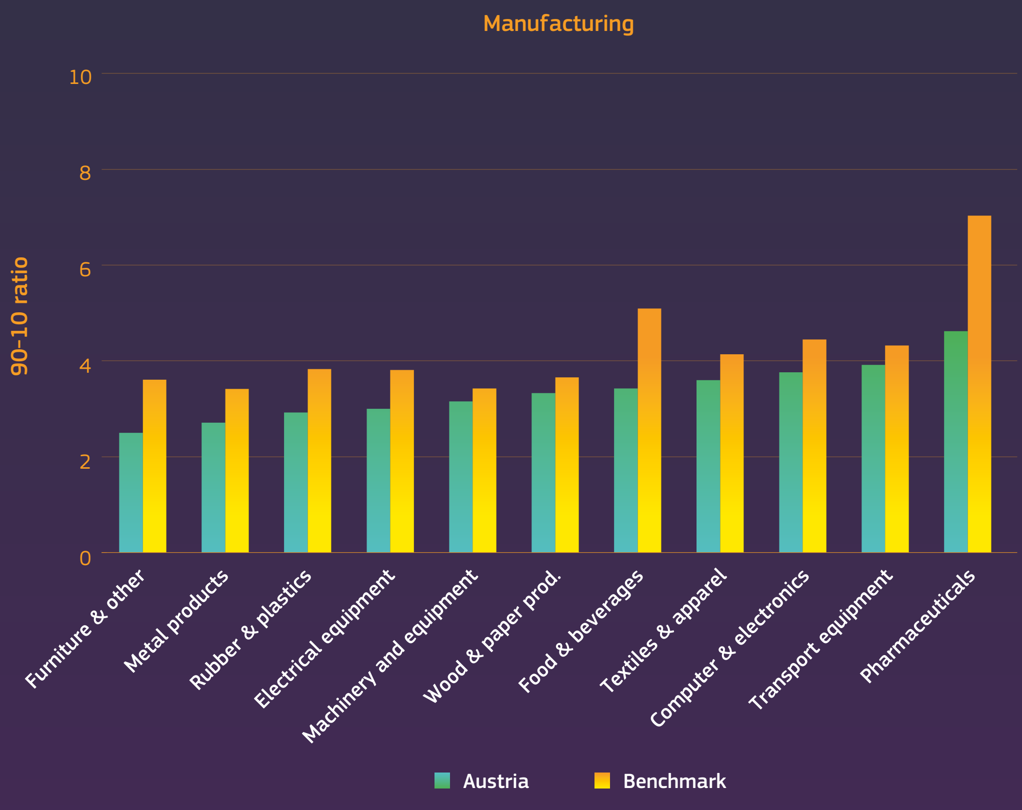
BOX 10-1 Heterogeneity in productivity developments across countries and sectors

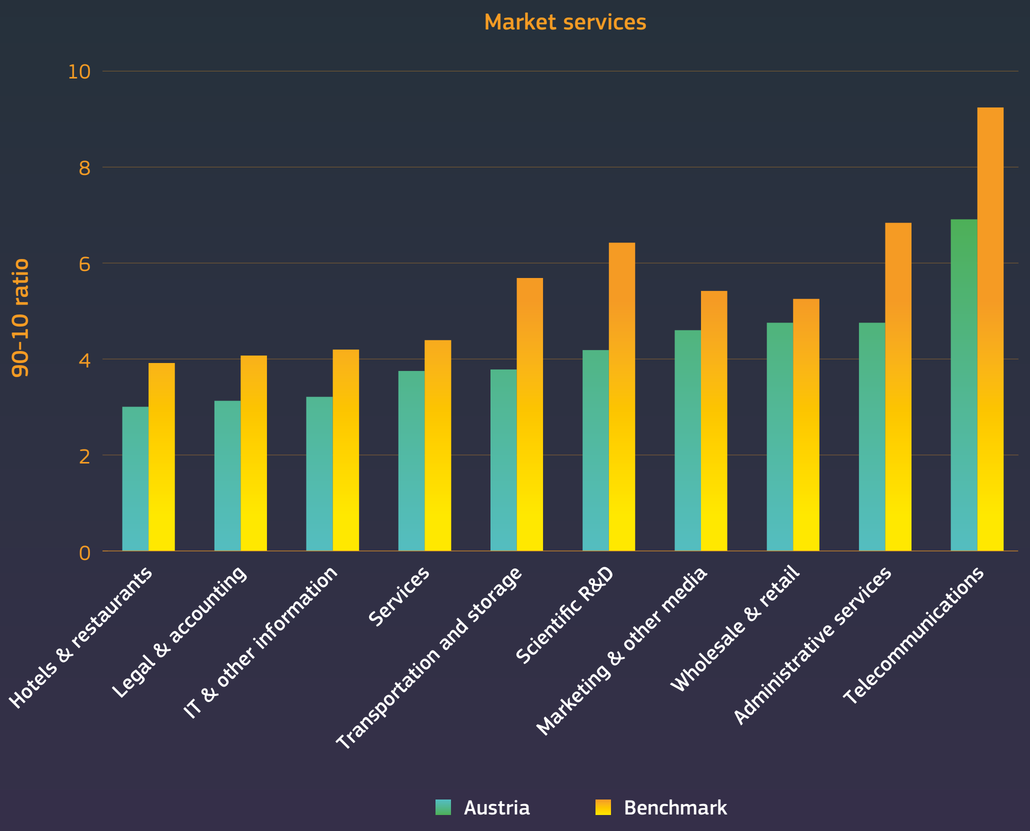
Recent OECD research has documented common trends in productivity and wage divergence within industries across advanced economies since the early 2000s. Yet, beyond these general trends, countries have experienced specific productivity and wage developments. The OECD MultiProd project gathers harmonised productivity-related data enabling cross-country comparisons of productivity developments over time at a fine level of disaggregation. The MultiProd data uniquely inform researchers and policymakers about country-specific productivity patterns and enable them to compare the nature of productivity developments across countries. This box gives a few examples:

Productivity dispersion across industries in Austria

Trends in labour productivity dispersion in Austria have been comparable to developments in other OECD economies since the Great Recession (OECD, 2019a). However, the level of within-industry productivity dispersion is lower in Austria than in other countries. Remarkably, average labour productivity dispersion is lower in every manufacturing and service industry over the period 2008-14 (Figure 10-1).

Figure 10-1 Average labour productivity dispersion, Austria, 2008-14





Source: OECD (2019a)
Note: This figure reports the average dispersion in labour productivity within industries in Austria and within country-industry pairs in a set of benchmark countries. Dispersion is measured as the ratio of the 90th percentile to the 10th percentile of the firm-productivity distribution. Figures are the within-industry yearly averages for 2008-14. Results are presented separately for manufacturing and non-financial market services based on detailed industries, following the SNA A38 classification (see Desnoyers-James, Calligaris and Calvino, 2019). Benchmark countries include Australia, Austria, Belgium, Canada, Chile, Denmark, Finland, France, Germany, Hungary, Ireland, Italy, Japan, Norway, Portugal and Switzerland. Data from the OECD MultiProd database, accessed February 2019.
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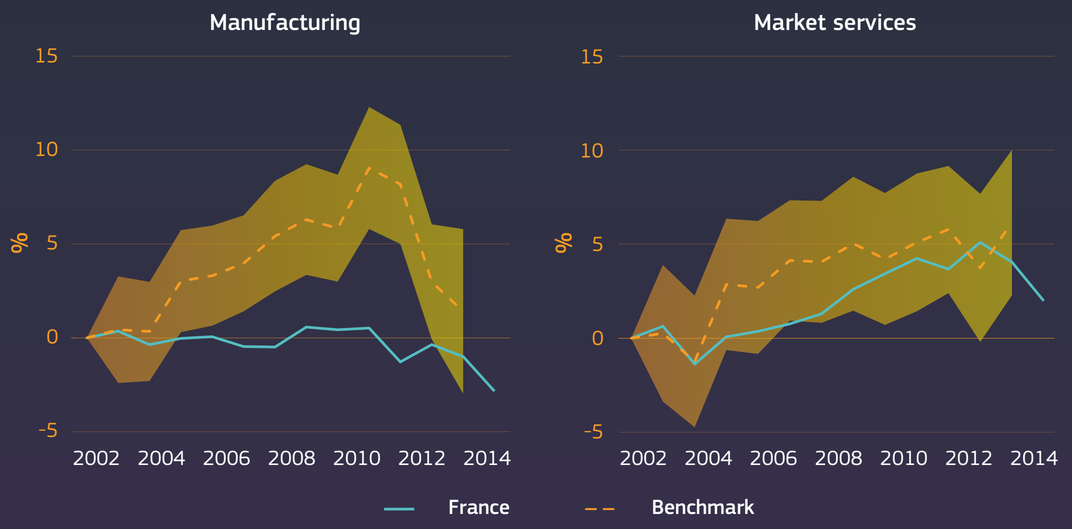
Wage dispersion in French manufacturing

While France has experienced an increase in wage dispersion overall, developments have been significantly heterogeneous across sectors over the period 2002-2015 (OECD, 2019b). While between-firm wage dispersion increased in service industries over that period, it did not in manufacturing industries, possibly pointing to the role of labour market institutions (Figure 10-2).

Figure 10-2 Cumulative change in wage dispersion, France



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Source: OECD (2019b)

Note: This figure reports the estimated year dummies of a regression of average log wage dispersion within industries in France and within country-industry pairs in a set of benchmark countries, taking the first year as baseline. Dispersion is measured as the ratio of the 90th percentile to the 10th percentile of the firm-wage distribution. The values correspond to the average growth within country-industry since 2002. Results are estimated separately for manufacturing and non-financial market services based on detailed industries, following the SNA A38 classification (see Desnoyers-James, Calligaris and Calvino, 2019). Benchmark countries include Australia, Austria, Belgium, Canada, Chile, Denmark, Finland, France, Germany, Hungary, Ireland, Italy, Japan, Norway, Portugal and Switzerland. Data from the OECD MultiProd database, accessed February 2019.

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Technology diffusion in Belgium

Increasing disparities between the most- and the least-productive firms point to insufficient technology and knowledge diffusion from frontier firms to laggards. While there is evidence that the pace of diffusion has decelerated across countries, Belgium seems to have experienced a significantly more pronounced slowdown (OECD, 2019c). The productivity gap between the domestic frontier and laggards has increased twice as much in Belgium as in other countries over the period 2000-2012 (Figure 10-3).

Figure 10-3 Cumulative change in the productivity gap between laggard and frontier firms, Belgium

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Source: OECD (2019c)

Note: This figure reports the estimated year dummies of a panel data regression of the average labour productivity gap between laggards and the domestic productivity frontier within industry-productivity performance group pairs in Belgium, and within country-industry-productivity performance group triplets in the set of benchmark countries. Laggards are firms belonging either to the bottom decile of the productivity distribution (0 to 10th percentile) or to the medium-low performance group (10th to 40th percentile). The domestic productivity frontier is defined as the top 10 % of the productivity distribution in each country-industry-year triplet. The labour productivity gap is defined as the distance between (log) labour productivity in each country-industry-productivity performance group-year among laggards and (log) LP of the domestic frontier in the corresponding country-industry-year. The first year is taken as the baseline. Results are estimated for manufacturing and non-financial market services based on detailed industries, following the SNA A38 classification (see Box 10-2 and Annex). Other European OECD countries are Denmark, Finland, France, Hungary, Ireland, Italy, Norway, Portugal and Sweden. Data from the OECD MultiProd database.

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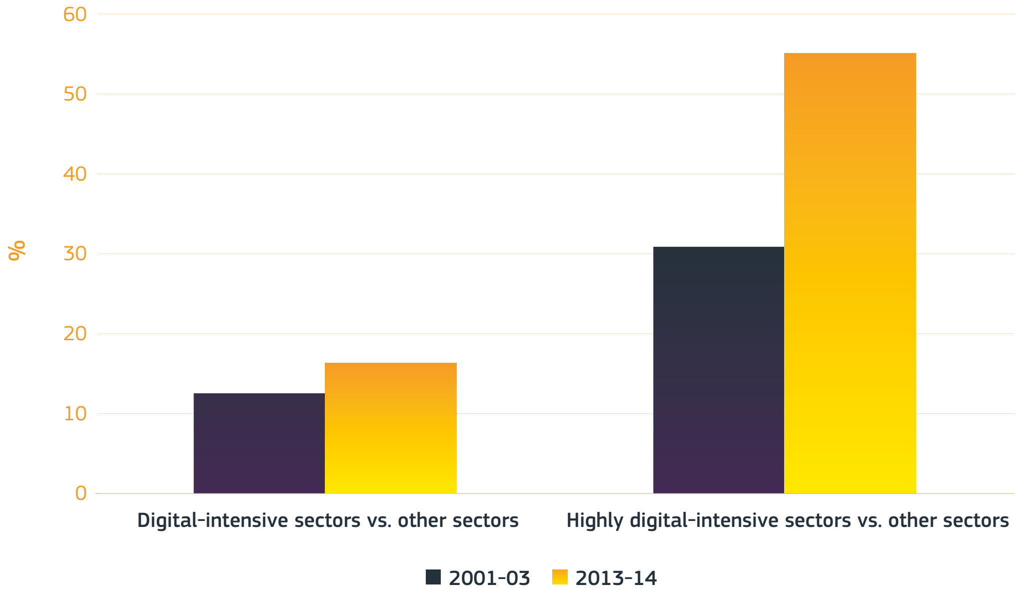
assets, such as organisational capital, data, etc. Second, they have the potential to affect the reallocation of resources across firms, and to create winner-takes-most dynamics, given the near-zero marginal costs of digital inputs and the potential for network effects. The resulting increase in productivity disparities between the most- and the least-productive firms could partially explain the productivity slowdown observed at the macroeconomic level. In addition, these now well-established productivity patterns hint at potential causes of the slowdown, namely insufficient technology diffusion from the frontier to laggards (Berlingieri et al., 2019) and slowing business dynamism (Calvino and Criscuolo, 2019) which slackens the process of creative destruction (Berlingieri, Blanchenay and Criscuolo, 2017).

Concomitant with this increase in productivity dispersion, advanced economies – and digital-intensive sectors within them, in particular – have experienced other major changes in their business dynamics and industry structure (Criscuolo, 2019). Against the backdrop of the productivity divergence, there has been: (i) a decline in business dynamism, measured as entry rates and jobs reallocation across firms (Calvino and Criscuolo, 2019); (ii) an increase in mark-ups, i.e. in the wedge between unit prices and marginal costs (Calligaris, Criscuolo and Marcolin, 2018); (iii) a rise in industry and revenue concentration (Bajgar et al., 2019); and (iv) a decline in the labour share of income (OECD, 2018). Taken together, these elements suggest that something is changing about competitive dynamics more generally, driven by common structural factors linked to the digital transformation. The remainder of this section briefly discusses these factors.

The digitalisation of the economy magnifies the importance of knowledge assets. The intensive use of intangible assets such as data analytics and the difficult replication of successful business models, together with declining IT capital prices, allow few firms, especially in digital-intensive sectors, to benefit from high and increasing mark-ups and to gain a large market share. These in turn may help industry leaders to sustain and advance their position leaving competitors behind.

In line with similar findings for the United States (De Loecker, Eeckhout and Unger, 2018), Calligaris, Criscuolo and Marcolin (2018) point to firm-level evidence of significant changes and increasing differences across companies when looking at firm mark-ups in advanced economies since the early 2000s. Moreover, this works provides novel evidence of a link between the increase in firm-level mark-ups and the digital intensity of firms' production technology, suggesting that, on average, firms operating in digital-intensive sectors have higher mark-ups (Figure 10-4).

Figure 10-4 Average mark-ups in digital-intensive sectors are higher and even more so today



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Source: Elaborations on Calligaris, S., Criscuolo, C. and Marcolin, L. (2018)

Note: The figure illustrates the increasing wedge in mark-ups between firms in digital-intensive and less-digital-intensive industries, 2001-03 and 2013-14. It reports the average percentage differences at the beginning and at end of the sample period, estimated from a pooled OLS regression explaining firm log mark-ups in the period, on the basis of the firm's capital intensity, age, productivity and country-year of operation, as well as a dummy variable with value 1 if the sector of operation is digital-intensive vs. less-digital-intensive (specifications on the left in the graph), or if the sector of operation is among the top 25 % of digital-intensive sectors vs. not (specifications on the right in the graph). Sectors are classified as 'digital-intensive' or 'highly digital-intensive' according to the taxonomy developed in Calvino et al. (2018). Mark-ups are estimated from a Cobb Douglas production function. With respect to Calligaris et al. (2018), in this elaboration the parameters of the production function have been estimated at the 3-digit industry level (rather than 2-digit), and including year dummies. Moreover, mark-ups lower than 1 but greater than 0.95 have been winsorized (rather than trimmed) to 1. Standard errors are clustered at the firm level. All coefficients are significant at the 1% level. This figure is an OECD elaboration on Calligaris, S., Criscuolo, C. and Marcolin, L. (2018), 'Mark-ups in the digital era', OECD Science, Technology and Industry Working Papers, No. 2018/10, OECD Publishing, Paris, https://doi.org/10.1787/4efe2d25-en, based on Orbis® data, July 2018. See https://doi.org/10.1787/888933928711

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A key complementary input to digital technologies, most intangible assets are non-rival in nature and easily scalable. Therefore, they can be used in many markets at near-zero marginal cost, which gives larger companies an inherent advantage when leveraging intangible investments over higher sales and more markets. Recent OECD work finds that intangible assets play a key role in enabling large firms to scale up, thereby increasing industry concentration (Bajgar, Criscuolo and Timmis, 2019, and Figure 10-5). Moreover, ongoing work suggests that laggard firms may not be able to transform digital technologies into productivity gains because they cannot afford complementary investments in intangible assets and skills (Berlingieri, Calligaris, Criscuolo and Verlhac, 2019; Berlingieri, Corrado, Criscuolo, Haskel, Himbert and Iona Lasinio, 2019).

Technological progress also affects labour, both by extending the range of existing tasks that can be performed by capital assets and by creating new tasks related to the use of these assets (Acemoglu and Restrepo, 2018). Over the past couple of decades, information and communication technologies seem to have displaced labour and facilitated the emergence of ‘superstar firms’ with very low labour shares (Autor et al., 2017; OECD, 2018). The increasing weight of these very large and productive firms in the digital economy may help explain the declining labour share of income across the OECD. Consistent with the decline in the labour share, the increasingly large pay differentials across firms account for a large share of the increase in wage inequality in recent decades (Berlingieri, Blanchenay and Criscuolo, 2017; OECD, 2018).

Figure 10-5 Top 8 concentration by potential concentration drivers — change since 2002

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Source: Bajgar, Criscuolo and Timmis (2019), 'Supersize me: intangibles and industry concentration', Mimeo

Note: The countries include BE, DK, ES, FI, FR, UK, EL, IT, JP, PT, SE and US. Included industries cover 2-digit manufacturing and non-financial market services. Concentration is measured by the share of top eight business groups in the sales of each industry in each country. The figure shows changes in the (unweighted) mean concentration across country-industry pairs. Panels A-D show concentration separately for country-industries with above- and below-median intensity of intangible investment (Panel A), country-industries with above- and below-median ratio of exports and imports to value added (Panel B), high-digital-intensity industries and less-digital-intensity (Panel C) and countries with above- and below-median values of the product market regulations index (Panel D). The interaction variables are calculated as the means over the period 2002-2014 with the exception of digitalisation, which refers to years 2001-2003.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/partii/chapter10/figure_10-5.xlsx

3. Divergence at the bottom

While the emergence of superstar firms points to the rising performance of firms at the top of the distribution as a source of the observed productivity divergence, the rising divergence at the bottom of the distribution suggests that the disappointing performance of laggard firms might also be at play. However, little is known about the characteristics of firms that operate at the bottom of the productivity distribution and what drives their performance, although understanding how their performance affects aggregate productivity growth is of prime interest. Recent OECD work bridges the gap by specifically focusing on the 40 % of least-productive firms, the so-called laggards (Berlingieri, Calligaris, Criscuolo and Verlhac, 2019). It highlights the characteristics of laggard firms, their contribution to the economy and the determinants of their productivity performance.

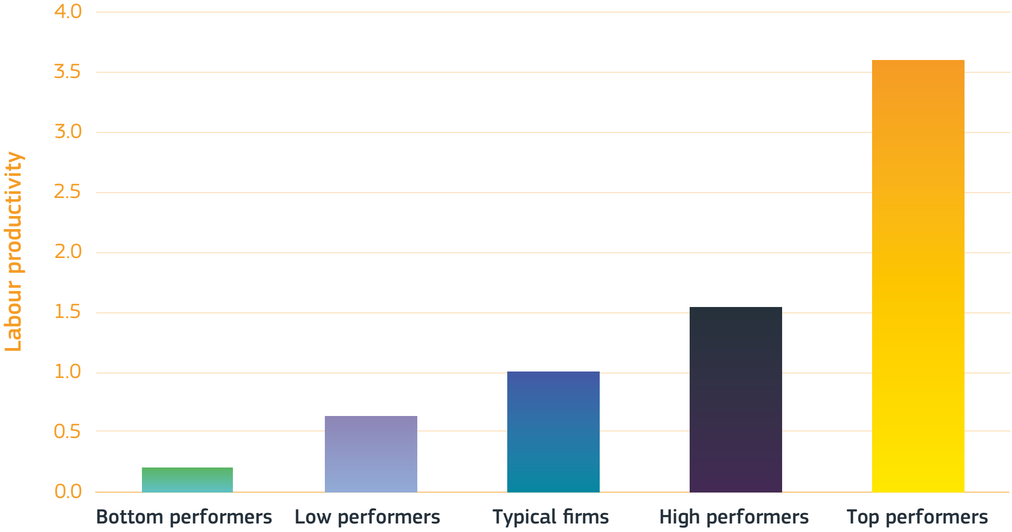
The analysis splits the business population into five groups of firms with different productivity levels in each country and two-digit industry across 13 countries:

- **'Bottom performers'**: firms with a productivity level lying below the 10th percentile of the productivity distribution, i.e. the bottom 10 % in terms of productivity performance;
- **'Low performers'**: firms with a productivity level lying between the 10th and the 40th percentile, i.e. firms with a relatively low productivity level, just below the median group, the 'typical firms' group (see below). They account for about 25 % of employment and 12 % of revenues in the sample;
- **'Typical firms'**: firms with a productivity level lying between the 40th and the 60th percentile, i.e. firms located around the median productivity level;
- **'High performers'**: firms with a productivity level lying between the 60th and the 90th percentile, i.e. firms with a relatively high productivity level, yet lower than the best performing firms, and accounting for 30 % of the population;
- **'Top performers'**: firms with a productivity level lying between the 90th and the 100th percentile of the distribution, i.e. the top 10 % in terms of productivity performance.

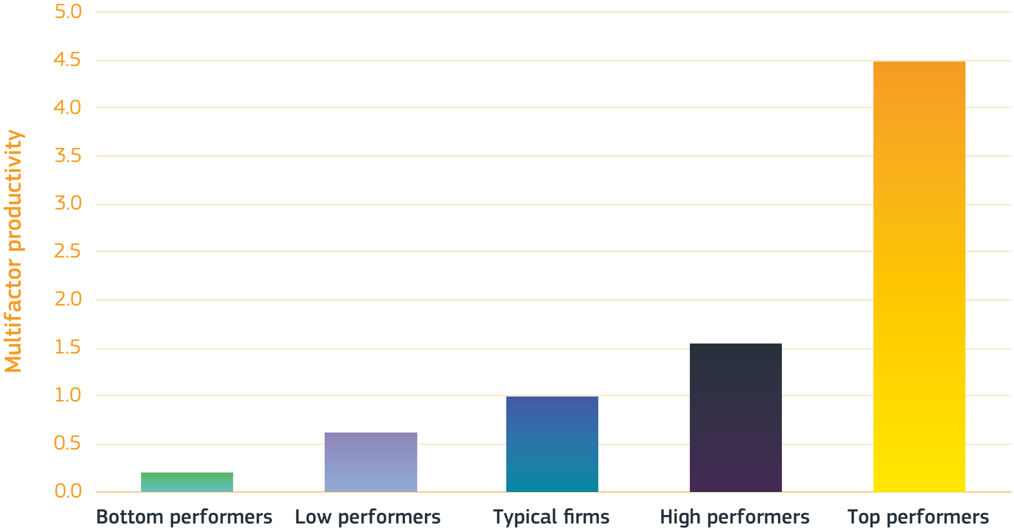
The group of laggards comprises firms belonging to either the bottom performers or the low performers. This classification allows for an analysis of firms based on their relative position in the productivity distribution. The relative average productivity in each productivity group provides evidence about the shape of the distribution and appears particularly relevant for analysing frontier firms and firms at the very bottom.

Figure 10-6 Average productivity by performance group relative to the 'typical firms' group

Panel A: productivity measured as labour productivity



Panel B: productivity measured as multifactor productivity



Source: Berlingieri, Calligaris, Criscuolo and Verlhac (2019), 'Last but not least: laggard firms, technology diffusion and its structural and policy determinants', Mimeo

Note: The figures plot the weighted average labour productivity (top panel A) and multifactor productivity (bottom panel B) in different groups of the productivity distribution with respect to the median bin. In particular, the productivity distribution has been split into five groups: 1st to 10th percentile, 10th to 40th, 40th to 60th, 60th to 90th, and 90th to 100th. Manufacturing and non-financial market services only. Countries included AU, BE, CA, CH, DK, FI, FR, HU, IE, IT, NO, PT, SE.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/partii/chapter10/figure_10-6.xlsx

Panel a in Figure 10-6 plots the employment-weighted average labour productivity (LP), defined as value added over employment, in each group relative to the 'typical' group and illustrates the large dispersion existing within country two-digit industries. On the one hand, top performers exhibit much higher levels of productivity, on average around 3.5 times as high as that of typical firms, which serve as the reference point. On the other hand, the average productivity of firms in the bottom performers is around one fifth of the average typical firm. Low performers exhibit productivity that is roughly 60% of a typical firm's productivity. Panel B in the same figure reports similar comparisons when productivity is measured as multifactor productivity (MFP).

Another way to look at the contribution from laggards is to focus on their contribution to aggregate productivity. The contribution of firms with different labour productivity performance (i.e. in different productivity quantiles) to aggregate labour productivity is determined by both the level of labour productivity and their employment. The data shows that the bottom performers account for less than 1% of total productivity in the average two-digit industry, whereas the low performers account for about 10% (Berlingieri, Calligaris, Criscuolo and Verlhac, 2019). This is the result of both low levels of productivity and relatively low employment shares driven, in turn, by the small average size of firms in these groups. However, the potential productivity gains resulting from a hypothetical situation where the (weighted) average productivity in these two groups is equalised to the level of the (weighted) average productivity in the typical firms group are significant.

Figure 10-7 Share of gross output, value added and employment by productivity group

Productivity group	Share of firms (%)	Share of gross output (%)	Share of value added (%)	Share of employment (%)
		Labour productivity (LP)		
Bottom performers	10	1.45	0.79	4.94
Low performers	30	10.36	10.36	24.43
Typical firms	20	12.21	12.84	19.92
High performers	30	38.65	39.21	37.88
Top performers	10	37.32	36.8	12.83
		Multifactor productivity (MFP)		
Bottom performers	10	5.07	4.28	6.77
Low performers	30	11.02	11.14	18.42
Typical firms	20	9.08	9.69	14.6
High performers	30	34.18	35.14	35.55
Top performers	10	40.72	39.8	24.75

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Source: Berlingieri, Calligaris, Criscuolo and Verlhac (2019)
Note: The figure reports the share of gross output (GO), value added (VA) and employment (L) in each group of the productivity distribution (LP in top panel; MFP in bottom panel). In particular, the productivity distribution has been split into five groups: bottom performers (1st to 10th percentile), low performers (10th to 40th percentile), typical firms (40th to 60th percentile), high performers (60th to 90th percentile) and top performers (90th to 100th percentile). The figure covers manufacturing and non-financial market services only. Countries included: AU, BE, CA, CH, DK, FI, FR, HU, IE, IT, NO, PT and SE.
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/partii/chapter10/figure_10-7.xlsx

These potential benefits raise the question of the nature of the productivity gap and whether improving laggards' productivity is feasible. To answer this question, it is necessary to better understand the characteristics of firms that are at the bottom of the productivity distribution, in particular in relation to firms at the top of the distribution. The richness of the MultiProd database, described in detail in Box 10-2, enables an investigation into the differences between firms in different productivity groups along multiple dimensions. Two characteristics are found to be particularly informative of the nature of laggards: the firms' age and size.

BOX 10-2 MultiProd: distributed microdata suitable for the analysis of the entire productivity distribution

Implementation of the MultiProd project, undertaken by the OECD, is based on a standardised STATA routine that micro-aggregates confidential firm-level data from production surveys and business registers, via a distributed microdata analysis. This methodology was pioneered in the early 2000s in a series of cross-country projects on firm demographics and productivity (Bartelsman et al., 2005; Bartelsman et al., 2009). The distributed micro-data analysis involves running a common code in a decentralised manner by representatives in national statistical agencies or experts in governments or public institutions who have access to the national micro-level data. The centrally designed, but locally executed, program codes generate micro-aggregated data which are then sent back to the OECD for comparative cross-country analysis.

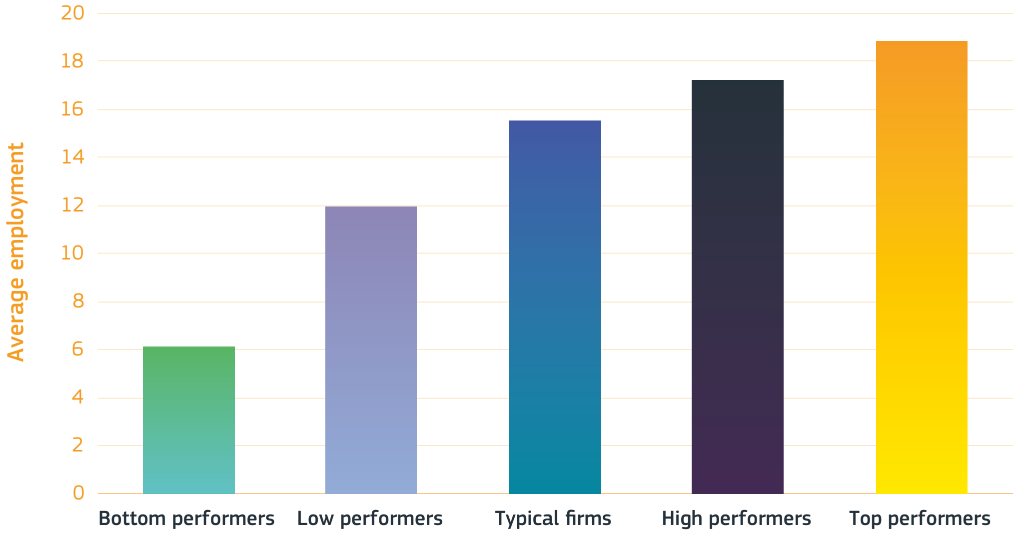
The MultiProd programme relies on two main data sources in each country. First, administrative data or production surveys (PS) which contain all the variables needed for productivity analysis but may be limited to a sample of firms. Second, business registers (BR) which contain a more limited set of variables but for the entire population of firms. The BR is not needed when administrative data on the full population of firms are available. When data come from a PS, however, the availability of the business register substantially improves the representativeness of results and, thus, their comparability across countries.

Indeed, census and administrative data normally cover the whole population of businesses with at least one employee. Still, these datasets do not always exist nor include all the information needed to calculate productivity. In these cases, PS data must be used. One of the big challenges of working with firm-level production surveys is that the selected sample of firms might yield a partial and biased picture of the economy. Thus, when available, BRs, which typically contain the whole population of firms, are used in MultiProd to compute a population structure by year-sector-size classes. This structure is then used to re-weight data contained in the PS in order to construct data that are as representative as possible of the whole population of firms and comparable across countries.

MultiProd is one of the few datasets to include the population of firms for a large number of countries and therefore to be highly representative of all parts of the productivity distribution. This peculiarity makes it particularly suitable to analyse the bottom part of the productivity distribution and allows for a closer look at laggard firms' contribution to productivity slowdown.

In terms of size, Figure 10-8 shows a positive relationship between firm size and productivity, confirming the theoretical prediction from Melitz (2003), and the empirical finding by Berlingieri et al. (2018) for manufacturing. Indeed, typical firms are 2.5 times bigger on average than the bottom performers and 1.3 times bigger than low performers.

Figure 10-8 Average size by productivity (LP) groups



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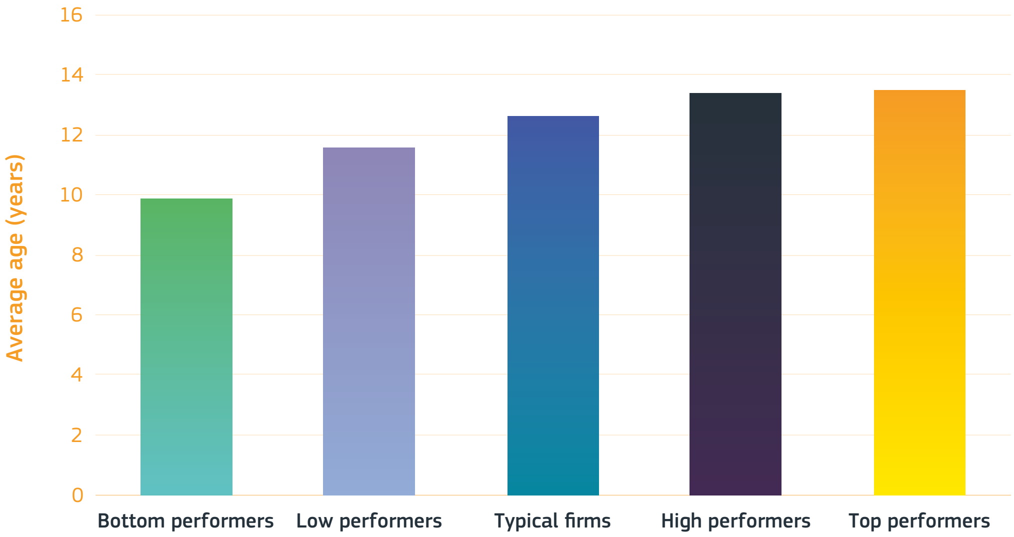
Source: Berlingieri, Calligaris, Criscuolo and Verlhac (2019), 'Last but not least: laggard firms, technology diffusion and its structural and policy determinants', Mimeo

Note: The figure plots the average size (employment) in different groups of the LP distribution. In particular, the LP distribution has been split into five groups: 1st to 10th percentile, 10th to 40th, 40th to 60th, 60th to 90th, and 90th to 100th. Manufacturing and non-financial market services only. Countries included: AU, BE, CA, CH, DK, FI, FR, HU, IE, IT, NO, PT, SE.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/partii/chapter10/figure_10-8.xlsx

In terms of age, laggards are younger than firms in the median group, as illustrated in Figure 10-9. In addition, Berlingieri, Calligaris, Criscuolo and Verlhac (2019) confirm these differences in a regression framework allowing for a comparison of firms in the same country, industry and year.

Figure 10-9 Average age by productivity (LP) performance groups



Science, research and innovation performance of the EU 2020

Source: Berlingieri, Calligaris, Criscuolo and Verlhac (2019), 'Last but not least: laggard firms, technology diffusion and its structural and policy determinants', Mimeo

Note: The figure plots the average age in different groups of the productivity distribution. In particular, the LP distribution has been split into five groups: 1st to 10th percentile, 10th to 40th, 40th to 60th, 60th to 90th, and 90th to 100th. Manufacturing and non-financial market services only. Countries included: BE, DK, FR, IE, IT, NO, SE.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/partii/chapter10/figure_10-9.xlsx

These differences between firms in different groups are key to understanding the nature of the laggards' productivity gap. There may be several reasons why firms have a productivity lower than the typical firm. Firms at the bottom may indeed be: (i) low-productivity firms that would typically exit in a competitive market, the so-called zombie firms (e.g. Caballero et al., 2008; Adalet McGowan et al., 2017); (ii) SMEs that by the nature of their governance (or a life-style choice) are likely to remain small and have limited scope for productivity growth (e.g. local services); but also (iii) firms entering the economy, which are likely to operate below their productivity potential during the first stage of their development.

The characteristics illustrated above are averages within the groups and thus highlight differences across groups but mask such within-group heterogeneity. However, they illustrate a key point for the analysis of laggards: the low tail of the productivity distribution is partly composed of young and small firms with a potential for growth. Therefore, the group of laggards is partly composed of firms that might only transit through the bottom of the productivity distribution to become high performers in the future. Pointing to the coexistence amongst laggards of firms with persistently low productivity (type (i) and (ii) above) and firms with temporarily low productivity but with high potential (type iii) is of primary importance for policy. It suggest that policies which aim to raise the productivity of laggards could matter for aggregate productivity and could be complementary to policies that allow the exit of zombie firms, e.g. efficient bankruptcy legislation, efficient financial systems, etc.

4. The role of business dynamism in the productivity gap

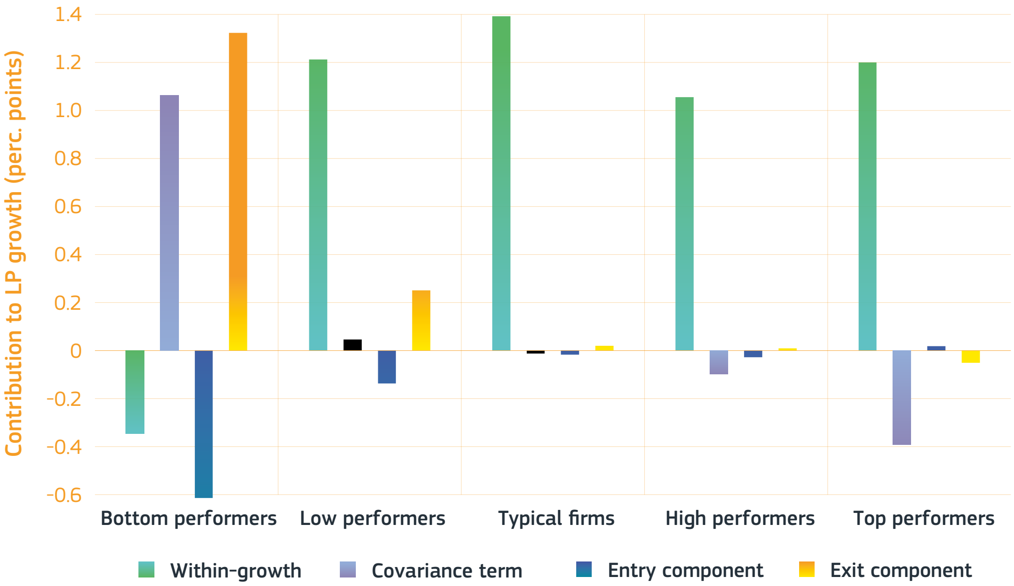
The age difference between laggards and more-productive firms raises the question about the connection between the existence of a large tail of low-productivity firms and business dynamism in the economy.

To answer this question, Berlingieri, Calligaris, Criscuolo and Verlhac (2019) apply the Melitz and Polanec (2015) dynamic decomposition of productivity growth to each productivity group. In this approach, the productivity growth of each group is decomposed into the following components: the contribution of incumbent firms (further decomposed into the change in the unweighted average productivity of incumbents and the change in the efficiency of resource allocation), and the contributions of entering and exiting firms.

Results of this decomposition are reported in Figure 10-10. The main take-away is that entry and exit account for a significant share of the laggards' productivity growth. Entrants and exiting firms transit through the group of laggards when entering and exiting the economy and, therefore, most of the firm churning occurs at the bottom. While for more productive groups the most important contribution comes by the average growth of incumbents' productivity, the reallocation term accounts for most of the growth of the bottom performers. In addition, while in the rest of the distribution, entry and exit play a very marginal role, in the bottom tail of the productivity distribution they are significant components of the overall productivity growth. The positive contribution of exit reveals that firms exiting the economy are generally less productive than the average surviving firms, suggesting a healthy market selection. In the same way, the negative contribution of entry suggests that newly created firms are also less productive than surviving ones, which explains the age difference observed previously.

Overall, the results presented so far stress the peculiarities of the bottom part of the productivity distribution, i.e. A more diverse environment with respect to the rest of the distribution, given the higher importance of entry, exit and reallocation of resources. These results provide a new insight into the nature of laggards and convey important policy implications. However, the importance of business dynamism for laggards suggests that the secular decline of business dynamism, the productivity slowdown and the poor performance of productivity growth observed over the last decade may be interrelated.

Figure 10-10 Melitz and Polanec decomposition by LP performance group



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Source: Berlingieri, Calligaris, Criscuolo and Verlhac (2019), 'Last but not least: laggard firms, technology diffusion and its structural and policy determinants', Mimeo

Note: The figure plots the Melitz and Polanec decomposition in different groups of the productivity distribution. In particular, the productivity distribution has been split into five groups: 1st to 10th percentile, 10th to 40th, 40th to 60th, 60th to 90th, and 90th to 100th. Manufacturing and non-financial market services only. Countries included: AU, BE, CA, CH, DK, FI, FR, HU, IE, IT, NO, PT, SE. The bars in this figure are computed in the following way: first gains are aggregated across industries within country and productivity bins using employment shares of the industry in the economy. Subsequently, a simple average is computed across years within each country-productivity bin. Finally, the median is computed over countries, separately for each group.

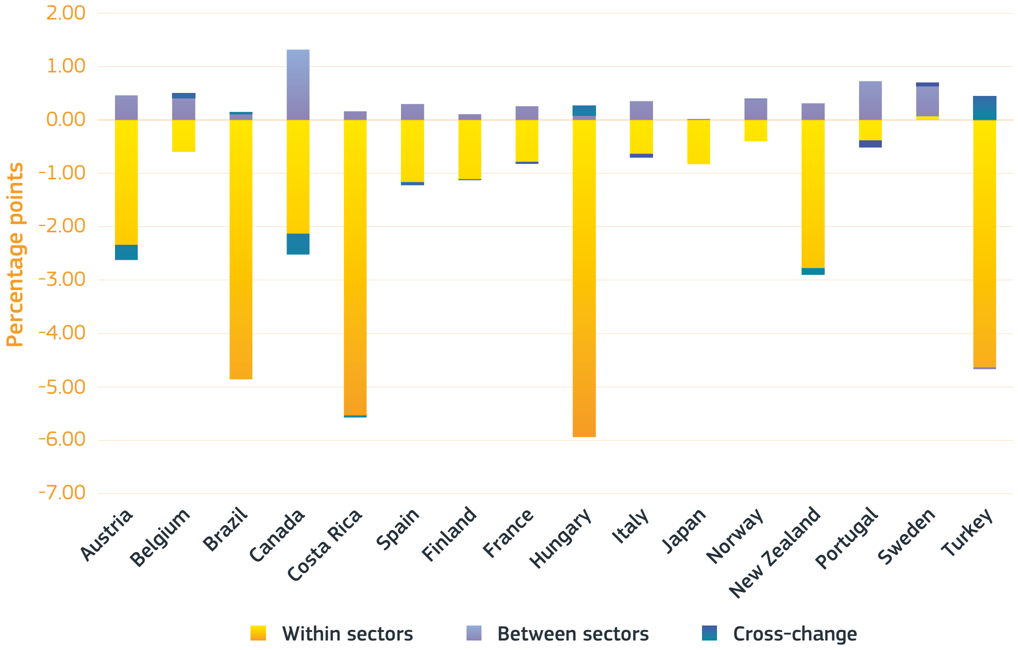
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/partii/chapter10/figure_10-10.xlsx

The secular decline in business dynamism takes various forms, but numerous studies have highlighted declining trends in entry rates, and this is considered as one of the top signs of such a decline (Haltiwanger et al., 2015). In particular, declines in entry rates have been prominent in the USA, as documented by Decker et al. (2016) (and by a number of subsequent publications) using the US Census Bureau's Longitudinal Business Database (LBD). Decker et al. (2016) show a marked decline of entry rates over the period 1980-2012. Other countries, such as Australia, Canada and Portugal, have experienced declines in entry rates. In particular, Bakhtiari (2017) reveals patterns of declining dynamism in Australia over the period 2002-2015, which entail a decline in entry rates. Focusing on entry and exit rates over almost 30 years (1984-2012), Macdonald (2014) reveals a downward trend in entry rates in industries in Canada. Sarmento and Nunes (2010) evaluate the entrepreneurship performance of Portugal, highlighting that the country has also experienced a relevant decline in dynamism.

Calvino, Criscuolo and Verlhac (2019) provide additional evidence of declining entry rates, reported in Figures 10-11 and 10-12. These figures illustrate two key facts: (i) overall, business dynamism has been steadily declining in a large number of countries; and (ii) this phenomenon is pervasive, affecting most industries to some extent. In addition, the authors explore possible drivers of the decline in business dynamism and highlight four groups of causes – in addition to cyclical factors affecting dynamism in the short run. Globalisation, demographic factors, technological change and changes in the regulatory framework are all likely to contribute to declining business dynamism.

Declining entry rates are of particular concern given the importance of firm dynamics for productivity growth, especially at the bottom of the productivity distribution. A corollary of results presented in Figure 10-10 indicates that the process of firm churning, i.e. firm entry and exit, determines the nature and composition of the group of laggards. Firm entry is profoundly associated with experimentation, enabling new firms to compete with incumbents, introduce innovation and gain market shares when successful. Market selection induces low productivity and non-profitable firms to exit the market so that resources can be used in more productive firms. Dynamic markets can be characterised by a high degree of experimentation, the productivity-enhancing selection of profitable firms and the scale-up of these firms (in terms of productivity, market shares and/or employment). Therefore, another facet of economic dynamism, of particular importance for the future of productivity, can be characterised by the extent to which the improvement of productivity by firms at the bottom of the productivity distribution is conditional on survival, through innovation, as well as imitation, technology adoption and knowledge diffusion.

Figure 10-11 **Contributions to changes in entry rates**

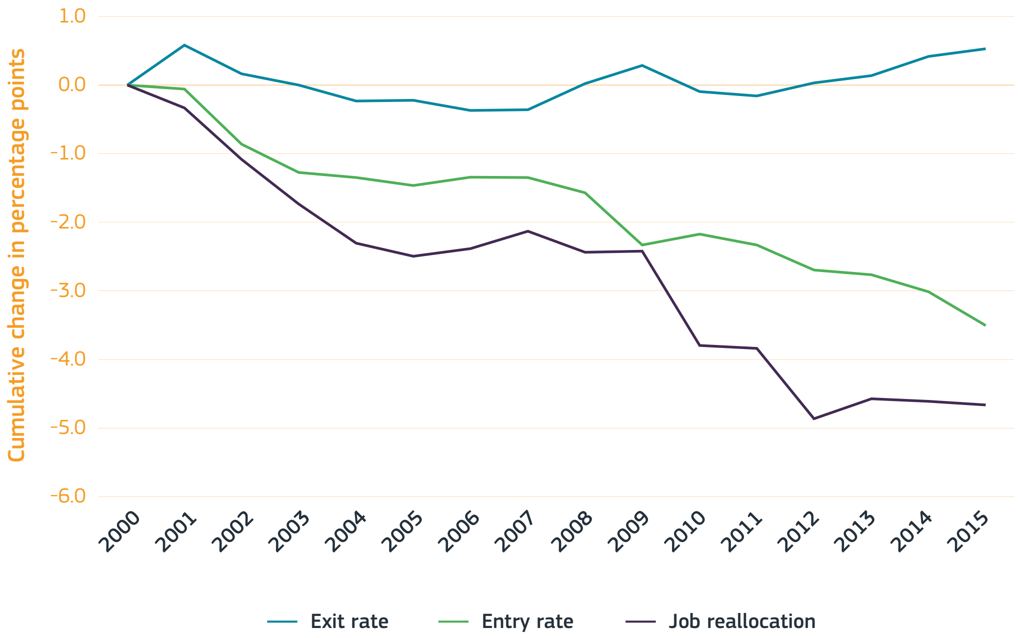


Source: Calvino, Criscuolo and Verlhac (2019), 'Declining business dynamism', Mimeo

Note: This figure reports, for each country, changes in entry rates between 2000-2015 due to variations within sectors ('within sector' component), due to changes in the share of industries with different levels of dynamism ('between-sectors' component), and due to the covariance between changes in a sector weight and its level of dynamism ('cross-change' term). For each country, the figure covers the period from the first to the last available year within the period 2000-2015. Data for some countries are preliminary.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/partii/chapter10/figure_10-11.xlsx

Figure 10-12 Average trends in job reallocation, entry and exit rates



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Source: Calvino, Criscuolo and Verlhac (2019), 'Declining business dynamism', Mimeo

Note: This figure reports average within-country-industry trends of job reallocation, entry and exit rates, based on the year coefficients of regressions within country-sector, for the period 2000-2015, including 16 countries: AT, BE, BR, CA, CR, ES, FI, FR, HU, IT, JP, NO, NZ, PT, SE and TR. Each point represents cumulative change in percentage points since 2000.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/partii/chapter10/figure_10-12.xlsx

5. Laggards catching up

The capacity of laggards, generally smaller and younger, to improve their productivity over time is a potential driver of future productivity growth. Young firms in their first stage of development operating below their efficiency levels are indeed more responsive to productivity shocks (Decker et al., 2018) and some may have the potential to become the future productivity frontier. Hence, the rest of this section evaluates the extent to which laggards are catching up with the national frontier.

Neo-Schumpeterian growth theory (e.g. Aghion and Howitt, 2006; Acemoglu et al., 2006) and models of competitive diffusion (e.g. Jovanovic and MacDonald, 1994) predict productivity convergence: laggard firms should grow faster, given the larger stock of unexploited technologies and knowledge that they can readily implement. Yet, the rising productivity gap between frontier firms and the rest, and especially laggards, questions whether ongoing transformations of the economy have affected the strength of this catch-up effect. A lack of diffusion stemming from relatively high costs for laggard firms to adapt to the new digital/knowledge-intensive economy, or from rising barriers in adopting technology due to a lack of absorptive capacity, may be a significant driver of the productivity divergence.

Berlingieri, Calligaris, Criscuolo and Verlhac (2019) confirm the existence of a catch-up effect for laggards and focus on the determinants of convergence forces and undermining factors. More specifically, based on an econometric framework derived from the neo-Schumpeterian concept of convergence, they confirm that laggards catch up with the national frontier. The methodology is outlined in Box 10-3.

BOX 10-3 Measuring the strength of the neo-Schumpeterian catch-up effect and its determinants

The 'catch-up effect' has been widely documented in the literature (e.g. Griffith et al., 2004; Bartelsman et al., 2008). Empirical studies have confirmed the existence of a catch-up effect both at the firm level (Griffith et al., 2009; Bartelsman et al., 2008; Andrews et al., 2015; Andrews et al., 2016) and at the industry level (Nicoletti and Scarpetta, 2003; Saia et al., 2015).

Testing the existence of the catch-up effect implies testing for a positive association between the distance to the frontier at time $t - 1$ and productivity growth between $t - 1$ and t, for surviving firms. The following specification is the starting point of the analysis:

$$\Delta P_{cjq,t} = \alpha + \beta_1 gap_{cjq,t-1} + \lambda \Delta P^F{}_{cjq,t} + \delta_{ct} + \tau_j + \epsilon_{cjq,t}$$

$P_{cjq,t}$ denotes the measured average produc-tivity (LP or MFP) in country c, industry j, productivity performance group q (productivity bins (p(0-10) and p(10-40)) and year t. $\Delta P^F{}_{cjq,t}$ is then the annual (log) productivity growth of firms belonging to the bottom 40% of the productivity distribution at time $t - 1$, whereas $\Delta P^F{}_{cjq,t}$ the annual (log) productivity growth of firms at the national frontier in t, defined as the top 10% of the productivity distribution in each country-2-digit industry-year. Moreover, $gap_{cjq,t-1}$ is the productivity gap at time $t - 1$, modelled as the distance in the level between (log) productivity in each country-industry-productivity bin-year in the bottom 40% of the productivity distribution and (log) productivity in the corresponding country-industry-year in the top 10%. Productivity growth can be affected by macroeconomic shocks at the country level and by industry characteristics, possibly correlated with the explanatory variables. To control for them, the error term in (12) is allowed to include country-year and industry fixed effects: $\delta_{ct} + \tau_j$. The existence of a catch-up effect is confirmed if $\beta_1 > 0$.

Berlingieri, Calligaris, Criscuolo and Verlhac (2019) extend this equation to uncover factors that can affect the catch-up. The following equation is estimated:

$$\Delta P_{cjq,t} = \alpha + \beta_1 gap_{cjq,t-1} + \beta_2 (gap_{cjq,t-1} \text{ x } X_{cjq,t-1}) + pX_{cjq,t-1} + \lambda \Delta P^F{}_{cjq,t} + \delta_{ct} + \tau_j + \epsilon_{cjq,t}$$

$X_{cjq,t-1}$ includes all main variables of interest, reflecting either firms' characteristics or structural factors affecting the strength. The paper focuses mainly on structural industry characteristics X_j.

The analysis in the study confirms a positive relationship between the productivity gap and the productivity growth of laggards, indicating the existence of convergence among firms, even at the bottom of the distribution. The existence of a catch-up effect is a necessary condition for laggards to exit the group of low-productivity firms and confirms that, on average, laggard firms have the potential to significantly improve their productivity. The results also show that younger laggard firms catch up more rapidly (although this result is only available for a subset of countries and the age variable is only available for 7 out of 13 countries). This suggests that the younger the group of laggards, the higher the potential for productivity growth at the bottom of the distribution through knowledge and technology diffusion.

Focusing on spillovers from the global productivity frontier, Andrews et al. (2016) document a decline in the speed of catching up, pointing to a breakdown in the diffusion machine (see also the discussion in Criscuolo, 2018). Berlingieri, Calligaris, Criscuolo and Verlhac (2019) also find that convergence forces driving productivity gains of laggards have weakened over time (Figure 10-13).

Figure 10-13 Catch-up over time

Source: Berlingieri, Calligaris, Criscuolo and Verlhac (2019)

Note: The figure represents the estimates for catch-up effect over time. It plots coefficients from a regression of productivity growth on the productivity gap interacted with year dummies, including country-year and industry fixed effects. Manufacturing and non-financial market services only. Countries included: AU, BE, CA, CH, DK, FI, FR, HU, IE, IT, NO, PT, SE.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/partii/chapter10/figure_10-13.xlsx

The decline in knowledge diffusion intensity is also discussed in depth by Akcigit and Ates (2019a) and Akcigit and Ates (2019b) as the main cause behind many of the current trends. Indeed, using an endogenous growth model of strategic interaction and innovation, the authors show that the decline in knowledge diffusion is the dominant factor behind a number of recent empirical trends, such as increasing productivity dispersion, rising market concentration, and a slowdown in business dynamism.

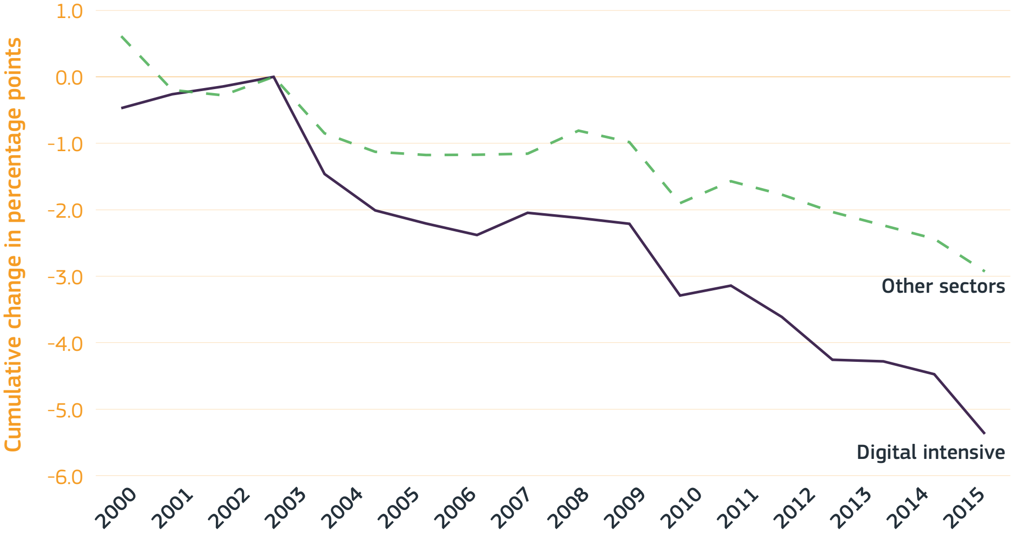
Berlingieri, Calligaris, Criscuolo and Verlhac (2019) associate the decline in diffusion to the ongoing transformation of the economy by analysing how some structural factors – and specifically digitalisation and knowledge intensity – affect catch-up. While the neo-Schumpeterian catch-up effect is a significant driver of productivity growth, the diffusion of innovation does not occur automatically, but requires a costly process of adoption, conditioned by firms' capabilities and incentives to learn from the most innovative ones (see Griffith et al., 2004, for instance). In addition, the digital transformation and transition to an economy based on ideas seem to have intensified the role of firms' capabilities and incentives (Andrews et al., 2016), thus raising additional obstacles to a broad diffusion of technology and knowledge. This transformation of the economy expands the scope for productivity growth but also brings with it several challenges. It increases the average level and the composition of skill requirements and the need for complementary investments in both tangible and intangible assets (software, database, management, etc.), and it requires higher levels of absorptive capacity for adopting more complex technologies and innovations.

To test whether this transformation may be linked to the slowdown in diffusion, Berlingieri, Calligaris, Criscuolo and Verlhac (2019) investigate differences in the speed of catch-up between sectors characterised by different levels of digital and skill intensity. Several dimensions are explored: First, industries are classified into digital- and non-digital-intensive, based on the taxonomy proposed by Calvino et al. (2018). Second, a number of sub-indicators of digital intensity are considered: (i) investment intensity in ICT equipment; (ii) investment intensity in software and databases; (iii) ICT goods as intermediate inputs; and iv) ICT services as intermediate inputs. Third, sectoral differences in skill requirements are also explored using indicators of: (i) ICT skill intensity; and (ii) the share of hours worked by high-skilled workers. Finally, services are divided into knowledge-intensive (KIS) and less-knowledge-intensive industries (LKIS). The association of industry characteristics and the speed of diffusion is evaluated using the methodology presented in Box 3. All results overwhelmingly point in the same direction: in more digital-intensive and more knowledge-intensive industries, laggards catch up with the productivity frontier more slowly. While a greater use of digital technologies and knowledge may be beneficial for overall productivity growth, nonetheless they seem to push towards divergence in productivity, especially in digital- and knowledge-intensive industries. On the contrary, laggards belonging to less digital- and knowledge-intensive industries are catching up faster with the frontier.

To summarise, laggard firms catch up at a lower speed in industries characterised by a high level of digitalisation and knowledge intensity, suggesting that they face higher obstacles to growth. Taken as a whole, these findings suggest that digitalisation and the transition to an economy based on ideas, although potentially beneficial for overall growth, may not benefit all firms equally. This in turn points to the existence of barriers to technology and knowledge diffusion raised by these recent mega-trends. Not having the necessary absorptive capacity to learn from the frontier, laggards struggle more to catch up in industries where digitalisation, intangibles and knowledge matter the most.

Interestingly, Berlingieri, Calligaris, Criscuolo and Verlhac (2019) emphasise the direct connection between slower diffusion and productivity dispersion and show that industries characterised by a slower catch-up also display higher levels of dispersion. These results also echo the finding by Calvino and Criscuolo (2019) who show that entry rates, and more generally business dynamism, have been declining faster in digital-intensive sectors, as illustrated in Figure 10-14.

Figure 10-14 Trends in entry rates for digital-intensive vs. other sectors



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Source: Calvino and Criscuolo (2019)

Note: The figures report average within country-industry trends, based on the year coefficients of regressions within country-sector, with and without interaction with the digital-intensity dummy. Digital-intensive sectors are reported with a solid line and other sectors with a dashed line. The dependent variable is entry rates. The baseline year is set to 2001. Each point represents average cumulative changes in percentage points since 2001.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/partii/chapter10/figure_10-14.xlsx

6. A framework and analysis of the role of policy

Digital-intensive sectors experience faster declines in entry rates, and laggards in these sectors catch up with the national frontier more slowly than less-digital-intensive industries. Given the importance of young firms' scale-up for the future of productivity, this calls for an investigation into the potential role of policies in helping laggards overcome such obstacles. This section provides a framework for policy responses, focusing first on policies that can influence entry rates in digital-intensive industries before outlining policy areas that could influence the speed of diffusion and catch-up.

6.1 Policies and business dynamism

Calvino and Criscuolo (2019) review policies that can encourage entrepreneurship and propose a guiding framework for policymakers. This framework and the methodology are presented in Box 10-4. Entry rates are related to the supply (quantity) and quality of entrepreneurs in a country. In this context, human capital, education – in terms of educational attainment but also of quality of the education system – and training workers play an important role and policymakers can influence these outcomes with the appropriate policy instruments.

The availability of capital, especially seed and early-stage financing but also to some extent bank loans, is crucial as it enables those potential entrepreneurs with the financial means needed to start their venture. In order to enter the market, such entrepreneurs need to have the right incentives and expected positive returns on their project. This is also linked to the possibility of successfully listing their company on the stock markets.

Potential entrepreneurs also need to be able to set up their business easily, which is possible when regulatory entry barriers and administrative burdens are low. Once entry has occurred, new firms need to face a level playing field and be given equal opportunities with respect to other incumbent firms. Important levers in this context are related to business regulations, efficiency in the enforcement of contracts, and innovation support measures. Finally, entrepreneurs must be able to experiment as this is a key feature of the creative destruction process. Policy related to the cost of reallocation (such as employment protection legislation) and to the cost of failure (efficiency of bankruptcy regulation) are important levers that policymakers can influence.

A summary of the econometric results of the study is presented in Figure 10-15. A positive (negative) coefficient is to be interpreted as an indication of the fact that the particular policy under investigation is positively (negatively) related to entry rates in digital-intensive sectors. In other words, an improvement along the particular policy setting examined are found to have a positive (negative) association with business dynamism in these sectors.

BOX 10-4 Policies and entry rates: methodological framework

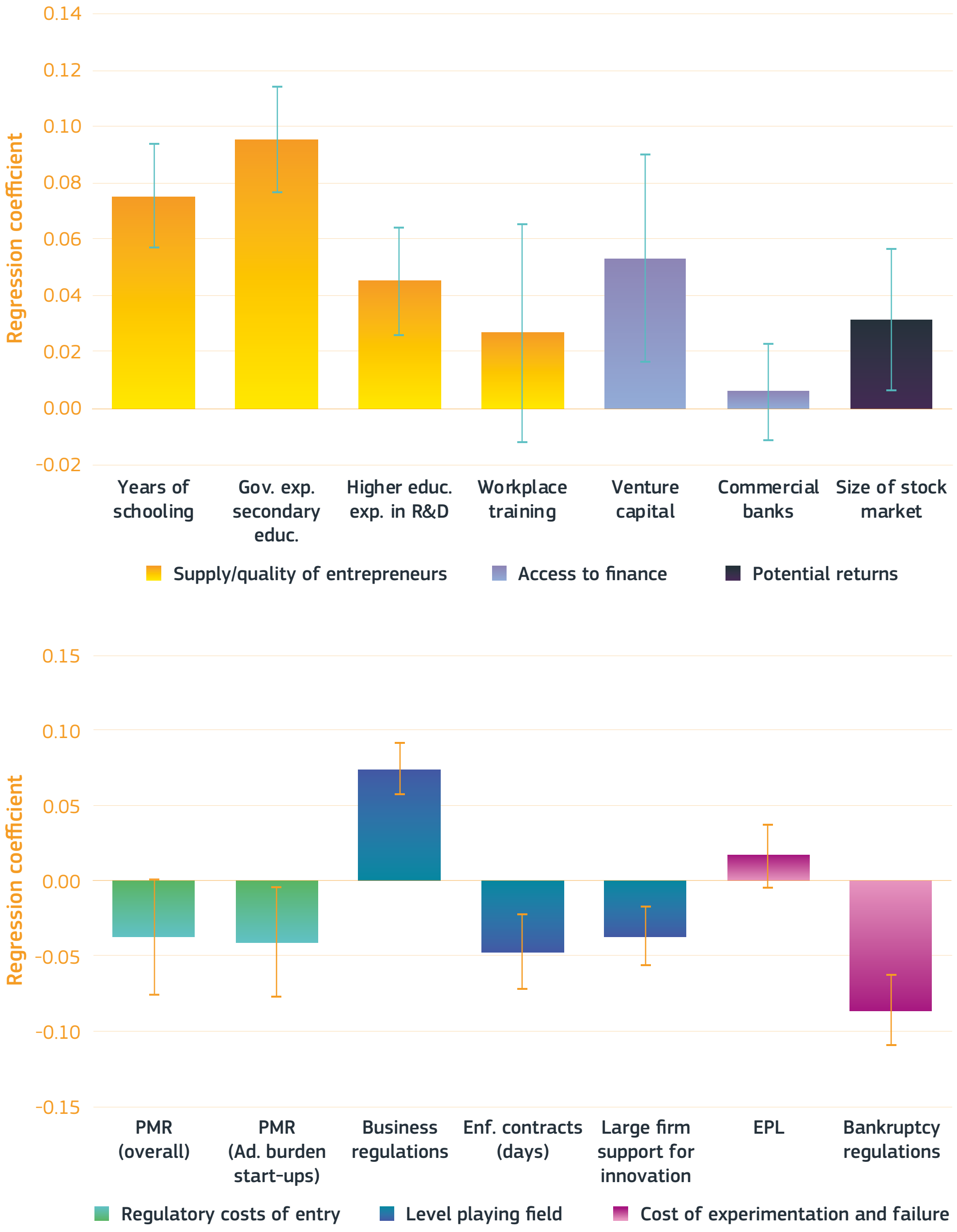
The main approach used to estimate the extent to which policy and institutional factors influence business dynamism in digital-intensive sectors follows the methodology proposed by Rajan and Zingales (1998). In particular, the basic intuition of this approach is that some sectors may be more exposed than others to the effect of certain national policies or framework conditions due to some of their (technological or structural) characteristics. Identifying the impact of policies is therefore based on this differential exposure of sectors to policy.

In this context, the approach is adapted using as the exposure variable the same digital-intensity measure used in the rest of this paper. This allows for an assessment of the extent to which different policies have a differential role for business dynamics mediated by digital intensity. The main model estimated becomes:

$$EntryRate_{c,s,t} = \beta \text{ x } Policy_{c,t} \text{ x } Digital_s + K_c \text{ x } \Theta_t + Y_s + \varepsilon_{c,s,t}$$

where *EntryRate* identifies the log of entry rates, *Policy* refers alternatively to each of the policy variables described above, *Digital* is the digital-intensity indicator used in the rest of the paper; *c* indicates countries, *t* year, and *s* sectors.

Figure 10-15 Entry rates and policies



Source: Calvino, F. and Criscuolo, C. (2019)

Note: The bars report coefficients based on separate regressions where the dependent variable is (the log of) entry rates, the exposure variable is the digital-intensity dummy and the policy variables are those listed in the text (see equation 1). All regressions include country-year and sector fixed effects. Confidence intervals (95 %) are also reported based on robust standard errors.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/partii/chapter10/figure_10-15.xlsx

6.2 Policies for diffusion

Policy intervention has a potential instrumental role in reducing these barriers to foster diffusion, and consequentially increasing aggregate productivity growth. Potentially significant barriers to adoption – hindering a wide diffusion of the benefits associated with technological progress – include the rapidly changing demand for skills in the economy inducing skill shortages in high-skilled jobs, costly complementary investments to technology, and a lack of absorptive capacity.

Berlingieri, Calligaris, Criscuolo and Verlhac (2019) explore three policy areas where policies could be effective in increasing the speed of catch-up: skills, finance, and R&D support. First, the analysis focuses on policy objectives and instruments related to changing skill needs in the economy, by looking at skill mismatch, under-qualification, the share of adults participating in training and expenditure in training targeting the unemployed. A good match between skills demand and supply is associated with a faster rate of catch-up, and there is evidence that this positive association is stronger in digital- and skill-intensive industries. Conversely, a higher share of underqualified workers in the economy is associated with a lower speed of catch-up, especially in industries that are more digital- and skill-intensive. The results also provide evidence that training adults may be effective in increasing the speed of catch-up, and that training the low-skilled may be particularly effective.

Next, SMEs' access to finance is investigated, as it can be informative about the financial conditions that laggards are facing – given the correlation between size and productivity. The results show that diffusion is more rapid in countries where a larger share of lending is directed towards SMEs and more specifically in industries where investments in digital technologies are more prevalent. Conversely, less-favourable financing conditions for SMEs, revealed by a higher interest rate spread between SMEs and large firms, are associated with a lower speed of catch-up only in sectors that require higher investment in ICT equipment and software and databases. These results suggest that appropriate financial support relaxing financial constraints could help unleash the potential of laggards to catch up. However, given the heterogeneity of this group, care should be taken over the design of such policies.

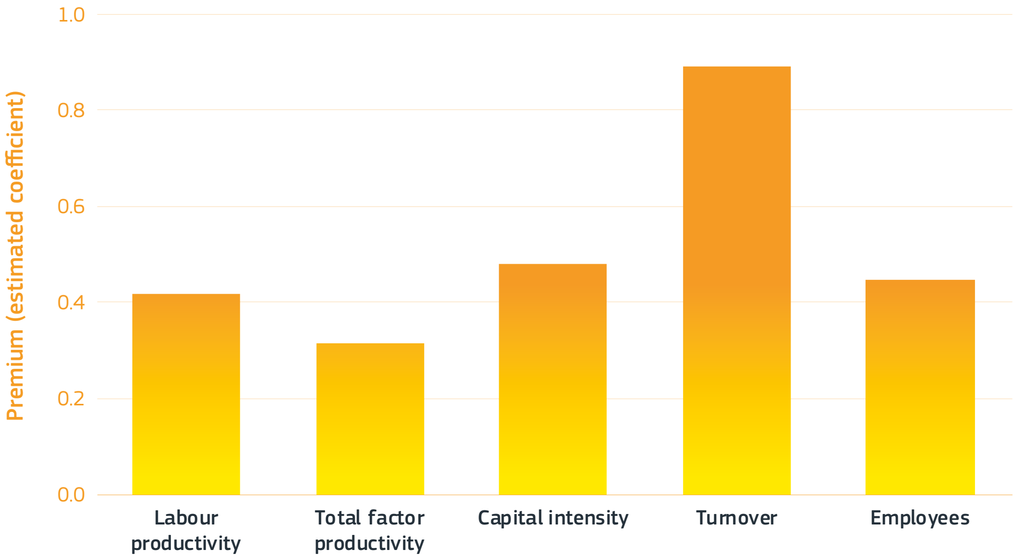
Finally, suggestive evidence shows that support to business R&D through direct government funding may encourage diffusion in digital- and skill-intensive industries. While further research is needed to confirm this link, it seems in line with the 'second face of R&D' unveiled by Griffith et al. (2004). Not only does R&D foster innovation, but it also enhances technology transfers by increasing firms' absorptive capacity. By engaging in R&D, firms accumulate a tacit knowledge that allows them to understand and assimilate existing technology and innovations.

6.3 Trade, trade openness and catch-up

The theoretical and empirical economic literature has extensively discussed the role of international trade on economic growth, convergence and catching up at the macro level. Inevitably, the dynamics are more complex when looking at the issue at the micro (i.e. firm) level.

First, empirical research has shown that firms which engage in exports are more productive than non-exporting firms, for two alternative – but not mutually exclusive – reasons. First, engaging in trading activities involves both per-unit and fixed costs; as a result, there is a self-selection into exporting, so that only the most competitive firms engage in export activity (Melitz, 2003). Recent analysis of EU firms has shown that new exporting firms (i.e. those that have just started to export) are, on average, about 15 % more productive than non-exporting firms in the same sector (ECB, 2017). Second, firms 'learn by exporting' and are more likely to innovate; they also have access to cheaper and higher-quality inputs (Mayer, Melitz and Ottaviano, 2014). In addition, exposure to trade leads to reallocation of resources across firms towards the most productive ones, with a positive impact on aggregate productivity.

Figure 10-16 Premia of exporters over non-exporters in selected EU countries, 2002-2016



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Source: European Commission, DG for Economic and Financial Affairs based on CompNet Database

Note: The chart shows the coefficient of the export dummy, indicating whether the firm is an exporter or not, from OLS regressions where the dependent variable is the log of the performance indicators, controlling for country, time and sector dummies. The coefficients are always significant at all levels. The analysis refers to firms with more than 20 employees. Due to data availability, countries included are HR, CZ, FI, FR, DE, HU, IT, LT, PL, RO, SK, SI and SE.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/partii/chapter10/figure_10-16.xlsx

However, exporting firms are different from non-exporters in other dimensions, too. Mayer and Ottaviano (2008) showed that exporters are generally bigger, more profitable, more capital-intensive and more productive than non-exporters (Mayer and Ottaviano, 2008). Figure 10-16 shows that this is indeed the case in the EU[1]. According to CompNet data, over the period 2002-2016, exporting firms in the countries covered here are bigger, on average (in terms of both number of employees and turnover), approximately 30-40 % more productive (in terms of labour productivity and total factor productivity), and more capital-intensive than non-exporting firms.

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[1] Data come from the CompNet Database. This database provides sectoral distributions for a number of variables and indicators based on firm-level data provided by national sources (statistical institutes or national central banks). The 6th vintage of the CompNet Database, released in November 2018, covers 19 EU countries. Of these countries, 13 also have data on the export status of firms which are relevant in this section. For more information: http://www.comp-net.org

Since the sample includes all exporters, the productivity gap between exporters and non-exporters depicted in Figure 12 is the result of both self-selection and learning-by-exporting[2].

The higher productivity of exporting firms is also due to their participation in global value chains (GVC)[3]. Recent research has shown that GVC participation can stimulate productivity growth through different channels. These include: (i) specialisation in the activities where they are most productive and outsource the others; (ii) access to a larger variety of cheaper, higher-quality and higher-technology goods as inputs; (iii) knowledge spillovers from foreign firms; and (iv) access to larger markets and competition lead to the growth of the most productive firms (see Criscuolo and Timmis, 2017).

Not only are exporters profoundly different from non-exporters, even in the same sector, as shown in Figure 10-16, but a large share of exports can be accounted for by just a handful of firms ('the happy few' in Mayer and Ottaviano, 2008), which therefore also have great influence on the aggregate performance and growth potential of regions, countries and sectors[4].

As mentioned above, there is a self-selection into exporting, implying that only those firms that are productive enough to overcome the costs associated with engaging in trade will start exporting. Therefore, there is a 'productivity threshold' below which firms would not engage in trade, and this differs across countries and is related to a number of macroeconomic and institutional factors[5]. Such 'new exporters' productivity premium', in particular, tends to be higher in countries with lower GDP per capita; Figure 10-17 shows that this is also the case in the EU. The explanation is intuitive: first, GDP per capita is correlated with productivity; therefore, in countries with higher average productivity, non-exporting firms are closer to the 'benchmark' set by internationalised firms. Second, converging economies usually have less-integrated markets which allow low-productivity non-exporters to stay in the market. Moreover, better institutions reduce the trade costs firms face (in particular, fixed costs, which particularly affect self-selection into exporting), and institutional quality and efficiency are generally correlated with GDP per capita. As a result, in countries with lower GDP per capita, highly productive export-oriented firms (that can afford the costs associated with exporting) will coexist in the same sector with low-productivity domestically oriented firms.

What are the implications of the discussion above on firms' productivity divergence and catch-up? At least within sectors, increases in trade exposure (for example, as a result of trade liberalisation or other measures facilitating firms' and markets' trade openness) should induce reallocation of labour and capital towards the most productive firms, while gradually driving less efficient firms out of the market. In principle, this would reduce within-sector productivity dispersion and foster higher productivity. However, if policies hinder product, labour and capital market flexibility, the result might be less clear cut since the reallocation process might not take place.

As regards global value chains, not only participation in GVC but, in particular, higher centrality in the production networks appears to

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[2] For this reason, this rough estimate is also not comparable to the 15 % premium mentioned at the beginning of this sub-section, which referred to new exporters only.

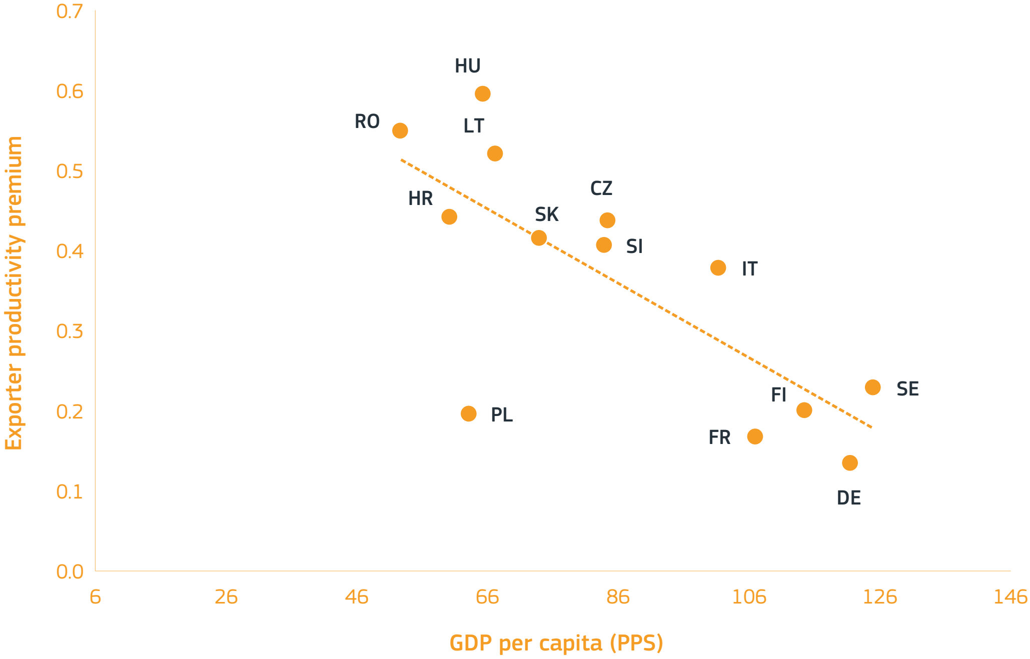
[3] In this respect, GVC participation does not refer only to offshoring and trading intermediate goods but also to indirect backward and forward linkages.

[4] Meyer and Ottaviano (2008), cit. and Altomonte, C. and Békés (2016) Measuring competitiveness in Europe: resource allocation, granularity and trade, Bruegel Blueprint Series, Brussels, Belgium.

[5] See ISGEP (2008) 'Understanding cross-country differences in exporter premia: comparable evidence for 14 countries', Review of World Economics 144(4) pp. 596-635 and Hallward-Driemeier, M., Iarossi, G. and Sokoloff, K.L. (2002) 'Exports and manufacturing productivity in East Asia: a comparative analysis with firm-level data', NBER Working Paper 8894.

be associated with higher productivity growth; this is especially true for non-frontier firms and economies[6]. At the same time, the actual structure of GVC has been evolving over the last couple of decades, and the centrality and importance of eastern European countries in particular has increased since their accession to the EU[7]. This implies that higher integration and influence in GVC can foster firms' catch-up process and might suggest that it can also explain, at least in part, the ongoing catching up of eastern European countries in terms of productivity and GDP per capita.

Figure 10-17 New exporters' productivity premium and GDP per capita in selected EU countries, 2002-2016



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Source: European Commission, DG for Economic and Financial Affairs based on CompNet Database and Eurostat

Note: The new exporters' productivity premium is defined here as the difference between (log) labour productivity of new exporters (defined as the group of firms which exported in year t and t+1 but did not export in t-1) and non-exporters.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/partii/chapter10/figure_10-17.xlsx

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[6] 'Centrality' in GVC measures influence within a production network due to both direct and indirect trade linkages.

[7] Criscuolo, C. and Timmis, J. (2018), The changing structure of Global Value Chains: are central hubs key for productivity?, *International Productivity Monitor* 34, pp. 64-80.

7. Concluding discussion on the role of policies

7.1 Fostering business dynamism

A well-functioning business environment should provide companies with a predictable, transparent, simple and inexpensive way to anticipate and comply with regulation.

While faced with sluggish growth performance, policymakers need to enhance business dynamism by focusing on three cornerstone policies: *product and labour market policy, innovation policy and competition policy*. Broadly speaking, the policies and measures that are put in place should foster, or at least not hinder, the process of creative destruction. At the same time, they should promote innovation at the frontier and diffusion of technological advances from leaders to laggards.

This subsection will focus on product and labour market policies as tools to foster business dynamism. The next subsections will focus on innovation and skills policy as a tool to promote innovation and technological diffusion, and we will conclude with regulation and competition policy as a tool to ensure a level-playing field.

Fostering business dynamism implies facilitating business creation and firm growth and removing the obstacles to the exit of non-profitable firms. Facilitating business creation is not only about reducing the time, cost and number of procedures to create a business – where EU countries have made important improvements in recent years, although many still underperform compared to their main competitors[8] – but also about improving the chances of survival and growth of young and promising startups.

To this end, improving access to finance is one of the key priorities. Sources of funding alternative to bank finance (e.g. crowdfunding, venture capital, private equity, private placements and issuance of debt) are especially important for SMEs, young innovative firms and startups. These firms in particular often struggle to get funding for their investments from banks due to higher perceived risks, and thus can benefit from better access to market-based sources of finance. Innovative firms with high potential might be driven out of the market – or not enter at all – not as a result of a well-functioning resource-reallocation process but because of existing barriers. However, the market for alternative sources of finance is still underdeveloped in Europe compared to its main competitors: for instance, in 2016, total venture capital investments in the EU equalled approximately EUR 4 billion compared to EUR 2.15 billion in Canada and over EUR 60 billion in the USA[9]. Moreover, recent survey data confirm that access to finance is seen as a barrier to investment more by younger companies than by established businesses[10].

To address these issues, in September 2015, the European Commission launched the Capital Markets Union (CMU) which will provide businesses with a greater choice of funding at lower costs, offer new opportunities for savers and investors and make the financial system more resilient. The initiatives approved under the CMU include VentureEU, a pan-European venture capital programme supported by the European Commission and the European Investment Fund and aimed at boosting investment in innovative startups and scale-up companies across the EU.

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[8] Canton, E. and Petrucci, M. (2017), Ease of doing business in the euro area, *Quarterly report on the euro area* Vol. 16, No. 2.

[9] Canton, E. and Petrucci, M. (2017), Ease of doing business in the euro area, *Quarterly report on the euro area* Vol. 16, No. 2.

[10] European Commission (2018), Flash Eurobarometer 459.

Addressing barriers to firm entry and growth, while further opening up to trade and foreign direct investment (FDI), is important to promote competitive domestic markets. Pro-competitive product and service markets regulation contributes to the efficient allocation of resources and functioning of supply chains. In addition, empirical studies have shown that growth in sales is a prime determinant of firm growth (in terms of employment)[11]. As a result, policies that open up markets and facilitate access to consumers can foster firm growth and avoid the 'small firm trap'. Moreover, there is a trade-off associated with policies, laws and measures that are size-dependent (e.g. legal thresholds imposing different employment rules based on firm size; investment support for SMEs and, more generally, preferential tax treatment). On the one hand, these are important because of the competitive disadvantage often faced by SMEs, especially micro firms. On the other hand, however, they might discourage firm growth.

The growth of the most efficient firms – and exit of the least efficient or 'zombie' ones – occurs through reallocation of capital and labour in the economy. Hence, well-functioning labour markets and insolvency frameworks also play a role. Labour market institutions that foster this reallocation not only have to deal with flexibility at the entry or exit, but also with a broader range of policies that facilitate geographic and industry mobility of workers. These include housing markets, well-functioning infrastructure services for commuters, lifelong learning and retraining, to name but a few. Inefficient insolvency frameworks can instead trap resources in zombie firms. Therefore, bankruptcy legislation and judicial efficiency also play an important role, as does the treatment of business failures by legislation (e.g. second-chance rules).

The recent EU Directive on business insolvency will contribute to improving insolvency frameworks in the EU. It includes, among other things, common principles on early restructuring (which may result in better recovery rates for lenders as well as helping companies to continue their activity); rules for a second chance for entrepreneurs (by reducing the period after which they can make a fresh start); and targeted measures for Member States to increase the efficiency of insolvency frameworks.

Policies facilitating trade have an important role to play for business dynamism and resource reallocation. Reducing trade barriers, including administrative procedures at customs, facilitates trade integration and is especially relevant to GVC integration, where intermediate inputs are traded several times. In this respect, in the case of the EU, this concerns not only the completion of the Single Market but also agreements with third countries. Moreover, to avoid reinforcing existing gaps, policy should not focus on the national champions and incumbent superstars, but rather promote intra-industry competition and access to markets. Over the past five years, the EU has finalised (and, in some cases, started to implement) trade agreements with 15 countries, including Canada, Singapore, Japan and the Mercosur countries.

It must be highlighted, however, that there is no silver bullet for business dynamism, since similar policies can have very different impacts on firms both across and within countries. Across countries, different sectoral composition, institutions and even cultural differences matter. Within countries, there can be important regional differences and specificities; in addition, the business environment can weigh differently on the operation and growth prospects of firms of different sizes. In this respect, for example, medium and large businesses appear to be relatively less affected than SMEs by a lack of

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[11] OECD (2017) Business Dynamics and Productivity, OECD Publishing, Paris.

access to, and the cost of, financing, as well as by crime, corruption and the anti-competitive effect of firms operating informally[12].

7.2 Fostering catching up: the role of public expenditure in R&D

An additional policy area that can be investigated relates to innovation policies, and more specifically to government support to R&D. Griffith et al. (2004) unveil a 'second face of R&D' showing that it not only fosters innovation, but also enhances technology transfers because it increases firms' absorptive capacity. By engaging in R&D, firms accumulate a tacit knowledge that enables them to understand and assimilate existing technology and innovations. However, the concentration of business expenditures in R&D (BERD) suggests that low-productivity firms – generally younger and smaller – may also lag in terms of their efforts devoted to R&D. Accordingly, policies supporting R&D expenditures could help laggard firms develop their absorptive capacity.

Berlingieri, Calligaris, Criscuolo and Verlhac (2019) look at the role of government direct funding of business expenditures in R&D (with contracts, loans, grants and subsidies) using two different measures. First, such direct funding is normalised by GDP to provide a comparable measure of the level of support across countries and over time. Second, a measure of the composition (the source) of R&D funding is used, defined as the share of business expenditure financed by the government over total BERD. In a nutshell, the authors' results show that direct government support to business expenditure in R&D is associated with faster catch-up, providing evidence that direct funding of R&D projects through grants, subsidies or procurements may effectively raise firms' absorptive capacity as these might be more effective policies for firms with growth potential to access support.

Direct public funding of business expenditure in R&D takes various forms, such as competitive grants, debt financing (loans), risk-sharing mechanisms or public procurements, which may be particularly relevant for laggards. For instance, grants, loans and risk-sharing through credit guarantee schemes can reduce the cost of R&D and improve access to finance for otherwise financially constrained firms.

R&D procurement creates a demand for technologies and services that might help young innovative firms and can also provide early-stage financial support before the commercialisation phase (pre-commercialisation procurements of R&D). Each of these instruments may be efficient in promoting R&D business expenditure for firms with growth potential, but such policies are also part of a broader policy mix that can reinforce the effectiveness of these instruments by exploiting their complementarities.

7.3 Fostering catching up: the role of skills

Recent OECD work investigates the effect of the allocation of human resources, using the proportion of workers whose educational attainment level is well matched to the level required in their job. Results show that a good match between skills demand and supply is associated with a higher speed of catch-up, and there is evidence that this positive association is stronger in digital- and skill-intensive industries.

The study then focuses on the share of workers who are underqualified, measured as the proportion of workers whose educational attainment level is lower than that required in their job. Thus, this particular dimension of skills mismatch focuses on skills shortage. Results show that a lack of appropriate skills (as measured by educational attainment) in the

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[12] Bartelsman et al. (2010), Cross-country and within-country differences in the business climate, *International Journal of Industrial Organisation* 28.

labour force reduces the speed of catch-up and might contribute to the widening productivity gap, possibly reflecting the fact that low-productivity firms may struggle when competing for talents. This negative association between skills mismatch and the strength of the catch-up effect is particularly strong in digital- and skill-intensive industries. This result corroborates the view that changing skills requirements associated with digitalisation of the economy and the growing importance of knowledge in the production of goods and services erect barriers to diffusion when such skills are in short supply.

The previously mentioned results suggest that policies addressing skill mismatches through the better allocation of workers and a greater supply of appropriate skills could thus alleviate obstacles to diffusion. The same report focuses on the effect of training employed adults, proxying for lifelong training, as well as that of targeted training provided in the context of active labour market policies (ALMP). It shows that both lifelong training and education support diffusion, but without a significant difference in digital- and skill-intensive industries. In addition, it points to a positive relationship between training expenditure (from ALMP) and the speed of catch-up, particularly for digital- and skill-intensive sectors.

The stronger association between the speed of diffusion and higher spending in adult training in the context of ALMP rather than training working adults could reflect the need for targeted training. Indeed, the results confirm that under-qualification of the workforce is hampering the process of diffusion. The higher participation of working adults in training allows them to adapt their skills to continuously changing skill requirements. However, there is evidence that low-skilled workers are less likely to participate in on-the-job training than other workers (Nedelkoska and Quintini, 2018). Conversely, training targeted at the unemployed or closely related groups (e.g. people who are inactive but would like to work, and employed people who are at known risk of involuntary job loss) might better contribute to reduce skills mismatch and might disproportionately benefit low-skilled workers. Policies aiming at enrolling low-skilled workers in training, as well as policies specifically designed to improve their literacy and numeracy skills (see Windisch, 2015, for a survey of such policies), might contribute to lifting barriers to diffusion. In addition, other instruments are available to policymakers to reduce the incidence of skills mismatch. For example, McGowan and Andrews (2015) find that framework conditions, such as well-designed product and labour markets and bankruptcy laws that do not overly penalise business failures, are associated with lower skills mismatches, possibly because they reduce hiring and firing costs and allow smoother transition across jobs and, thus, better reallocation of resources across firms. The digital transformation not only alters the bundle of skills that is required, but also changes more broadly the relative demand of occupations, with some occupations becoming more prevalent and in high demand while others decline. This requires training and education policies that may be costly, reinforcing the need to define possible and acceptable transitions towards other occupations, while minimising the cost of such policies (Andrieu et al., 2019; Bechichi et al., 2019).

7.4 Fostering supporting framework conditions

Policy has an important role in addressing market failures and, more generally, fostering supporting framework conditions. High-quality regulation together with effective competition policy can complement flexible product and labour markets and innovation and skills policy by creating a level playing field.

Improving the quality of regulation implies simplifying and reducing regulatory costs without undermining the aims or benefits of the legislation, whereas badly designed laws and fragmented regulations act as a drag on the business environment. Services markets in the EU still present a number of inefficiencies that are closely related to the fragmentation of product market regulation[13]. Policy reforms aiming at simplifying product market regulation and completing the Single Market for services in the EU could help to unlock European growth potential notably by improving conditions for the services sector to make a greater contribution to productivity growth. For instance, ensuring better homogeneity in regulation could allow ICT to enter into non-digital sectors, thereby fostering the improvement of business models and potentially resource allocation[14].

Moreover, since investment in intangible capital is more sensitive to the regulatory framework than investment in tangible capital (i.e. labour and product market regulation)[15], improving regulatory quality could be particularly relevant for the most innovative firms which also invest more in intangibles. Indeed, Europe suffers from a persistent business innovation gap vis-à-vis the main competitors. For instance, new firms fail to play a significant role in European industry, especially in the high-tech sectors[16]. In addition to improving the regulatory framework and sound R&D and skills policies (as discussed in the previous section), strengthening the cooperation between academia and the business economy could then help to turn high-quality research into business ideas.

One of the key elements for supporting framework conditions is sound and effective competition policy. The European economic landscape still presents many industries with excessively high mark-ups, with persistent barriers to the entry of new competitors, stressing the importance of strengthening competition policy[17]. In addition, although the European framework of competition law has so far provided evidence of being sound and sufficiently flexible to protect competition in the digital era, the very evolving nature of digital markets calls for vigilance[18]. There are at least two types of challenges for competition policy in the data economy: (i) the identification of the market to regulate (i.e. regional, national, EU Single Market); and (ii) the presence of winner-takes-all dynamics, since the first movers tend to have a substantial advantage over potential new entrants, based on their learning. Without intervention, the market dynamics may lead to the creation of monopolies, while positive externalities may reinforce this trend further.

It is therefore essential to protect competition 'for' the market and 'on' the market. To protect it for the market, policy should make sure that incumbents do not enjoy an unfair advantage and erect barriers to the entry of new competitors. In the data economy, for example, this implies working towards multi-homing, protocol and data interoperability, and differentiation. To protect competition on the market, policy must ensure a level playing field so that firms enjoying a dominant position do not use their rule-setting power to determine market outcomes. In sectors that are open to international competition, this also implies that safeguarding, inflating, or helping incumbents just because they are 'national champions' should be avoided.

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CHAPTER
11

THE CONSEQUENCES OF AI-BASED TECHNOLOGIES FOR JOBS

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Summary

This contribution follows the recent public debate on the changes across industrial countries that stem from information technology, including notions of artificial intelligence and its implications for how work is performed. While acknowledging the size and pervasiveness of these discussions, the article discusses the core arguments related to the impact of information technology on the way businesses and organisations operate, how these changes could translate to the labour market, and other potential outcomes such as lower wages or unemployment.

The argument begins with an introduction to the two ways in which people tend to anticipate future developments. This either happens through estimates based on prior experience (commonly known as forecasting) or through a belief in a real uncertainty of future developments and reliance on other kinds of evidence besides traditional forecasts. The article maps the projected impact of technological uptake on the labour markets and reviews the empirical evidence. It touches upon many of the above-discussed trends, such as skill-biased technological change or routine-biased technological change, and their implications for skills demand. Applying an historic perspective, the article argues that predictions based on the past may be less relevant in the current context. Although new equipment and practices could eliminate certain jobs, on balance they do not necessarily destroy jobs because their overall effects on improving productivity and overall wealth create jobs elsewhere.

To understand why assumptions claiming that the future is like the past are not correct and extrapolations from prior experiences are unlikely to be accurate predictors of the future, read this chapter.

Recent discussion first in the business press and then in related public policy communities has considered the notion that industrial countries are on the verge of important changes that stem from information technology (IT) broadly, including notions of artificial intelligence (AI), and its implications for how work is performed. The size and pervasiveness of these discussions merits a serious look at the ideas behind them and the fundamental question they ask: is there something happening already or about to happen in information technology that will change in a fundamental way businesses and organisations, jobs, and outcomes like pay and unemployment? I consider these issues below.

1. The nature of the discussion

Before considering the arguments and assertions about the implications of evolving IT, it is worth thinking through the context in which those stories take place. Followers of the media are well aware that there is a bias toward reporting stories that represent something new, especially something new and dramatic. That includes claims about developments that will happen, even if there is little or no evidence of them yet. We may notice these stories especially when they relate to health, e.g. epidemiological studies showing that some particular food group is associated with either remarkably better or worse life outcomes. It is extremely difficult to run a story that says, for example, 'still nothing new in effective weight loss'. A first question to ask is whether the apparent magnitude of the stories of technological change reflects a change in the nature of the media and public discourse rather than reflecting something about the merits of the arguments themselves.

There have been changes in the media that might help create the impression that particular stories are more important than would have been the case in the past, such as the fact that there are now many more outlets for stories, including social media, where surprising or frightening accounts are repeated and reinforced over and over. There is also considerable expansion of organisations focused on public policy, especially those businesses which advocate ideas that are important and support those that attract attention. Hosting discussions, producing reports, commenting on media stories are standard practices for such organisations. Every major consulting company now produces reports and markets their views on policy-related stories, including technology and workplace topics.

The fact that there is a great deal of discussion about IT certainly suggests that it is a topic worth investigating, although it is not prima facie evidence that the arguments which provoke that discussion are correct. The truth is typically more boring than the speculations.

2. Anticipating the future

Assessing the merits of arguments about the potential effects of IT in the workplace or elsewhere should begin with thoughts about epistemology: what is it that we know, and how can we know it? Specifically, how can we distinguish reasonable belief from mere opinion? What constitutes knowledge is always a pertinent question, but it is especially important in this context because of the unique nature of the claims being made. They are claims about the future rather than the present, although they may well be informed by the present.

There are at least two quite different types of claims about the future that are made in the social sciences. The first concerns probabilities and risk: we have very little idea about, for example, whether my house will burn down but, based on prior experience of houses like mine, we can estimate with considerable accuracy what the odds of that are.

Forecasts move us from predictions about common events and about individual units in a population to anticipating events that have not happened before. They go a step further than identifying average experiences in the past to extrapolate from the past. To predict, for instance, the unemployment rate in a year's time, they look back to previous unemployment rates and to variables that determined them or at least were associated with them. If the model using those variables explained a reasonable amount of the variation in previous unemployment rates then we will try to use it to extrapolate into the future. We do so by assuming that the structure of the model remains the same going forward or, in practical terms, that the coefficients of regression-related models in the future will be the same as they are in the model. Assuming we have more recent values for the variables in the model, we apply them to that model and generate an estimate or forecast as to what the unemployment rate will be in the future.

A great advantage of this approach in terms of epistemology is that we have some ability to assess how accurate our forecast of the future is, based on how well our model has predicted outcomes in the past.

The downside of the approach is that the assessment of accuracy does not work, nor will the model produce an accurate forecast, if the model's underlying structure (the relationship between the variables and the outcome being forecast) changes from the earlier period. For example, economic forecasting models in the United States that proved remarkably predictive in the 1960s stopped being very accurate in the 1970s and after, apparently because of changes in the structure of the economy. It took some time to recognise that change, and the accuracy of the models never recovered to their previous levels.

The second type of claim is one where we believe that there is true uncertainty about the future, where average experience in the past is not likely to continue into the future, and the structure of forecasting models changes in ways that are not clear *a priori*. In this context, the concerns of epistemology become much more important. Other kinds of evidence besides traditional forecasts also become more important. For example, explanations that have predicted well in the past, perhaps in different contexts, might be useful. The role of theory that has been supported over time by evidence becomes important. We might not now have a good idea what the effects of new technologies will be in the future, for example, but we might well believe that the effects of previous technologies would be informative and that principles like supply and demand will still be relevant in explaining what they will be. Other evidence might include examples consistent with the prediction in subsets of the population or trends in the direction of the prediction (e.g. leading companies are doing this).

The complication in assessing claims about the influence of IT and AI is that most of the attention-getting claims are based on the assertion that the future is not like the past, that the new developments in AI will change the structure of the relationships such that extrapolations from prior experiences are unlikely to be accurate predictors of the future. We might think of this as a double uncertainty: we cannot say with any certainty what IT innovations will look like in the future, let alone how they will affect the economy. Such claims are difficult to assess in traditional ways because they do not have an empirical basis. When we cannot test how well explanations actually work – in this case because the events being explained have not yet happened – we are forced to use other kinds of assessments.

These other approaches rely on the structure of the arguments being made. A common standard is whether the explanations are deduced appropriately from principles that have already been established, the standard deductive-normative format for generating normal science hypotheses. Beyond that, we often use criteria that are not well justified, such as *ad hominem* arguments – the person making the case has been right before or they are an 'expert' on the topic.

In recent decades, one of the more important developments in business has been to come to grips with the problem of uncertainty. On the one hand, we can never be certain about any aspect of the future, although we may be confident that some aspects are good enough to plan on, such as the sun coming up tomorrow. But what can we do when we are aware that our predictions or forecasts are not very good? We use these concepts below to consider the merits of the arguments about the future impact of AI.

3. The nature of the claims

A major complication in assessing the claims about what AI might do to the workplace and to employment in particular is that there are so many of these claims. In many cases, the same individuals have made quite different claims over time, requiring some condensing and organising of them.

The place to begin is with a definition of AI. A standard for determining what a term means is that it should not overlap with other terms that refer to similar concepts. The common and arguably standard definition of AI in dictionaries and elsewhere dates from a 1956 symposium of cognitive scientists who proposed a research programme to investigate it (Minsky, 1994). The general idea at the time was that AI is machine-based thinking that mimics what humans can do.

However, defining what thinking actually is continues to be elusive. Alan Turing (1950) proposed a simple test of AI which is whether a machine could fool a person into believing that its responses to questioning were actually from a person. More sophisticated and didactic definitions focus on thinking that only humans can do, which includes reasoning, judgment and learning. By that definition, AI would seem to be a continually shrinking domain as machines become capable of more and more tasks: computing power and programs that formalise decision-making enable computers to solve more problems. Calculations that only humans could do generations ago can now be done on pocket calculators.

Definitions of AI continue to change as practice changes. At least some observers have abandoned the notion that AI is about distinctly human intelligence and describe it as the study of any kind of intelligence; others differentiate between 'weak' or 'narrow' AI, focused on solving particular problems, and 'strong' or 'general' AI that can solve problems across domains.

Whether one sees these debates over the nature of AI as semantic, practical, reacting to developments in practice, or conceptual – ultimately turning on epistemology and notions of knowledge – securing agreement on a definition is difficult. Fortunately, it is probably not necessary for the task at hand to have a clear differentiation about what AI means as the claims about effects on the labour market are mainly about IT as it is conceptualised now.

Arguably, the most useful applications of computers today are in data science with the most immediate implications for jobs. Here, many of the new applications do not necessarily involve reasoning, judgment, learning or anything like thinking. 'Big data', for example, is simply software to handle statistical processes with data sets that had been too large for traditional programs to handle; machine learning, at least in its general format, is a technique for finding relationships between variables; and algorithms are just decision rules derived from evidence that do not necessarily require computer power, while those derived from machine learning make predictions that can be validated. Natural language processing and speech recognition are, in essence, pattern-recognition problems that become possible for machines to do as computing power increases. Most of the claims concerning the effects of AI are, in fact, assertions about data-science tools like those above.

The next step in beginning our analysis is much more straightforward: i.e. to consider the outcomes of IT that are of interest. Following the debate in the popular press, we are concerned with the effects of AI on jobs – in particular, whether it increases or reduces the number of them – and, to a lesser extent, how it might change the tasks required of jobs, the skills needed to perform them, and the quality of jobs widely considered.

That leads directly to the claims about the effects of AI that are currently the focus of attention. The most important of these are assertions that developments in AI will eliminate large numbers of jobs and, in the process, create long-term structural unemployment and lower wages, especially for lower-skilled individuals.

4. A brief history of research on AI and the labour market

Concerns that modern technology will lead to unemployment go back to the early days of industrialisation, at least to the Luddites in the early 1800s who protested against the new factory system that threatened the income of more skilled workers (Thomas, 1970). The possibility that new industrial technology was eliminating jobs became a long-standing political question thereafter in the UK and in much of Europe, but less so in the United States where unemployment, at least until the Great Depression, was less of a concern. In all industrialising countries, the mechanisation of farming, along with new agricultural techniques, were displacing workers and the concern arising from looking at projections was that the manufacturing economy could not accommodate all those soon-to-be displaced workers (Fano, 1991). The Great Depression kindled the debate about the role of technology in jobs, not just because unemployment was so high but because the evidence even then suggested that, in the 1930s, the United States experienced a massive jump in productivity (Bix, 2000) that was seen as contributing to job losses.

Nevertheless, in the 1960s, a period of dramatic economic growth and low unemployment, concern that technology and automation were causing unemployment was a political concern because of the perception that technology was and would be advancing quickly. America's President Johnson set up a commission to investigate the evidence for that concern, which subsequently concluded that there was little evidence for it (Automation Commission 1966).

The concern about computers and jobs *per se* developed later, partly because the rise of computers became quite gradually. Perhaps ironically, initial concerns appeared to be driven by a question of financial accountability when investments in computers and IT generally began to increase. Complaints from the world of investors questioned these investments because there did not appear to be an associated pay-off from them in terms of operating efficiencies (e.g. Straussman, 1997). The famous quip from economist Robert Solow – 'we can see the computer age everywhere but in the productivity statistics' – captured the difference between the rhetoric about the value of IT and the apparent reality. That apparent reality became known as 'the productivity paradox'.

For our purposes, the evidence on IT investments and productivity matters because productivity is typically measured in terms of labour, output per employee. The most straightforward manner in which productivity increases is when firms use fewer workers for the same output, or a smaller proportion of workers for greater output. Dedrick et al. (2003) review the earlier literature on this topic and note that initial studies, through the mid-1990s, did not find evidence of any significant return on the investment in IT.

Research into labour economics about computers had been energised by Krueger's (1993) finding that wages were higher, other things being equal, for individuals who used computers at work. This finding helped to kick off a number of arguments that are continuing today, suggesting that using computers contributes to better-paying jobs, presumably because such jobs require more skill. (It should be noted that this is the opposite of most contemporary claims that computers will make outcomes worse for workers.) The implications were that jobs that did not require computers would fall behind in pay, helping to explain an aspect of the 'digital divide', inequality of various kinds but especially in pay associated with access to IT and the internet.

Cold water was thrown on this conclusion – although frankly only in the academic world – by DiNardo and Pischke's (1997) finding that workers who used pencils also earned higher pay. Their tongue-in-cheek title about pencil use referred to their finding that workers who were using tools associated with working at a desk earned more, suggesting that it may not have been the use of computers that was associated with higher wages but simply doing the kind of jobs for which computers would be useful that paid off. The study illustrated the common problem of omitted variables, in this case that what was associated with computer use also mattered.

By the 1990s, there were two different streams of research interested in the relationship between computer use and employment outcomes: economists studying the effects of IT on business, whose interest was looking for productivity improvements, and economists and some sociologists, whose interest was looking for explanations for wage differences. As Dedrick et al. (2003) note, the former stream of research shifted for the analysis from the national and industry-level down to individual firms where they began to find evidence of greater business outcomes associated with IT investments. These results were replicated in Europe although not in developing countries, while the size of the effects appeared crucially to depend on accounting decisions that determine which costs are associated with IT investment measures: is it just the hardware and software, does it include the training costs of employees, the reorganisation costs, and so forth.

An important finding in many of these studies was the considerable variation in the relationship between IT and performance across organisations. Bresnahan (1999) helped kick off a new direction in the IT productivity debate related to that variability by focusing on the changes in business organisation – more commonly referred to today as restructuring – that are associated with the successful introduction of IT investments. Bresnahan, Brynjolfsson and Hitt (2002) and a string of subsequent studies identified the synergies between investing in IT and changing the organisation of work to explain performance improvements. This research relates to the DiNardo and Pischke notion that it may not be the computers *per se* that are driving the outcomes of interest but rather the changes in existing practices that they produced.

On the labour economics front, Autor, Katz and Krueger (1998) found that skill upgrading was greatest in those industries that had made largest investments in IT, suggesting a different complementarity between labour and IT. This result is related to the earlier Krueger (1993) finding – the idea that computer use raises skill requirements and, in turn, wages. Autor, Levy and Murnane (2003) examined the apparent association between the introduction of computer-based systems and more college-based labour with an explanation that computers take over repetitive, lower-level tasks and therefore eliminate lower-paid jobs and provided evidence at the economy level to support it. These studies align with others about the rising relative wages of college graduates compared to those with qualifications less than college degrees to reinforce a notion that became known as 'skill-biased technology change'. This view of the world articulated by the labour economic studies remains dominant in the popular press although, as is shown below, the evidence related to it increasingly counters that view.

Before turning to the extensive body of research carried out since then, virtually all done in economics, it is important to understand some of the assumptions that underlie that research. First, when economists talk about 'technology' in the broad sense, they mean anything that changes the production function – new management techniques, capital investments in equipment or IT, presumably even new priorities, and so forth (see Auto, Katz and Kearney 2008 for an explicit statement on this). Observers often assume that conclusions about the effects of technology refer to IT, but unless the studies are measuring IT explicitly, that is not the case.

Second, with few exceptions, studies that measure computer investments claim to be capturing the influence of IT *per se* and not, as Bresnahan and others found, a mix of organisational transformation and new ways of organising work which are associated with the introduction of computers. This relates to the *ceteris paribus* assumption and, when it is violated, to the problem of omitted variables.

Third, the assumption is that the educational qualifications of those in jobs are an accurate measure of the requirements of those jobs. The practical reason for this assumption is that it is relatively easy to access data on the education of individual employees but quite difficult to get data on the requirements of jobs. As a result, changes in the percentage of individuals with college degrees and in the wages associated with those jobs are interpreted as changes in skill requirements and in the demand for skill. Careful observers, especially those outside economics, question the reasonableness of that assumption (see, e.g. Liu and Grusky, 2013).

Finally, economists, indeed all social scientists, attempt to advance arguments associated with their paradigm typically at the expense of other explanations. It is often heard that historians attempt to provide a complete explanation of the phenomena they are studying, but there is no credible claim for that in the social sciences. A simple explanation, consistent with the underlying paradigms, is far preferable in our respective disciplines to a complicated explanation that includes multiple and particularly unrelated components, even if the latter explains much more of the phenomenon. Evidence for this is easy to see in any empirical study, where the amount of variation explained by the explanations submitted is only a fraction of the total variation.

This last point is especially important in making sense of the research on IT where it is often claimed that x is the cause of y when, in fact, the best we can claim is likely to be that x is one factor associated with y.

5. Skill-biased technological change

Although not related to IT *per se*, the notion of skill-biased technological change is often used to explain or at least support the claims about how IT is changing outcomes in the job market. At its heart is an older theoretical argument often credited to Polanyi (1944) which asserts that new technology inevitably raises skill requirements, because higher skills are needed to use the new technology[1]. The inevitability assertion is manifestly not true as the thrust of modern industry and techniques such as scientific management were designed precisely to reduce the skill requirements in individual jobs, e.g. by breaking them up into simpler sub-tasks. (It may well be true that the initial introduction of a new technology, such as computers, requires considerable skill to use them, but later modifications make them easier and easier to use. For example, cash registers with pictures on them are computers for checkout assistants that do not even require literacy. 'Technology' in these studies is not measured directly but is assumed as an underlying development of modern economies.

Katz and Murphy's (1992) extremely influential study arguably kicked off the contemporary version of this idea by finding that the 'college premium' – the ratio of what an average college graduate earned in the economy to what the average high-school graduate earned – rose sharply in the United States at a time when the proportion of the labour force with a college degree was also rising. Despite the rising supply, the apparent price of skill had also been rising, as measured by the college wage premium. The authors argued that changes in demographics and, more generally, on the supply side did not account at least for the recent rise in the college premium, so the explanation must lie with an increase in demand.

Something of a consensus developed among many that new technology, particularly information technology, caused an increase in the demand for skill. The topic was particularly popular because it was seen as an explanation for the dominant issue of the early 2000s, which was rising wage inequality. Many studies followed the Katz and Murphy paper in exploring changes in the college wage premium. A broader and more general study of the relationship between education, technology and wages makes a similar claim over a much longer period of time, suggesting that surges in the supply of college graduates moderated the fairly continuous increases in the demand for skill in American economic history (Goldin and Katz, 2008). The phrase 'skill-biased technological change' emerged from these empirical studies.

Although they received less attention, many studies questioned the skill-biased technological change idea. In particular, the occupational shifts that seemed to be the basis of the evidence of skill upgrading had been under way for at least a decade before IT investments became substantial. Card and DiNardo (2001) noted that the college wage premium did not track measures of actual technological change well and concluded that it was not a very helpful concept for understanding changes in wage structures. Card and Leimuix (2001) found that, in the 1990s, the sharply rising college premium was not true across the labour force but was mainly attributable just to the experience of young people. (Mishel and Bernstein (1994) present a sweeping critique of the IT explanation.)

Despite the lack of correspondence with much of the evidence, skill-biased technological change had a great deal of appeal because it was useful in understanding growing wage inequality, a topic of enormous policy interest, and the related issue of the apparent growing wage premium for college graduates over non-graduates. Later critiques further weakened empirical support for the idea, however. Schmitt, Shierholz and Mishel (2013) presented a series of examples in which the notion of skill-biased technological change is inconsistent with the evidence. This included the fact that it was

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[1] Polanyi actually says very little about technology as his arguments focus on the relationship between markets and institutions in the transition to industrial economies.

inconsistent with wage trends after 2000. More recently, Beaudry, Green and Sand (2014) found that the demand for higher skill appears to have declined since the early 2000s. Valetta (2017) also found that the college premium has been declining.

Acemoglu and Autor (2012) signalled a pivot away from the simple view of skill-biased technological change. They noted that it did not work outside of the 1963-1987 period which was the basis for the Katz and Murphy study. They calculated workers' average weekly, with inflation discounted, over time and by education level – high-school dropouts, high-school grads, those with some college background, college grads, and those with graduate degrees – and found that the wage gap between those different groups in the early 1960s and then again in the mid- to late 1970s was quite small, as Richard Freeman had noted earlier. Then right after the 1981 recession, real wages for everyone with less education than a four-year college degree started to collapse and continued to decline through the early 1990s. The rapid decline in high-paying, union manufacturing jobs and the rise of low-wage competition from China in particular certainly played a big part in the explanation. Although wages for college grads did not take off, they did eventually recover some of their lost ground.

The result of these two movements – the decline of real wages for everyone, the continuing decline for high-school graduates, and the modest improvement for college graduates – created the wide gap between the groups and a sizeable wage premium for college graduates which started in the 1980s. The fact that the college premium appeared to be caused more by the decline in high-school wages than by the rise of college wages did not fit the demand-side explanation of skill- biased technological change. It appeared to be a story about which group lost the fastest as both high-school and college graduates have seen a fall in real wages since 2002 (Shierholz, Davis and Kimball, 2014). Demographic trends also had a big effect on wages across age cohorts (Jeong, Kim and Manovskii, 2014) which affected the college premium across cohorts; the college premium for students from poorer families is about half of that for wealthier families (Bartik and Hershbein, 2018), partly reflecting the graduates' unobserved attributes. More than one-fifth of the college wage premium also appears to be associated with cost of living differences because college graduates tend to live in more expensive places than high-school only graduates (Moretti, 2011).

Acemoglu and Autor (2012) moved the discussion back towards a different explanation of technology that was consistent with Autor's earlier studies – i.e. that computers in particular eliminate routine jobs. The difference now is the assertion that those routine jobs were in the middle of occupational and wage structures. We could call this the 'hollowing out' view. From this point on, most research abandoned the simple notion of skill-biased technological change that economic growth inevitably generated higher skill requirements.

Schmitt, Shierholz, and Michel (2013) presented a sweeping critique of the hollowing-out notion as well, noting that it does not explain changes in occupational distribution after 2000 (in particular, low-wage jobs have been growing), that occupational changes have not driven changes in the wage distribution, and perhaps more importantly, that changes in the occupational distribution associated with a shrinking middle began long before the modern computer age[2]. Barany and Siegel

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[2] The fact that the studies from the Economic Policy Institute (EPI) attack so consistently the simple explanations for changes in wages and jobs may be seen by some as reflecting an interest in focusing the discussion on the role of policy in shaping labour market outcomes. However, but it is also fair to note that, unlike the paradigm-based research articles, they are focused on explaining the phenomena per se rather than advocating a conceptual explanation.

(2018) document that the declining middle in the US occupational structure was under way decades before the IT expansion of the 1990s and appears to be related in the economy as a whole to the shift from manufacturing jobs to service jobs. We consider more studies below on IT *per se* that also contradict this notion.

What should we conclude about the skills- biased technological change idea? First, the original incarnation of the argument, that technology inexorably increases skill requirements and, in turn, alters the demand for skill and wages, has been largely abandoned by researchers. Second, the job-polarisation version differs fundamentally from the original – in particular, there is no assumption of ever-increasing skill requirements – and mainly only shares an underlying supply-and-demand mechanism.

As Howell and Kalleberg (forthcoming) note in their extensive review of explanations for recent wage and occupation changes, there are other explanations at least equally – and arguably more – compelling than job polarisation for labour market outcomes. These focus on changing power relationships which have allowed employers to squeeze lower-skilled workers and the highest earning individuals to secure more income. For example, Kristal (2013) finds that the introduction of computers made workers more replaceable which lowered their wages. These arguments do not have the advocacy the job-polarisation idea and its supply-and-demand underpinning have, at least among a large number of economists studying labour market outcomes.

As shown below, there is certainly some evidence for IT changing occupational structures, although how much of the change is truly driven by IT as opposed to coinciding with trends already under way, and how much is caused by factors associated with IT, such as the associated restructuring of organisations, is not clear.

6. Forecasting the effects of IT on jobs

Although the above-mentioned research has had considerable influence on popular thinking about the effects of IT, more important for our purposes are the studies concentrating on the topic of IT use. Recently, much and arguably most of the research on the relationship between IT and jobs has been motivated by the practical concern as to whether IT will eliminate jobs. This stream of research has been motivated largely as a reaction to forecasts, specifically pessimistic forecasts, about the likely effects of continuing advances in IT which claim that new and emerging developments in computing power, in software, and in data science are fundamentally different from those seen before.

Arguably the most important of these prediction arguments is from Brynjolfsson and McAfee (2011) who argue that the IT technology emerging now is fundamentally different from what has been seen before and will affect the workplace differently than what has been seen before. The most attention-grabbing claim in their book, which appeared at a time of substantial unemployment in the United States, is that this new technology will lead to substantial job loss. Schwab (2016) essentially adopted this view, as did many reports written by consulting companies.

It is not possible here to review or even catalogue all the reports from outside the academic and policy world, although they have some common themes. First, in terms of approach, they are typically authored by practitioners outside IT fields. They tend to rely on surveys that ask executives what they believe about the future. Second, in terms of conclusions, none of them appear to claim that the future will look more or less like the past or that the changes associated with IT are similar to those experienced before. The typical conclusions repeat assertions that IT will 'disrupt' the way business is done and that businesses need to figure out how to deal with these developments. Many of these conclusions are dramatic: Bain, for example, forecasts that half of all current jobs in the United States could be eliminated in 15 years and that US employers will need 30 to 40 million fewer workers by 2030 (Harris, Kimson and Schwedel, 2018).

By contemporary research standards, these claims contradict evidence which has been consistent since the Industrial Revolution that while new equipment and practices eliminate certain jobs, on balance, they do not destroy jobs because of their overall effects on improving productivity and overall wealth create jobs elsewhere. Autor (2018) articulates the many paths through which technology that increases productivity boosts economic growth and why, in modern history, it has not yet led to job losses.

As noted above, the epistemological problem raised in assessing these reports is how to separate assertions that we might dismiss as mere opinion from something that we would consider a true belief. If it is reasonable to conclude that future developments in IT are so unlike the past that we cannot use prior experience to assess them, then we cannot use evidence to assess those assertions.

One approach, adopted below, is to dismiss the claim that when new IT developments come they will be so distinctive that we cannot learn anything about their likely effects from prior experience with technology. When we think about historical developments in transformative technology, such as the rise of steam power, electricity, the first computers, and so forth, it does not seem credible to suggest that nothing could be learned from such experiences. If we have yet to see these technologies, then assertions about whether their effects will be so different from anything seen before seems very much like opinion rather than a true belief.

There are areas of inquiry where predictions are made consistently about events for which we cannot generate traditional forecasting models because in the past there were not enough similar circumstances – possibly none – to use as a basis. We could consider these sui generis predictions. Concerns about how a political leader will react to a challenge, whether countries will go to war at a particular moment, or whether 'society has changed' may fit this prediction category. It is also the case that we have to make predictions where forecasting models are at least conceptually possible although, for a variety of reasons, such as time pressure or lack of resources, they cannot be constructed.

We might describe the effort to make such predictions as 'expert judgment'. Tetlock (2017) studied the phenomenon of predictions by experts extensively, in particular with respect to political events. He found that experts' accuracy in making these predictions barely surpassed 'monkeys tossing darts at a dartboard' or, less creatively, were no better than chance. Predictions of societal and political events are perhaps not common enough to be able to tell if those who are 'good' at predicting have just been lucky. However, Tetlock and Gardner (2018) engaged in a sizeable exercise to see what makes some individuals better than others at actually predicting events that could be confirmed later. Their conclusions are important to bear in mind when looking at forecasts concerning the future of IT.

Those who are worse at predicting are highly confident of their abilities – over-confident; experts who are deeply focused on their subject, 'hedgehogs' according to Isaiah Berlin, are also worse when compared to those with wider expertise, the 'foxes'. Followers of grand theory, which would include the economics paradigm, are worse at predicting. Conversely, those who question assumptions, who look for comparable situations and events elsewhere, and who consider the counter arguments to their positions do better at predicting.

The reports above tend to assume the most important conclusion – that IT developments will be transformational – and from there pursue implications that sometimes extrapolate from current circumstances. Applying Tetlock and Gardner's (2018) criteria, the studies rarely, if ever, question or even identify their assumptions, consider counter arguments, or believe that much could be learned from other circumstances. It is also worth noting that consulting companies in particular have a material interest in securing business that is not always perfectly aligned with presenting the most accurate story. These reports are marketed aggressively and have considerable influence on business leaders who, in turn, are often the empirical source for the next set of studies.

One of the most influential predictions about the impact of IT, especially among practitioners, was conducted by Frey and Osborne (2017). It asked computer experts to assess whether, under the best circumstances, it was possible for computers to take over the central tasks of a set of jobs or if it will be possible to do so soon. Their assertion that almost half of the jobs could be taken over by computers forms the basis for the conclusion in many of the practitioner reports that those jobs *will* be taken over by computers and soon.

Unfortunately, the prediction stopped there. The question did not ask for a prediction of what will actually happen in the real world. There is an enormous gap between what is technically possible to do, the question asked of computer experts, and what is practically useful or financially viable to do. We can, for example, go to construction sites almost anywhere in the world and find tasks being performed by hand that could easily be performed by existing machines. The fact that loads are carried by hand and holes dug using shovels in many parts of the developing world reflects the fact that labour is so much cheaper than equipment, not that the workers are unaware of trucks or backhoes. Then there are tasks that IT and robots can perform now, although they are not good at them. Mechanical robots can create alcoholic mixed drinks the same way as bartenders do, but a colleague who observed this indicated that the quality of the drinks was poor and it took two employees to support and service the robot whenever it was in operation. The machine did the task, poorly, and at incredible expense.

The Organisation for Economic Co-operation and Development (OECD) (2018) took the Frey and Osborne estimates at face value and then used estimates of job requirements from the Programme for the International Assessment of Adult Competencies (PIAAC) skills survey and concluded that roughly 14% of jobs met the criterion that machines could or soon would be able to perform them – i.e. A much smaller number. Whether they will take over those tasks and whether doing so will eliminate jobs is another question considered below. Arntz et al. (2016) had earlier conducted an estimate similar to that of Frey and Osborne and concluded that 9% of employees were in jobs that were likely to be automated.

Forecasts for the effects of technology have been more difficult to predict than the political and social events studied by Tetlock (2017) and Tetlock and Gardner (2018). In fact, there is something of a sport in reminding us of how poorly we have been able to anticipate not only which technologies will succeed and when they will arrive but what their influence will be when they do. For example, Funk (2017) revisited the technology predictions of MIT's Technology Review and found few examples of success, while management scholar Joseph Switter (1965) predicted that, by 1985, computers would take over most management tasks. Predicting the implications of technology was a hot topic in the 1960s, when researchers were aware of the many factors outside of technology *per se* that affect its introduction, such as actual demand for it, especially relative to competing solutions, social and political implications of using the technology, and so forth. They articulated techniques for making such predictions that include analysing switching costs to new technologies (see Quinn 1967 for an example), none of which seem to be used in the current forecasts.

7. Evidence of the effect of IT on jobs

We turn now to recent empirical evidence that relates to the predictions above. Beginning with the Brynjolfsson and McAfee (2011) assertion that new IT technology is fundamentally different and will lead to a net reduction in jobs, the current economic environment, at least in the United States with record low unemployment, offers that notion less sympathy than when it was articulated during the Great Recession. More recent research gives it no support. The job-polarisation hypothesis – that IT is eliminating and will continue to eliminate more routine jobs – also receives little support in more recent research.

Bessen (2016) looks at US data and finds that increased IT use is actually associated with more jobs. He also finds no evidence of job polarisation associated with greater IT use. Aum, Lee and Shin (2017) found that IT investments were actually smaller for lower-level jobs doing routine work than for higher-level jobs, which is inconsistent both with an earlier view that IT eliminates lower-level jobs and with the notion that it disproportionately targets middle-level jobs. Gregory, Salomons and Zierhn (2016) also conclude that there is no evidence of IT use reducing employment in Europe. Boreland and Coelli (2017) examine IT use and employment in Australia and find no evidence that greater IT use has reduced employment or has it decreased employment in jobs that would seem to be routine in terms of skill. In fact, there is no evidence that greater IT use has been associated with greater changes in sectors of the economy where IT investments have been the greatest.

The underlying logic behind the job-loss idea is that where IT does not eliminate jobs altogether, it changes skill requirements, rendering incumbents unqualified for further employment and costing them their jobs. Allen and de Grip (2012) examine the general question of whether skill obsolescence increases the probability that individuals will lose their jobs and conclude that, in practice, it does not. One explanation for that lack or relationship is that individuals and employers recognise when skills may become obsolete and respond accordingly, through retraining and other ways.

An important issue in understanding the outcomes of IT on jobs and labour outcomes in general is the distinction between tasks and jobs. Jobs are typically defined as a collection of tasks. Except for the very simplest assembly-line work, most jobs include many tasks: virtually every job description and employee handbook in the United States ends the description of any job with the phrase 'and tasks as assigned', which means that supervisors can add virtually any task to the job of any employee.

This simple fact that jobs comprise many tasks gets to the heart of many misunderstandings about the effects of IT on employment. The applications of IT to work are typically task-by-task: at the lower-skill end, dispensing cash through ATMs, at the higher end, reading x-rays and digital images. The reason the pundits were wrong in expecting that ATMs would eliminate bank teller jobs is that tellers have many tasks besides simply dispensing cash. Radiologists do read x-rays, but they also have many other tasks, including consulting with other doctors and patients, advising on treatment, and so forth, which means that algorithms which 'read' x-rays do not eliminate their job (Brynjolfsson, Mitchell and Rock, 2018 acknowledged this complication).

The fascination with autonomous or self-driving vehicles that swept the business press a few years ago fixated on the prediction that such vehicles would eliminate the job of truck driver: the European Automobile Manufacturers' Association (2017) predicted, for example, that half of all trucking jobs would be gone within 10 years. That conclusion ignored the reality of what most truck drivers do, which is to make deliveries, only one part of which is to drive to the locations in question. No sensible business would pay for self-driving trucks and then hire a worker just to ride along until they arrived at a delivery point unless the cost of such trucks became negligible. Gittleman and Monaco (2019) calculate that if autonomous trucks do arrive, the job losses associated with them are roughly one-tenth of what popular accounts are claiming because of the above-mentioned caveats.

Remus and Levy (2016) examine how IT and data-science technologies are affecting the practice of law. This is relevant because the ability to search cases and build legal arguments can now be done electronically. They conclude that these technologies are not eliminating lawyers – they are simply automating one research-related task, allowing lawyers to focus more time on others. As an example, consider situations where IT simply provides new information used in decisions. As noted above, machine-learning algorithms that read x-rays to look for tumours or interpret other medical tests are not eliminating the doctors who make the diagnosis about a patient. They provide a new and important set of information that is combined with other information – patient histories, blood and genetic tests, and so forth – that doctors use to make diagnoses. It is possible to imagine a future where the entire judgment process is taken over by robots, but that vision is so far away at this point that we are simply projecting it. Autor (2015) also notes that even when new technologies do eliminate tasks, and possibly jobs, the changes take place quite gradually.

Bresnahan and Yi (2016) offer the most sweeping refutation of the notion that new IT will eliminate jobs by reminding us that IT and technology generally alter products and services in ways that give customers additional benefits and features rather than simply automating existing features. They are typically not producing the exact same product or service. As a result, tasks are not necessarily eliminated. The technology itself creates new products and services or aspects of existing services that create new tasks. One such example is the now common experience of shopping online where the website suggests other products and services the shopper might purchase. Some of those products and services may require connection to an employee. Online travel bookings may lead to recommendations for insurance purchases or requests for advice on health issues associated with travel, such as vaccinations. In that case, the new technology has created new services that did not previously exist and new tasks for humans, thereby increasing the demand for human labour.

We also know that many tasks that appear to be done by IT actually involve workers behind the scenes. Gray and Suri (2019) document an entire workforce that has been created to support – unseen – tasks associated with doing business on the internet, such as matching individuals' images to their security photos or editing social media content. No doubt at some point those tasks might become automated, but at present it is cheaper and easier to have them done by people. (The jobs are low wage and performed by arms-length contractors so we should not imply that good jobs have been created.)

8. Robotics and automation

Robotics – the field associated with robots – is the arena where we might expect to see the greatest effects on jobs. It seems quite difficult to come up with an exact definition of a robot, but it is clear that it relates to the application of computer-science techniques to tasks that mimic human behaviour, typically involving the physical world. What differentiates robots from machine tools is that robots have some autonomy: their programming allows them to adapt or adjust to change how it responds to circumstances. A metal press may be a sophisticated and expensive tool that increases labour productivity but it is not a robot. If we add computer programming to it so that it can adapt its performance to the differences it perceives in the metal coming into contact with it, then it may well be. Similarly, 'chat bots' that answer questions asked by individuals in conversation form are typically seen as a type of robot even though they do not engage with the physical world. Although the ability to process natural language in the form of human voices is impressive, their ability to adapt – which is central to robotics – rather than simply respond to an array of questions is quite limited.

Because robots are a specific application of IT to human tasks, we might expect their use to be particularly associated with changes in jobs. However, as with other forms of IT, the ability to take on individual tasks does not necessarily correspond to a complete job. Like the more general aspects of IT noted above, the robotic industry appears to have shifted its focus from efforts to take over complete jobs to efforts to assist workers in jobs by taking over individual tasks, a much simpler outcome than attempting to take over all the tasks an individual has to perform. In this context, it is useful to note that the set of tasks assembled to create jobs that people do is based on both the logic of what humans can do as well as what organisations need. That logic is not the same as what machines and IT can do, so the notion that IT will somehow will neatly map on to existing jobs is mistaken.

Assessing the possible effects of robots on jobs is essentially the same exercise as assessing the effects of IT in general on jobs. There have been some specific efforts to examine investments in robots *per se*, with Acemoglu and Restrepo (2017) attracting the most attention with their study on spending on robotics showing a negative relationship with regional employment. As Mishel and Bivens (2017) point out, such results do not hold for automation other than robots which had a positive relationship with employment. Graetz and Michaels (2018) use evidence across 17 countries and find that a greater use of robots did not have a significant negative effect on employment. Dixon, Hong and Wu (2019) conduct one of the very few studies at the firm level, using data from Canada on computer use matched to data on firm practices and outcomes. They found that greater computer use was associated with greater employment growth but a reduction in managerial employment as the introduction of robots appears to lead to changes in work organisation. Borjas and Freeman (2019) compare the effects of the introduction of industrial robots (i.e. larger machines and associated with substituting routine labour tasks) vs. immigrants in US manufacturing industries and conclude that the introduction of these robots is associated with a far greater reduction in total employment than the increase in immigrants, as much as two to three workers for each industrial robot.

To summarise, the evidence is mixed. The studies focus on manufacturing *per se* and would not necessarily capture *employment* effects elsewhere, where increased productivity and robotic sales and service may generate jobs in other contexts. Given that, it is surprising that the studies do not find negative effects on employment. The fact that as many find positive as negative effects leads to the conclusion that, as yet, clear evidence of negative employment effects cannot be seen.

The term 'automation' has surfaced recently in discussions about the potential effect of AI on jobs, presumably related to the robotics idea of applications specifically designed to replace workers in jobs. In the United States, the discussion on automation first came to the fore while trying to explain the slow growth of employment in US manufacturing after the Great Depression. The fact that productivity appeared to have jumped in manufacturing was seen as consistent with the possibility that IT had ramped up productivity there. As a result, the claim was that investments in technology held down jobs in manufacturing (see, e.g. Perry, 2017).

The problem with this argument is that closer inspection suggested that it was just not true. The apparent jump in productivity in US manufacturing was attributable in part to changes in what counts as manufacturing: companies like Caterpillar that manufacture expensive heavy equipment have also moved into services – repairing and financing equipment. The income from those service operations has been counted towards manufacturing because the company itself is a manufacturing company. To the extent that the sharp increase in manufacturing was real, it seems attributable largely to one industry – computer manufacturing – and that has not continued.

Houseman (2018) explains these developments and notes there is little support for the idea that increasing productivity was eliminating manufacturing jobs. Furthermore, the jump in productivity in the computer industry was not because of improvements in labour productivity of the kind that is evident in typical industries – i.e. fewer workers required to build the same computer or less labour input in the construction of a computer. It is because changes in computer design, especially in computer chips, make the same computer considerably more valuable when productivity is measured in terms of revenue per employee.

A different kind of argument about IT and productivity surfaced in popular discussion around the publication of Robert Gordon's (2016) contemporary history of economic growth in the US and what it suggests about the future. The history itself is not controversial although surprising to non-experts: productivity growth in the United States hit its contemporary peak in the 1930s as machine-age innovations were adapted to more everyday uses. Since then, productivity growth and the technological change that drives much of it at least have declined, despite repeated claims in the business and policy world that we are always living in a time of unprecedented change.

The part of the argument that generated controversy is Gordon's assertion that, at least in the foreseeable future, there is little evidence of technological changes that will drive faster rates of productivity and economic growth. This argument is essentially a forecast based on how growth came about in the past and looking at the current state of play.

This forecast is quite pessimistic and not particularly popular with the public, although others have made similar claims. Summers (2015), for example, coined the term 'secular stagnation' to describe the low current growth rates, in his view driven by policy mistakes. Other economists are more optimistic about future growth, including the role that new technology might play (see Teulings and Baldwin, 2014, for these debates). Brynjolffson presents a counter view from his popular writings, that paradigm-breaking IT developments which do not follow the usual rules for growth are on the horizon[3].

This discussion about the future of growth might be described as two views talking past each other: Gordon and others saying that current evidence leads to a pessimistic view of future growth; the sceptics saying, beyond what we can see with our current approach, growth will return and may be considerable.

9. Looking past empirical evidence on IT effects

Recent studies by Autor (2018) and by Acemoglu and Restrepo (2019) have articulated in more formal terms the traditional explanation about why improvements in technology and labour-saving techniques do not lead to fewer jobs: productivity increases fuel demand in the economy as a whole, which in turn creates more jobs, albeit typically in other areas than where the initial productivity improvements take place. There are many paths through which the connection between productivity improvements and demand can take place[4].

When we review the empirical evidence from studies of IT use and jobs, there is no support for the view articulated by Brynjolffson and McAfee (2011; 2014) that IT and associated AI advances contributed to lower job growth. At least in the United States, during the Great Recession the slack labour market that gave support to such an argument has turned around now and undercut it. The more complex argument that IT use has led to automation of the most routine jobs and expansion of more sophisticated jobs has greater face value, but empirical evidence for it is at best mixed, and there are several studies with results that directly contradict it.

That leaves one more set of arguments where the usual forecasts are left behind. Here the idea is that something is coming in IT and related AI developments that will be different in its effects on jobs than anything we have seen so far. It is not just the technologies themselves that will be different, but how they will interact with jobs will also be different. As noted above, these are not forecasts because they claim explicitly that the future will not look like the past. As such, projections are

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[3] This 'debate' derives from a TED talk: https://www.youtube.com/watch?v=ofWK5WgIgiI

[4] Acemoglu and Restrepo (2019) go further and argue that some productivity improvements may be more labour-saving and less demand-creating than others. They claim that in the face of lower overall productivity growth in recent decades, there has been a shift towards the kind of growth that has less impact on jobs, although they have no direct way of measuring that change and inferring it from lower wage growth which, of course, could have many other causes.

not relevant. Furthermore, the construction of those arguments is inconsistent with what we know about what makes for good predictions, not just in suggesting that prior experience is not a guide to them but also that current examples do not provide a guide.

The examples given by Bresnahan and Yi (2016) show that current data-science tools which generate algorithms for decisions do not necessarily eliminate jobs even in the areas where they are applied. They seem closest to the type of IT innovations that proponents claim will eliminate jobs.

Nordhaus (2015) takes a novel and quite different approach to test directly the claim of a forthcoming, paradigm-breaking advance in IT that will transform business and jobs. He addresses Brynjolfsson and McAfee (2014) explicitly, which is more or less an extension of their 2011 argument. He asks what we would see in the economy if such a development occurred in terms of developments such as the share of capital devoted to IT in the economy. At least in the contemporary economy, he sees little evidence that we are on the way towards such a development.

It might be fair to describe arguments about the future of IT as researchers limiting their interest to analyses of the present, on the one hand, and 'expert judgment' prediction of a future fundamentally different from the past, on the other. It is virtually impossible to refute a claim about something that might happen in the future, especially when the claim itself (effects on jobs) relies on something that has yet to exist (path-breaking IT). There is a joke in the field of forecasting that we are safe in making any claim about the future so long as we do not have to specify when it will come true: we cannot rule out events that may happen in the future, which few people remember, or hold accountable, claims that eventually turn out to be false, and, as noted above, there are short-term benefits in the attention that authors can secure with spectacular claims.

The fact that the current evidence is inconsistent with the general notion that IT innovations will have dramatic effects on jobs does not prove that it is impossible for IT innovations of some kind to ever have such an effect. However, it should considerably lower our estimate as to whether such a scenario is likely. Furthermore, the fact that, as yet, there is no clear evidence for the simple explanations as to the kind of effects that IT is having on the labour force – e.g. eliminating low-wage or mid-level jobs – does not mean that a consensus view will never emerge about such changes. It does mean that acting now on any of those views is not advisable.

10. What to do about an uncertain future

The notion that the future is uncertain is hardly novel, not just with respect to the workplace but related to almost any aspect of human endeavour. It is also wholly unsatisfying not to be able to know with any certainty what to do about the future.

It is common and, in some circles, to still hear people say that we should take our best guess about the future and go with it, even if we know that guess is not very good. In some circumstances that must be right: the building is on fire, there are two different exits, and even delaying the choice until we are more certain is not a smart strategy. But there are also circumstances where we are not forced to choose, the consequences of being wrong are great, and the consequences of waiting are minimal. If we are climbing a mountain, for example, we will probably wait to get an accurate weather forecast before ascending towards the summit because the cost of waiting is small compared to the cost of making the wrong decision.

With respect to economic and workforce planning, the track record has not been very good at predicting which jobs will be in high demand far into the future. Even if we are reasonably sure that some jobs will decline in importance in the future, retraining programmes are difficult to put in place unless we are also reasonably sure which jobs will be in demand then. A sensible alternative, therefore, is to wait for better information before acting and shortening the time period involved because forecasts are dramatically better the shorter they are.

It is true that government policies often take a long time to set up and execute, and that makes longer-term efforts more attractive. But in that context, our policy attention might be better spent on designing procedures that allow us to respond faster rather than going with longer-term forecasts that have a poor track record.

One approach to faster and more accurate forecasts might be to think about programmes that are executed at the level of the individual employer rather than the economy as a whole. Particularly with respect to changes associated with technology, we know that the spread of new techniques is not instantaneous: businesses with more resources or with strategies better suited to new approaches will go first, while others may never adopt the changes because of their unique cost structures or business approaches. Estimating what will happen to jobs in a given organisation two years on is far easier and more accurate than estimating what will happen to jobs in the economy as a whole because at least some of the factors that drive outcomes in a given organisation are known and indeed determined by decisions made within that organisation.

Furthermore, if we believe that IT-related technologies may eliminate jobs, intervening when those developments actually do so – within individual employers – is a far better use of resources than putting in place economy-wide programmes that may only be used by a small group of employees at any specific time. We also know that where individuals must transition from one job to another, the easiest way to make those transitions is within the same organisation where their organisation-specific skills remain relevant. Retraining policies that operate within individual employers may also make sense for that reason.

Another general approach to addressing the problem of uncertainty begins with the recognition that even good forecasting models simply tell us the most likely outcome, or in the words of modellers, the ‘point estimate’ of the outcome in question. In most cases, the most probable outcome may not be all that likely, so it is important to know what the second most likely outcome is, as well as the third. Sometimes the second and third outcomes are similar in their implications, in which case it is safer to bet on them than on the most likely outcome. Scenario planning is one technique used to address these situations. Simulations are another, where we have a forecasting model and we change the assumptions or the values of the variables to see what happens.

Once we have a better sense of the outlines of the uncertainty we face, a reasonable approach involves hedging our bets. The world of finance has formalised this practice in the form of options, and the world of management has done something similar with the idea of 'real options', placing bets to hedge against real phenomenon. For example, the probability might be extremely high that there will not be a pandemic, but the consequences if it does happen are high enough that we might at least put plans in place to deal with it should it happen. If it turns out that evidence of dramatic IT-related job changes becomes stronger, it may make sense to place some bets about it occurring even if the odds are still small that those changes will occur. An example of such a bet might be more detailed and fine-grained monitoring of how IT is being used in the workplace.

Even if we were to believe that new IT technologies, whatever they may be, are unlike any we have seen before, that would not suggest that the process through which any such technologies will be introduced is without precedent. The introduction of electricity, for example, was a path-breaking and 'disruptive' technology with little precedent. We learned a great deal over time about why it took so long to spread and what determined its advance. If we look at manufacturing, where technological change has been most obvious and studied, we know that its introduction rarely has uniform effects everywhere. In the 1970s, the term 'productivity bargaining' was used to describe an approach which began in the UK whereby unions and management negotiated over the terms on which new technology and other productivity-improving approaches would be introduced that would protect as many current jobs as possible and share some of the benefits of cost savings with employees (e.g. McKersie and Hunter, 1973). A simple accommodation was to let labour-saving play out through attrition and buy-outs rather than mass layoffs.

Arguably, the first 'robotics' wave in manufacturing was the introduction of numerically controlled machines, taking over at least some of the most important tasks of machinists. Here, organisations faced a choice as to whether to get rid of their machinists who had performed those tasks, replacing them with engineers proficient in computer programming, or to retrain their existing machinists to take over the programming tasks. Productivity was actually higher in the latter case (Kelley, 1994). The former approach is massively disruptive for employees; the latter much less so (see Keefe, 1991 for an assessment of overall effects on jobs), and employers had considerable discretion as to which one to choose. The policy approach learned from that is first that these two options have very different implications for society and for employees and second that it would have been possible to shape the choices.

The assertion that we should initiate massive retraining programmes now on the chance that new IT innovations will be massively disruptive is not the only option, even if it was feasible to do, nor even the best given what we know first about the lack of evidence for such a disruption and second about how technological change actually plays out. Fortunately, there are better options.

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CHAPTER
12

THE RESEARCH AND INNOVATION DIVIDE IN THE EU AND ITS ECONOMIC CONSEQUENCES

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Summary

This contribution looks at the economic consequences of the R&I divide across EU regions and highlights the policy challenge they represent. It reviews the theoretical factors behind current levels of territorial polarisation, maps the current state of this divide, and presents an econometric approach to identifying the effects.

The core of the argument is that research and development (R&D) investment alone does not trigger the same returns on investment everywhere because of several factors. These are linked to the cost of technology accessibility in different places, the distance to the technological frontier, positive externalities from larger and denser regions, the quality of local institutions, and hampered knowledge sharing.

Many of these factors disadvantage the less-developed regions in their efforts to broaden their innovation capacities with the aim of unleashing greater economic activity and growth. Nevertheless, most of the R&D growth in less-developed regions has been in the higher education sector, which has led to a substantial improvement in scientific output. The chapter discusses how to improve the efficiency of investment in R&I systems and strengthen innovation-driven economic growth.

In its conclusions, it not only diagnoses the situation but also suggests elements of innovation policy for less-developed regions. These aim to close the innovation divide between more- and less-developed areas in the EU while increasing the EU's competitiveness through a stronger role for innovation as a trigger of economic dynamism.

1. The policy challenge

One of the main aims of the European Union is to enhance the competitiveness of all European economic actors in what has become an increasingly integrated world. Given Europe's history, economic structure and social model, there is a consensus that this cannot be achieved by cutting costs and reducing workers' rights. If Europe is to keep and improve its place in the world, a different route is required. And this route needs to rely on inventiveness and creativity, rather than cheap labour. For the EU, increasing competitiveness and preserving the European social model entails moving up the technological and innovation scale (EU, 2014).

To achieve this goal, both individual European countries and the EU as a whole have put research and innovation (R&I) policy at the heart of their innovation efforts. Innovation policies in Europe – both at the national and European-wide scale – have, to a greater or lesser extent, remained anchored in the belief that more investment in research and development (R&D) leads to greater innovation and that innovation triggers economic growth. Consequently, a considerable – and, until the beginning of the crisis, growing – amount of resources has been devoted to R&D across Europe. Most of this effort has been aimed at achieving a quantitative target: securing an R&D investment of 3% of GDP, of which two thirds are expected to be accomplished by the private sector. The 3% of GDP target reflects not just a belief in the benefits of greater R&D

investment but is also a political response to the perception that the EU as a whole has been falling behind its main competitors in innovative capacity. For most of the 1990s and 2000s, investment in R&D in the EU languished at levels slightly below 2% of GDP. Japan (generally over 3%) and the US (just short of 3%) have been pulling ahead. At the same time, emerging countries, such as South Korea and, more recently, China have caught up and surpassed the EU in terms of relative R&D investment (Dosi et al., 2006; Crescenzi et al., 2007). Hence, geopolitics and the fear of being left behind has contributed to setting the 3% of GDP objective as one of the main pillars of, first, the Lisbon Strategy and, later, the Europe 2020 Strategy (Uppenberg, 2009). High hopes have been put on the economic impact of achieving such an objective: the Europe 2020 Flagship Initiative estimated the benefits of reaching an investment in R&D of 3% of GDP by 2020 at 3.7 million additional jobs and an annual GDP increase of EUR 800 billion by 2025 (EU, 2014).

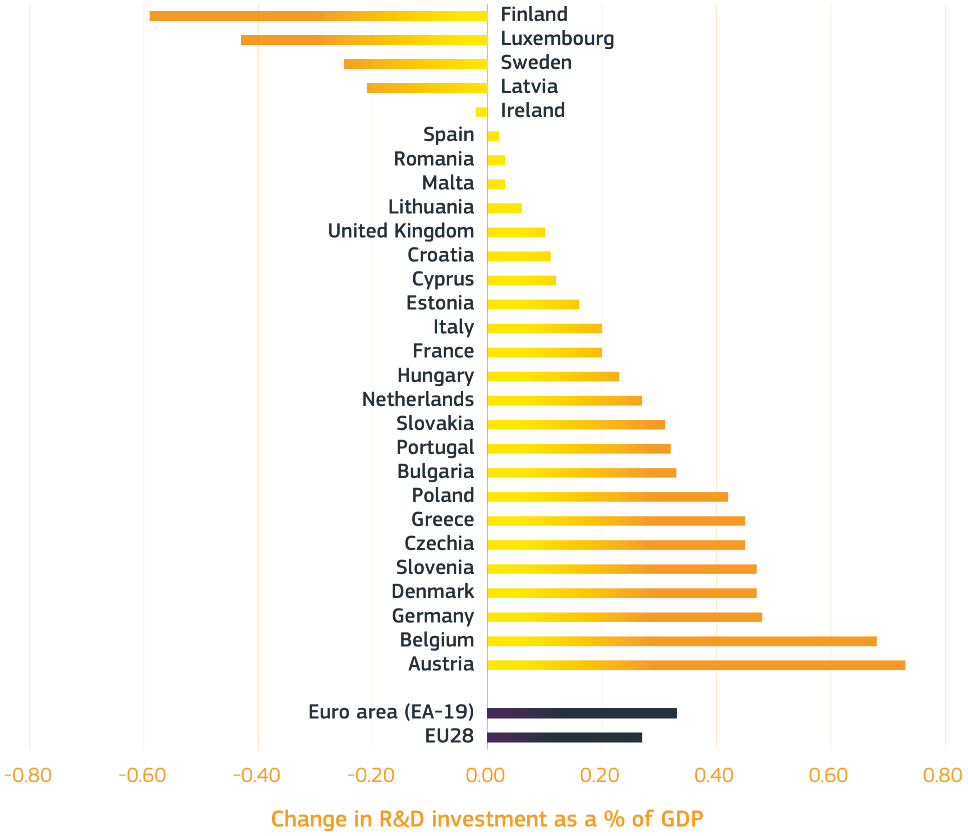
Nevertheless, the adequacy of such a quantitative target has been questioned from almost the very beginning (e.g. Kok, 2004; Van Pottelsberghe de la Potterie, 2008). The target has also proved elusive (Van Pottelsberghe de la Potterie, 2008). Europe as a whole has not only failed to come close to it but has also been incapable of keeping up with the R&D drive of its competitors – from the United States to Japan, South Korea or China (Dosi et al., 2006; Crescenzi et al., 2007, 2013). Over the last 20 years, competitor countries have either consistently invested more in R&D (e.g. Japan, South Korea and the United States) or, as in the case of China and South Korea, increased their innovation efforts to a far greater extent than the EU as a whole.

In addition, the overall pursuit of R&D and innovation at the European level has not been without victims. Investment in R&D, despite some geographical catching up, has not become much more territorially even than three decades ago. In the name of excellence, scarce public and private R&D resources have become highly concentrated, both within countries and across the EU. This is an outcome of targeting R&D towards those economic agents considered to have the greatest capacity to generate new products and processes. The problem is that the most innovative actors are geographically concentrated in specific countries and in specific cities and regions within these countries (Usai, 2011). Core countries and core urban regions host and attract a disproportionate share of innovative firms and research centres and, consequently, scientists. The shift from an 'old' to a 'new' digital economy – or from Industry 2.0 to Industry 4.0 (Schwab, 2017) – further fuels the clustering of research activities into large agglomerations and the redesign of global innovation value chains to the benefit of core areas (Brun et al., 2019). In these core and innovation-prone environments, positive externalities from the agglomeration of R&I activities arise (Audretsch and Feldman, 1996; Rodríguez-Pose, 1999). This widens the innovation divide as the dominant conviction is that – following the endogenous growth theory (Romer, 1986; Lucas, 1988) – increasing returns on investment in R&D will mainly happen in innovation-prone areas. From this perspective, if Europe is to remain innovative and competitive, the R&D effort should be concentrated in those regions where the greatest returns can be achieved.

Yet, conscious of the growing innovation divide, the EU and European countries have tried for years to prevent the scientific and knowledge gap between R&D rich and poor countries, cities and regions from growing. The public sector has deliberately channelled public R&D into universities and public research centres in some of the less-well-off areas with the aim of bringing them closer to the technological and innovation frontiers and triggering the conditions for innovation to take hold. In 2016, or the most recent year for which data are available, the public sector (universities and government research sectors) was responsible for 100% of all R&D investment in South-East Romania. It represented more than 90% of all R&D expenditure in South-West Oltenia (Romania), the Ionian Islands, the Aegean Islands, Crete, the Peloponnese, and Thessaly (Greece), the Overseas Departments (France), and the Azores (Portugal). Furthermore, the number of relatively less-developed regions where the public R&D investment exceeds 80% of the total remains huge. It includes, among others, Trier and Leipzig in Germany, most of Greece outside Athens, Extremadura, the Balearic and the Canary Islands in Spain, Corsica in France, Molise, Calabria and Sardinia in Italy, Lubelskie in Poland, or Nord-Est in Romania (DG Regio data).

The Great Recession, however, triggered a reduction in the overall amount of public expenditure in R&D, without necessarily dynamising the role of the private sector in the innovation realm in lagging-behind areas. The prolonged crisis, the hit it made on public finances and local firms, and the ensuing austerity had an immediate knock-on effect on the R&I effort. The first impact of the crisis was a decline in R&D investment in whole swathes of Europe and, although a recovery has ensued, it has been slow and territorially uneven. In 2016, R&D investment in the EU28 was marginally higher than in 2006. The R&D effort across the whole of the EU jumped from 1.76% of GDP in 2006 to 2.03% in 2016. However, some countries have yet to return to the levels of R&D intensity witnessed in pre-crisis times. This includes the two countries with the highest levels of R&D intensity before the crisis (Sweden and Finland) as well as that with the lowest relative investment, Latvia (Figure 12-1). The post-crisis recovery of R&D intensity has been almost negligible in many Member States which, in 2006, registered levels of R&D intensity at 1.2% of GDP or lower. In Latvia, Ireland, Spain, Romania, Malta, Lithuania, Croatia, Cyprus, Italy and Hungary, R&D intensity growth between 2006 and 2016 was below the EU average for the period (Figure 12-1). The highest growth in R&D intensity has occurred in countries such as Austria, Belgium, Germany and Denmark, all of which were above the EU average in 2006.

Figure 12-1 Change in R&D intensity in the EU28 by country (2006-2016)



Science, research and innovation performance of the EU 2020

Source: Author's elaboration using Eurostat data

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/partii/chapter12/figure_12-1.xlsx

Since the crisis, the innovation-inducing effort has tended to follow, to a far greater extent than before, efficiency criteria at the expense of nurturing new innovation poles and creating the right ecosystems for innovation to thrive outside the traditional innovation hubs. With the exception of Sweden and Finland (which still ranked first and fifth, respectively, in R&D intensity in the EU28 league in 2016), a certain polarisation in the R&D effort has ensued. In spite of significant improvements in a handful of some of the less-developed EU countries – and, especially in Slovenia, Czechia, Greece, and Poland – most less-developed countries and regions lag well behind the core of Europe in terms of both capacity to invest in R&D and innovation. Today, as is the case in other parts of the world (Carlino and Kerr, 2015) the innovation divide in the EU remains far larger than the gap for most other basic economic indicators, such as GDP per capita, employment or productivity. Such an R&D gap signals that addressing inequalities in wealth, employment or productivity may be made harder by the low innovation capacity of many of Europe's less-developed areas.

This panorama derives mainly from the clash between conflicting principles at the heart of the EU. The pursuit of excellence in innovation is at odds with the objectives of delivering harmonious development and territorial cohesion (Article 174 of the Treaty). This represents an important conundrum for the EU. On the one hand, invention and innovation today increasingly demand larger, more complex projects, involving top research centres and firms and a critical mass of scientists that are mostly found in a limited number of areas (Buzard et al., 2017). Thus, greater efficiency is regularly achieved via the territorial concentration of investment. On the other hand, innovation polarisation may imply that considerable talent for innovation and ample research potential is being left untapped. It can also lead to brain and firm drain that can leave many areas of the EU increasingly vulnerable and incapable of facing competition (De Noni et al., 2018). Worse still, the lack of innovation in less-developed areas can render many of them dependent on government assistance and brewing social and economic tensions. Thus, the R&I divide may be contributing to a geography of discontent that threatens to undermine the very system on which the pursuit of excellence in innovation is based (McCann, 2019; Rodríguez-Pose, 2018).

This contribution to the Science, Research and Innovation Performance of the EU (SRIP) Report looks at the economic consequences of the R&I divide across EU regions and highlights the policy challenge this represents by considering the opportunities and risks that the concentration of the innovation effort and of innovative outcomes entail for Europe's future position in the world. First, this contribution will review the theoretical factors behind current levels of territorial polarisation in innovation. It will then present the evidence and highlight how the geographical gaps in R&D investment and in innovation affect both the production of innovation and economic growth for the EU as a whole and across its different types of regions, according to the level of development. The final section develops some policy implications and general recommendations.

2. Why does innovation tend to concentrate geographically?

A somewhat oversimplified version of the linear model of innovation (Bush, 1945; Maclaurin, 1950) assumes that innovation is a direct consequence of investment in R&D (Balconi et al., 2010). Places that invest more in R&D innovate more and, as a result, experience increases in productivity and greater economic dynamism and growth. From this point of view, the logical policy for achieving greater innovation and economic growth is increasing investment in R&D. This is precisely what the EU and most countries within it have done until recently.

However, more recent theoretical developments suggest that R&D investment alone does not trigger the same returns on investment everywhere. There are several reasons for this.

First, technology is not equally and ubiquitously accessible at similar costs. Moreover, investment in technology does not necessarily benefit from constant or decreasing returns to scale, as assumed by the neoclassical growth theory (Swan, 1956; Solow, 1957). This implies that, whereas in certain areas investment in R&D

may make a lot of sense in order to achieve innovation, in others, similar investments may yield much lower returns or simply be wasted. According to the endogenous growth theory (Romer, 1986: Lucas, 1988), investment aimed at triggering greater innovation can produce increasing returns to scale, especially in places with better endowments in basic factors, such as infrastructure (which facilitates accessibility) and labour skills. Consequently, one additional euro in locations with good physical and human capital would result in greater innovation than in areas where those endowments are far weaker.

Second, many lagging-behind areas cannot make the most of any additional investment in R&D because they are too far away from the technological frontier (Aghion and Griffith, 2008). Distance from the technological frontier reduces the capacity of territories to develop and host innovative activity as they not only lack the necessary critical mass but are also far less likely to have sufficient endowment in human capital and the adequate 'economic fabric' to transform R&D into innovation. Such often economically lagging-behind areas are regarded as less able to generate, import and absorb knowledge and, consequently, to make the leap from investment to innovation, meaning that most investment in R&D would just be money wasted (Rodríguez-Pose, 2001).

Third, larger and denser regions provide – according to the new economic geography approach (Ottaviano and Puga, 1998; Fujita, Krugman and Venables, 2001) and to urban economics (Glaeser, 2012) – the positive externalities that facilitate the interaction and networking behind the exchange of knowledge. Large and dense urban agglomerations contain the suitably skilled human capital and knowledge infrastructure and the economies of scale, specialisation and diversification that facilitate the generation and circulation of new knowledge. By having a large number of innovative actors co-located in one place, the right environment is created for the formation and diffusion of new knowledge. Most of this new knowledge is in the form of 'tacit' knowledge which is knowledge that is distributed through non-codified channels which benefit from the co-location of economic actors and the proximity to innovation that large and densely agglomerated environments afford (Feldman and Florida, 1994; Gertler, 1995). This is what Marshall (1895) described as 'something is in the air' and what Storper and Venables (2004) called the 'buzz' of the city. Smaller and less-dense cities and regions lack these favourable ecosystems, making the field of innovation an uneven one.

Furthermore, the quality of local institutions also plays an important role in defining the capacity of different places to innovate. Larger cities and metropolises tend to innovate more and not only because they benefit from considerable positive externalities. They also enjoy, as a whole, better institutional quality. As indicated by Rodríguez-Pose and Di Cataldo (2015: 693), 'knowledge production structures in lagging regions are massively affected by quality of government': the lower the quality of government, the smaller the chances to innovate. Quality of government thresholds often prevent investment in R&D in lagging-behind regions from yielding significant economic returns.

Finally, knowledge tends to be 'sticky' and travels with great difficulty (Moreno et al., 2005; Rodríguez-Pose and Crescenzi, 2008; Sonn and Storper, 2008). Thus, physical proximity becomes a fundamental driver of R&I. Agglomeration externalities and the co-location of innovative actors can result in the creation of geographically bounded networks or systems characterised by high degrees of trust, collaboration and cooperation within which knowledge may be exchanged and shared. Physical agglomeration is considered to be at the root of frequent and repeated transfers of information and knowledge, enabling the emergence of new ideas and their rapid transformation into economically viable activities (Duranton and Puga, 2001; Storper and Venables, 2004). This knowledge transfer takes place in both a codified and tacit way (Storper and Venables, 2004; Leamer and Storper, 2014), facilitated by the frequent face-to-face interactions that the high density of innovative actors in core areas affords (McCann, 2007). The key role played by physical proximity can, therefore, justify an increasing concentration of the R&I effort in core areas.

Wrapping up, it has often been argued that large and densely populated core areas provide the most adequate ecosystems for new knowledge to come to fruition and for innovation to take hold (Duranton and Puga, 2001; Puga, 2010). They have a considerable advantage in R&I endowments vis-à-vis less-developed regions, as they concentrate both the largest knowledge infrastructure, ranging from public research centres, laboratories and universities to firms with the greatest capacity to invest in and conduct R&I activities. These facilities, in turn, generate and attract large numbers of researchers and skilled individuals.

In contrast, there is a dearth of innovative resources in less-developed areas which, in addition to their distance to the technological frontier (Aghion and Griffith, 2008), can represent an insuperable barrier for the creation of new knowledge, its circulation, and its transformation into viable and sustainable economic activity. As a consequence, smaller and/or less-developed cities and regions are generally perceived to be less capable of hosting innovative activity.

To summarise, in the pursuit of R&I excellence and maximisation of the returns of R&D and innovation investment, core areas are not only generally thought to be in a better position to attract more resources because of the sheer concentration of innovative actors, but they are also perceived as more likely to offer considerably higher returns than when investment takes place in peripheral areas.

3. The innovation input and output divide in the EU

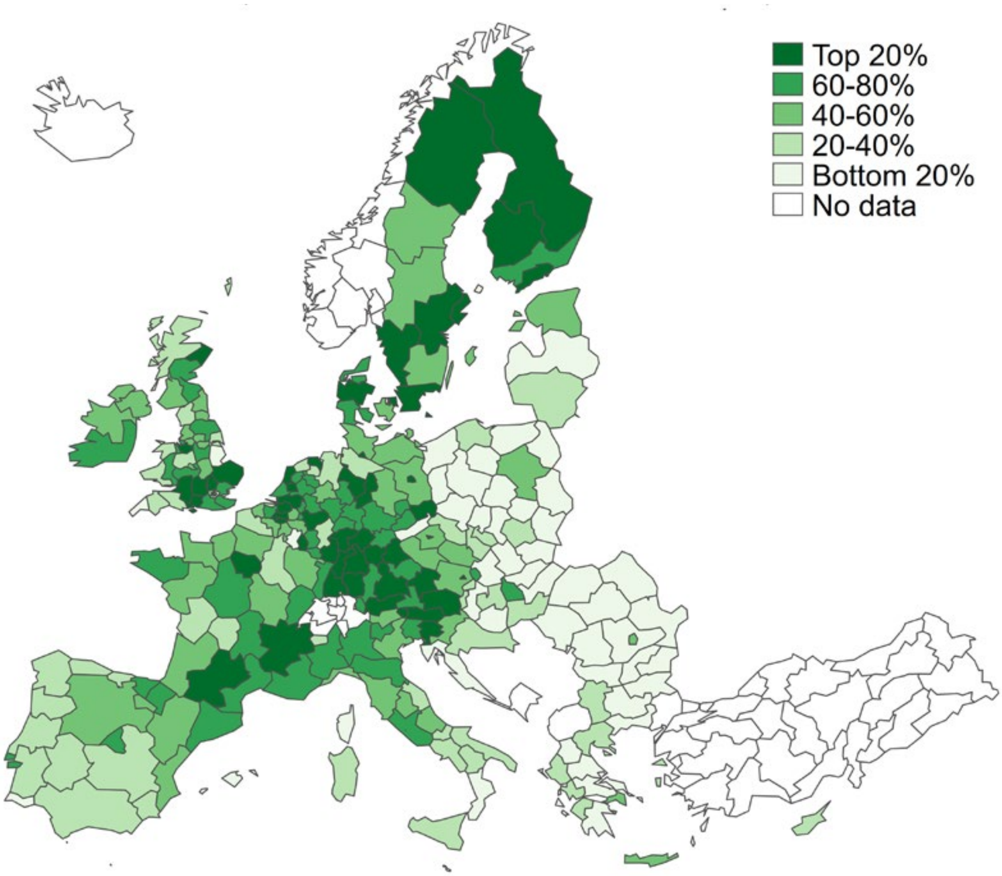
To what extent has Europe followed the dominant trend? Are innovation inputs geographically concentrated in order to potentially deliver higher economic returns? Figure 12-2 portrays the geographical distribution of total R&D investment (in 2005, euros) for the NUTS 2 regions of the EU28 during the period 2000 to 2016. The different levels of expenditure by region are expressed in quintiles.

Three groups of regions can be distinguished among the top spenders on R&D. As expected from the theory, the first group comprises some of the largest agglomerations in the EU. Inner London, Paris, Madrid, the Randstad, Berlin, Copenhagen, Stockholm and Helsinki belong to this category. Agglomerations of innovative firms, skilled individuals and public research centres and leading universities are behind the high levels of R&D expenditure in these regions. The second group follows the so-called 'Blue Banana': a set of regions stretching from the northern Alps in Austria and Germany, along the Rhine Valley into the southern and western

Netherlands and northern Belgium, to the south of England. This is the traditional industrial and economic motor of the EU. The third set of regions has its centre in the Nordic countries – involving the whole of Finland, numerous regions in Sweden and, to a lesser extent, Denmark. These regions have the greatest degree of R&D expenditure in the EU (Figure 12-2).

At the opposite end of the spectrum, very limited R&D investment took place in that same period in many central and eastern European countries outside the national capitals and largest agglomerations. That was the case for Bulgaria, Romania and Slovakia and, with limited exceptions, Hungary and Poland. In 2016, Latvia had the lowest R&D investment intensity in Europe, with just 0.44% of GDP.

Figure 12-2 Total intramural R&D expenditure in PPS per inhabitant, average 2000-2016 (EUR)



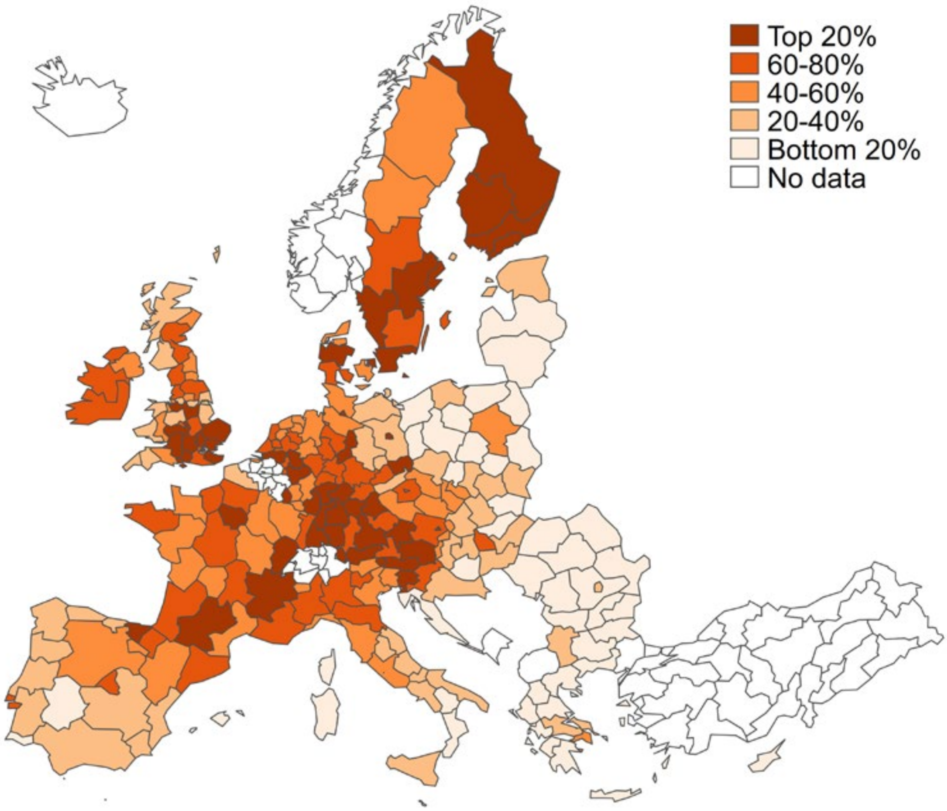
Source: Author's elaboration using Eurostat data

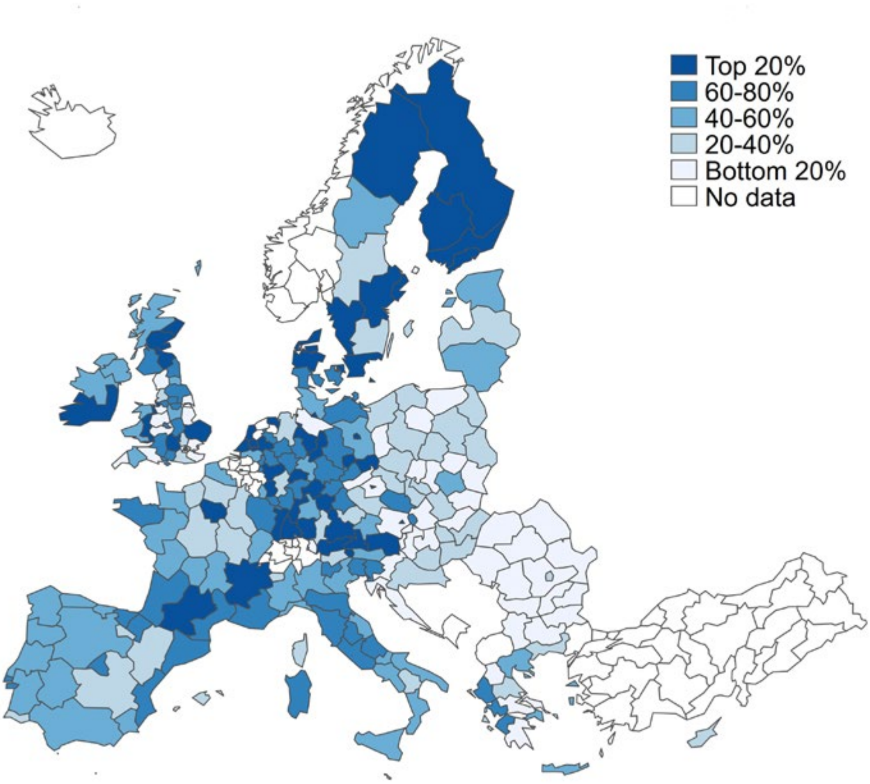
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/partii/chapter12/figure_12-2.xlsx

Are there differences in this distribution between the R&D effort in the private and the public sectors? Figure 12-3 maps this difference by focusing on R&D investment by region in the business sector and in higher education. The map for the business sector follows closely that of total R&D expenditure, as business-sector expenditure represents roughly two thirds of all R&D efforts in the EU. The three types of regions identified in Figure 12-2 are still very much in evidence: large metropolises, Blue Banana, and Nordic regions.

The panorama is somewhat different when considering the higher education sector. While the big spending regions still coincide with those with the greatest agglomeration, and most eastern European regions remain at the bottom of the investment ladder, this is not so likely to be the case in many southern European regions. Investment in higher education in a number of southern French regions, most regions in Spain and Portugal, areas of central and southern Italy, or Western Slovenia is higher than their overall level of R&D investment might suggest. In many of these cases – as in Andalusia and Extremadura in Spain, Centro and Alentejo in Portugal, or Campania and Puglia in Italy – the government and higher education sectors compensate for the absence of a private sector capable of pursuing R&D activities.

Figure 12-3 **Total intramural R&D expenditure in PPS per inhabitant, average 2000-2016, in the business (first map) and the higher education (second map) sectors (in euros)**

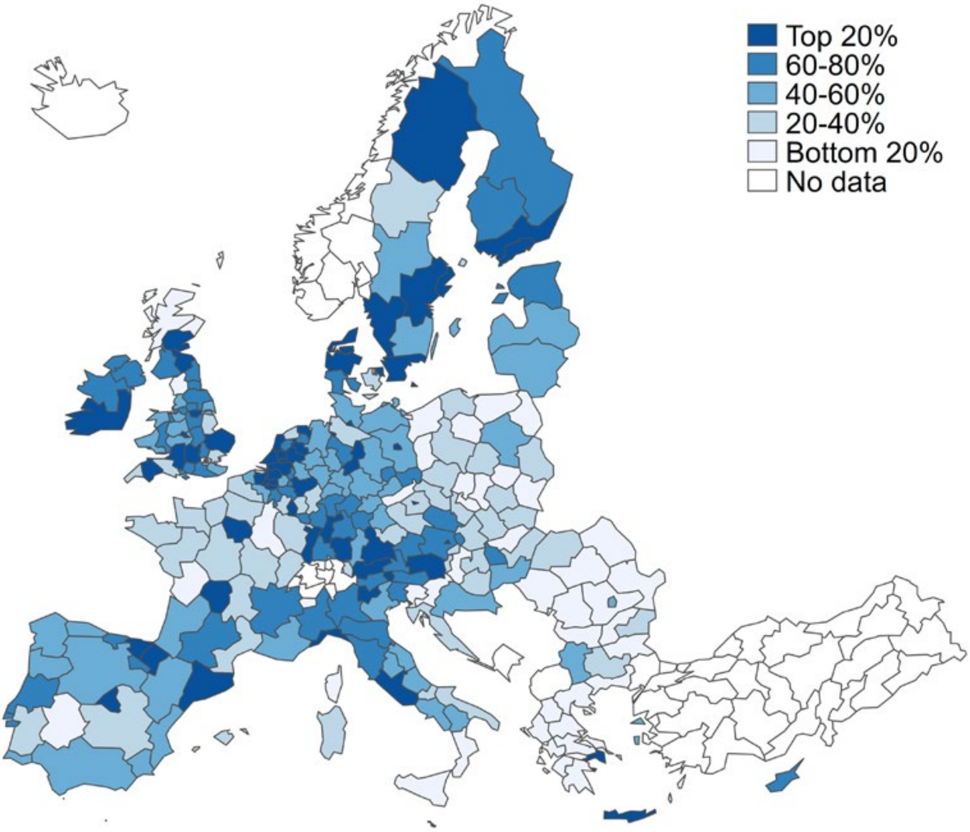




Source: Author's elaboration using Eurostat data
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/partii/chapter12/figure_12-3.xlsx

The concentration of innovation-leading inputs is not limited to R&D. The EU has set up a number of flagship research programmes whose main aim is the pursuit of excellence in research. This implies funding the best proposals by the best researchers and the best research teams, regardless of location. As research capabilities are unevenly distributed across the geography of the EU, the territorial allocation of research funding under these programmes is equally uneven. Figure 12-4 presents the distribution of EU research funding within the Seventh Framework Programme (FP7) (2007-2013).

Figure 12-4 Seventh Framework Programme (2007-2013) expenditure per head



Science, research and innovation performance of the EU 2020

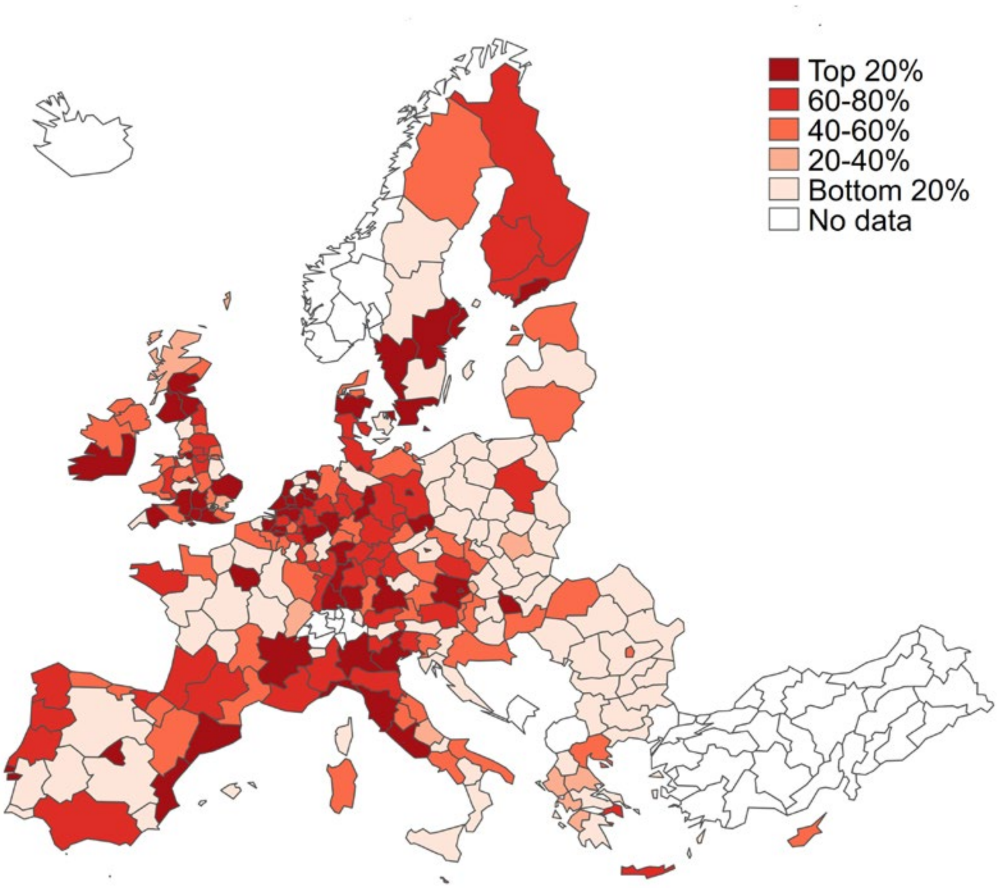
Source: Author's elaboration based on DG Research and Innovation, Corda data

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/partii/chapter12/figure_12-4.xlsx

Although there is less concentration of FP7 research funding than when considering overall R&D expenditure, the top areas attracting European research funds follow relatively familiar patterns. Capital cities and large agglomerations (with the exception of London), regions around the Alps and along the Rhine (e.g. Upper Bavaria, Karlsruhe, Alsace, Cologne, Antwerp), and a number of Nordic regions attract the bulk of the funding. Despite some exceptions in central and eastern Europe, such as Athens, Bratislava, Crete, Estonia and Prague, the lowest share of funding per capita is found when moving eastwards. Most of Romania, the whole of Greece outside Athens and Crete, and 9 out of 17 regions in Poland are in the bottom 20% in terms of FP7 expenditure per capita.

This pattern is reproduced when only considering the resources disbursed by the European Research Council (ERC) during the period 2014-2018 (Figure 12-5). With some exceptions (Athens, Crete, Estonia, Limousin), the regions in the top 20% expenditure category reproduced what has already been highlighted for R&D and the overall FP7 expenditure. Core regions or large urban agglomerations, strongly endowed with human capital, research facilities, and some of

Figure 12-5 European Research Council payments per capita per region (2014-2018)



Source: Author's elaboration based on DG Research and Innovation, Corda data
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/partii/chapter12/figure_12-5.xlsx

the best universities in Europe are the greatest beneficiaries of this European-wide scheme.

The regional differences in innovation inputs are reproduced to a considerable extent in terms of innovation outputs. When mapping the only innovation output that is available over a considerable period of time for the whole of the EU at a regional level – patent applications[1] – a very uneven geography of innovation emerges.

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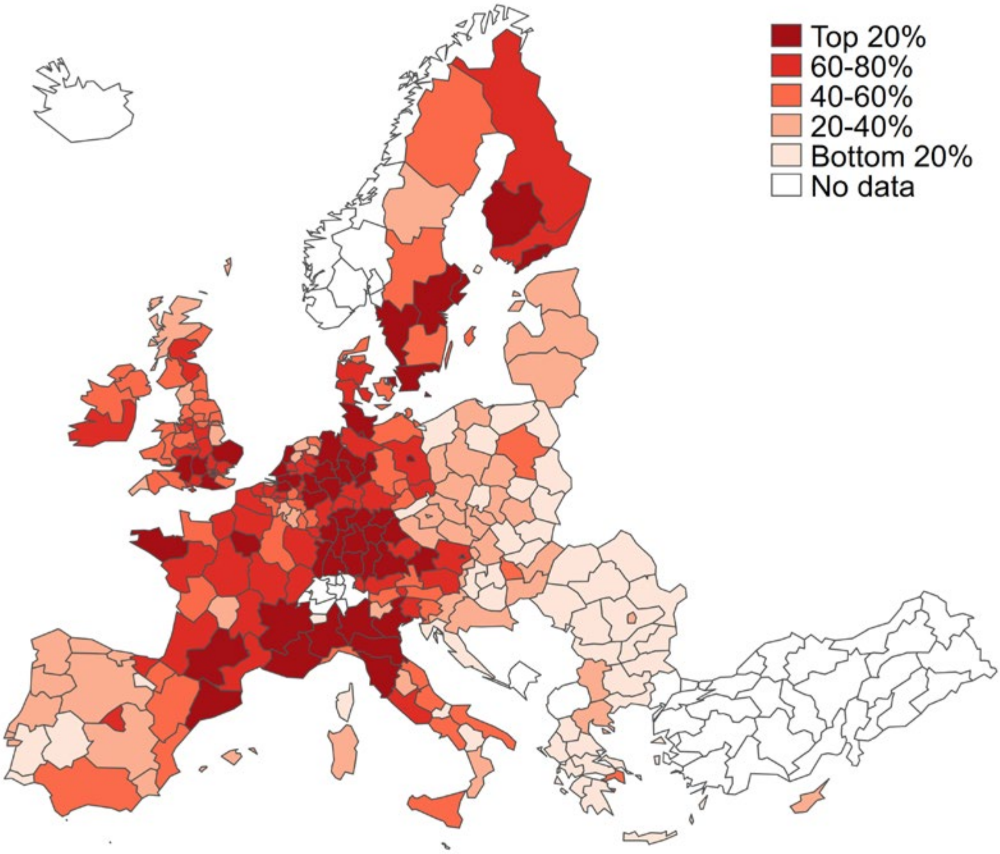
[1] Patent applications are, however, a highly imperfect measure of innovation outputs. Patents tend to reflect more invention and radical product innovation than process, organisational, marketing or incremental product innovation. They also boost the innovative capacity of areas specialising in manufacturing, relative to those whose economic structure is more reliant on services. And, within manufacturing, they favour those areas specialising in sectors such as chemicals or pharmaceuticals that routinely rely on patenting as a way of appropriating the returns on their innovation.

Figure 12-6 Patent applications to the European Patent Office (EPO), per million of active population (2000-2012)



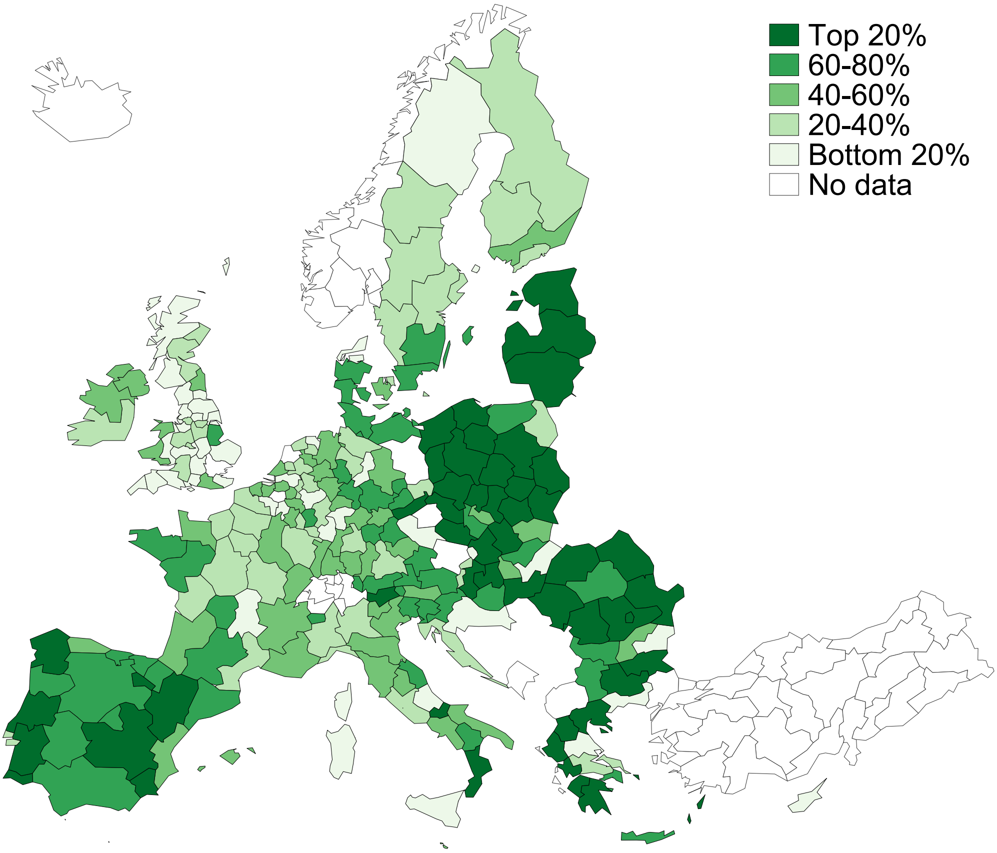
Source: Author's elaboration based on Eurostat data

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/partii/chapter12/figure_12-6.xlsx

There are some minor differences between the geographical distribution of the groups of regions in terms of patenting and that derived from the innovation input maps. Both Germany and the north of Italy, the two areas in the EU with the largest manufacturing sectors, score well. The top 20% of patenting regions are populated by southern German and northern Italian regions. Most capital cities in the EU's economic core, from Paris to London, Stockholm, Helsinki and Copenhagen, to Amsterdam, Berlin and Vienna are also over-represented in the top category. However, the former Iron Curtain is still very much in evidence. With very few exceptions (Budapest, Warsaw), regions in central and eastern Europe cluster in the bottom 40% of EU regions in terms of patenting. From Estonia to Crete, from western Slovenia to north-east Romania, patent applications have remained well below those found in most western European regions. Only some regions in the Italian Mezzogiorno and the least-developed areas of the Iberian Peninsula have comparable low levels of patent applications to those found in most central and eastern European regions.

However, the patenting divide across EU regions has been gradually declining since the turn of the century. Regions in the Baltics, the Visegrád countries, Romania, Bulgaria, Greece, southern Italy and the Iberian Peninsula have been catching up, albeit starting from very low levels in some cases, compared to the core of the EU. Outside this group, only the Italian region of Alto Adige is in the top 20% of catching-up regions. In contrast, some of the lowest growth in patenting took place in regions in the United Kingdom, Wallonia in Belgium, Brunswick, Cologne, Darmstadt and Rhine-Hesse-Palatinate in Germany, or North Brabant in the Netherlands. However, not all regions in areas lagging-behind in innovation have caught up. Abruzzo, Sardinia and Sicily in Italy, Eastern Macedonia and Thrace and Thessaly in Greece, North-eastern Bulgaria, the Northern Great Plain in Hungary, the South-west of Czechia and Continental Croatia were stuck in the bottom category of patent application growth, which means these regions achieved much lower innovation progress than the EU average.

Figure 12-7 **Patent application growth (2000-2012)**



Source: Author's elaboration based on Eurostat data

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/partii/chapter12/figure_12-7.xlsx

4. The R&D divide, innovation and economic performance

What are the consequences of the R&D and innovation divide for innovation and economic growth, respectively, in Europe? Does the innovation divide in the EU affect its overall economic prospects? Are the regions at the bottom of the innovation scale particularly disadvantaged? This section of the paper focuses on these questions. Following the basic logic of the linear model of innovation, which has articulated the majority of innovation policies in Europe to date, the first question concerns the extent to which regional differences in innovation efforts affect innovation across EU regions. This is then followed by an analysis of how regional differences in innovation capacity in the EU impinge on economic growth. Two econometric models reflecting these two stages are proposed. The model for innovation adopts the following form:

$$Ln\ Pat_{i,t} = a + \beta_1 GDPpc_{i,t-1} + \beta_2 R\&D_{i,t-1} + \delta_1 X_{i,t-1} + \varepsilon_{i,t}$$

and

$\varepsilon_{i,t} = v_t + v_e$

where:

Pat	depicts patent applications in region i per million active population;
GDPpc	is the gross domestic product (GDP) per capita;
R&D	represents total R&D investment in euros per person in region i during period t. Particular attention is devoted to the R&D effort in the less-developed regions, both in central and eastern Europe as well as southern Europe;
X	is a vector of the key factors which – according to the endogenous growth, new economic geography, and urban economics theories – should affect innovation. These include the region's total population, representing agglomeration externalities; the population density; and the share of the adult population (25-64 years) with tertiary education; plus the overall government quality index at a regional level, as measured by the Quality of Government Institute at the University of Gothenburg (Charron et al., 2014). This latter variable is also interacted with the share of R&D investment, as local government quality may affect the returns on R&D policy;
v_t, v_e	v_t capture time fixed effects; and v_e the error term;
i,t	depict region and time, respectively. Depending on the regression, t can cover either 1991-2012 – for regression (1) with no controls, or 2000-2012, as the human capital control has only been available since 2000.

For the second stage of the linear model, assessing the connection between innovation and economic growth, the regression adopts the following form:

$$Ln\ GDP_{i,t} = a + \beta_1 PAT_{i,t-1} + \delta_1 X_{i,t-1} + \varepsilon_{i,t}$$

and

$\varepsilon_{i,t} = v_t + v_e$

where:

GDP	represents GDP per capita in a given EU region;
Pat	depicts the change in patent applications per million active population;
X	is a vector of the key factors which, according to the main theories of economic growth, are bound to shape regional growth. These include the four controls considered in equation (1), as well as the interaction term involving regional quality of government and R&D investment;
v_t , v_e	v_t capture time fixed effects; and v_e the error term.

The econometric analysis is conducted using a static panel data estimation with fixed effects (FE), including interaction effects to explore potential differences in the association of the R&D and patenting variables on innovation outputs and economic growth, respectively, in less-developed regions, in general, and in the less-developed regions in central and eastern Europe and southern Europe, in particular. The use of panel data analysis with FE requires the use of levels in both depending variables to assess change in patenting and economic growth. The standard errors are clustered in order to control for arbitrary heterogeneity and autocorrelation.

The results for the innovation equation [Model (1)] are presented in Figure 12-8.

Figure 12-8 From regional R&D investment to patenting in the EU

	1991-2012	2000-2012			
Dep. variable: change in regional patent applications	**(1) FE**	**(2) FE**	**(3) FE**	**(4) FE**	**(5) FE**
GDP per capita (ln)	-25.3613 (15.966)	-11.1401 (11.849)	-32.9371 (25.121)	-25.0009 (24.257)	-26.2811 (23.392)
Investment in R&D	2.03058*** (0.202)	1.97186*** (0.213)	2.59703*** (0.398)	2.61802*** (0.402)	2.61378*** (0.405)
Less-developed regions				-0.9484*** (0.253)	
Less-developed regions (eastern Europe)					-0.8133* (0.479)
Less-developed regions (southern Europe)					-0.8133* (0.479)
Population			-0.00002 (0.000)	-0.00002 (0.000)	-0.00002 (0.000)
Population density			0.06164*** (0.017)	0.06106*** (0.017)	0.06144*** (0.017)
Share of adults with higher education			2.03352** (0.876)	2.21038** (0.880)	2.15108** (0.895)
Government quality			28.0973* (15.051)	27.0416* (14.996)	27.9861* (15.022)
Interaction R&D inv.*government quality			-0.59242* (0.306)	-0.59752* (0.308)	-0.60771* (0.312)
Observations	4 227	3 345	3 022	3 022	3 022
Number of regions	273	273	253	253	253
R^2	0.617	0.648	0.666	0.670	0.667
Adjusted R^2	0.615	0.646	0.664	0.668	0.664
F test	14.54	18.14	19.05	19.33	19.38

Source: Author's own calculations

Note: Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/partii/chapter12/figure_12-8.xlsx

The results highlight that innovation – proxied by patent applications to the EPO per million of active population – in the EU regions is fundamentally linked to four factors: investment in R&D, population density, a higher share of population with tertiary education, and government quality (Figure 12-8, equation 3). Regions in the EU that have invested the most in R&D have, by and large, managed to transform said investment into patents. This is valid for analyses covering both the period starting in 1991 (equation 1) and that since 2000 (equation 2). However, the transformation of R&D into innovation has been far more problematic in the less-developed regions of the EU[2]. In the latter regions, the returns in terms of patenting of additional investment in R&D were far lower than in more-developed areas (see also Sterlacchini, 2008). And the greater difficulty to transform the science and technology effort into innovation affected less-developed regions in central and eastern and in southern Europe in a similar way (Figure 12-8, equation 5). Investment in R&D in these regions yielded lower innovation returns.

Education also emerges as an important driver of innovation. Regions with greater educational endowment – proxied by the share of the adult population with higher education – innovated more that those with weaker human capital (Rodríguez-Pose and Crescenzi, 2008; Marrocu et al., 2013; Faggian et al., 2017). Density – generally considered to be a fundamental factor in the transfer of knowledge (Duranton and Puga, 2001; Storper and Venables, 2004; Glaeser, 2012) – also played an important role in the generation of patents, relative to the contribution of sheer agglomeration (Figure 12-8, equations 4 and 5).

Finally, government quality has a profound association with innovation, which is both direct and indirect. Directly, poor quality government discourages innovation (Rodríguez-Pose and Ketterer, 2019). Indirectly, marginal improvements in R&D yield higher returns in terms of innovation in regions with better government quality. In addition, the benefits from increases in the R&D effort linked to more efficient government institutions accrue, to a greater extent, to regions with initially poor government quality on the periphery of Europe than to regions in the core that already enjoy far better government institutions (Rodríguez-Pose and Di Cataldo, 2015).

However, the transition from innovation into greater economic activity and growth in the EU has been less evident. Figure 12-9 presents the results of estimating the growth model, using an FE approach [Model (2)]. The coefficients for patent applications show the link between patenting over the last three decades and regional economic growth in the EU. These coefficients indicate that there has been no evidence of a link between patenting and regional economic performance in the EU since the early 1990s (Figure 12-9, equations 1 to 3). Regions that have patented the most have not grown faster. In contrast, the endowment of human capital and the institutional quality at a regional level are strongly and significantly connected to regional economic growth. Regions with the best human capital and government institutions have grown considerably more rapidly than those with greater shortages in these two domains. Both agglomeration and density are negatively connected with economic growth (Figure 12-9, equation 3).

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[2] Defined here as all those regions that qualified as less developed (Objective 1) during the programming period 2000-2006.

Figure 12-9 From patenting to economic growth in the EU

Dep. variable: change in GDP per head	1991-2012	2000-2012			
	(1) FE	(2) FE	(3) FE	(4) FE	(5) FE
Patent applications	0.00004 (0.000)	0.00006 (0.000)	0.00017 (0.000)	0.00015 (0.000)	0.00002 (0.000)
Less-developed regions				0.00094*** (0.000)	
Less-developed regions (eastern Europe)					0.01026*** (0.002)
Less-developed regions (southern Europe)					0.00011 (0.001)
Population			-0.0000*** (0.000)	-0.0000*** (0.000)	-0.0000*** (0.000)
Population density			-0.0001*** (0.000)	-0.0001*** (0.000)	-0.0001*** (0.000)
Share of adults with higher education			0.00338** (0.002)	0.00318** (0.002)	0.00242* (0.001)
Government quality			0.07304*** (0.025)	0.07351*** (0.025)	0.06641*** (0.023)
Interaction R&D inv.*government quality			-0.00017 (0.000)	-0.00016 (0.000)	-0.00004 (0.000)
Observations	4 227	3 345	3 022	3 022	3 022
Number of regions	273	273	253	253	253
R^2	0.612	0.434	0.511	0.519	0.553
Adjusted R^2	0.610	0.432	0.508	0.512	0.550
F test	82.80	103.3	77.74	76.15	66.99

Source: Author's own calculations

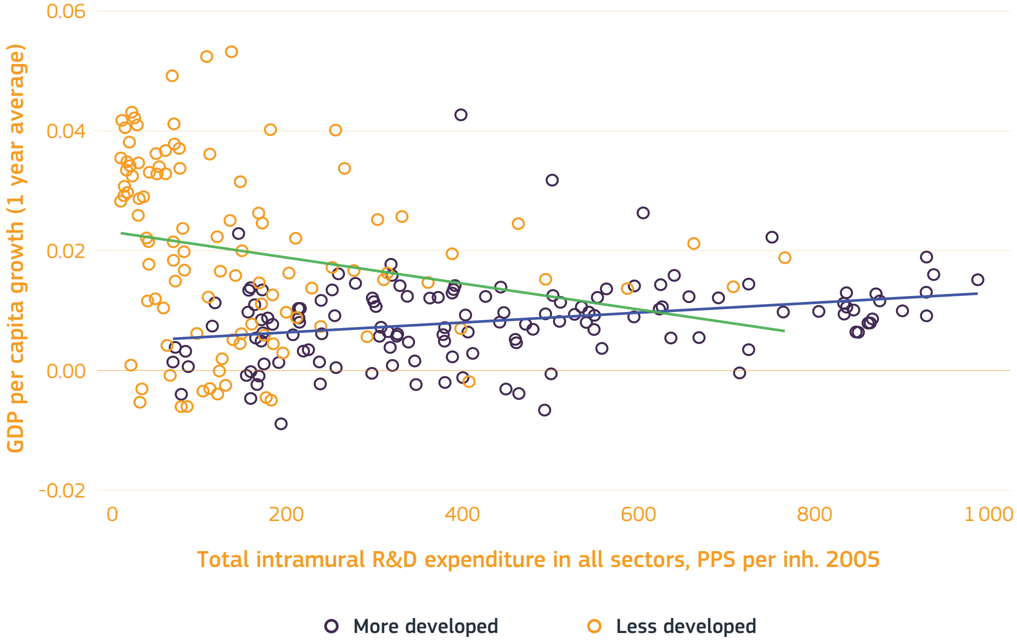
Note: Robust standard errors in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/partii/chapter12/figure_12-9.xlsx

As indicated in Figure 12-8, although less-developed regions have had greater difficulties in transforming R&D into innovation, innovation outputs in these areas seem to be more connected to economic growth than in more-developed EU regions (Figure 12-9, equation 4). This process, however, is entirely driven by the less-developed regions of central and eastern Europe, whereas those in southern Europe suffer from the same problems of converting innovation into economic growth as the average European region (Figure 12.9, equation 5),

Overall, across the EU regions, there is a positive connection between R&D activities and innovation, measured by patenting. However, translating innovation into economic growth is far less forthcoming (e.g. Bilbao-Osorio and Rodríguez-Pose, 2004). Likewise, Europe's less-developed regions are less capable of generating innovation from R&D inputs which, in turn, may curtail their capacity to grow in the medium to long term. Hence, the basic tenet of the linear model of innovation – that R&D investment leads to greater innovation and, in turn, innovation leads to growth – is challenged in the EU, in particular across most of its less-developed regions. This evidence is graphically represented in Figure 12-10 which traces the transition from R&D investment in 2000 (measured in constant (2005) euros per capita) and regional economic growth between 2000 and 2012.

Figure 12-10 From investment in R&D to economic growth in both less- and more-developed regions



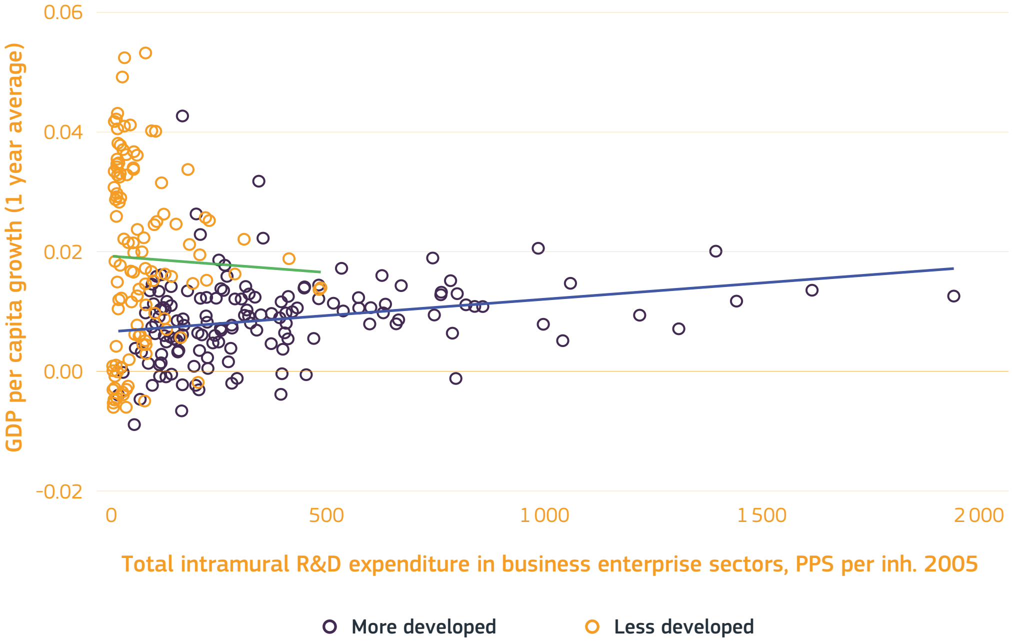
Source: Author's own elaboration

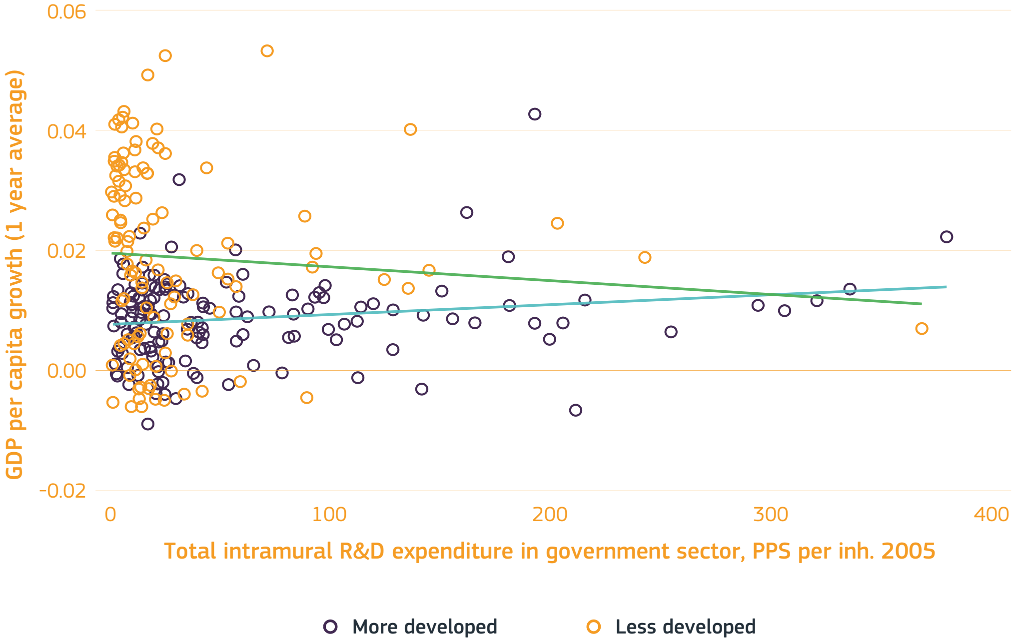
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/partii/chapter12/figure_12-10.xlsx

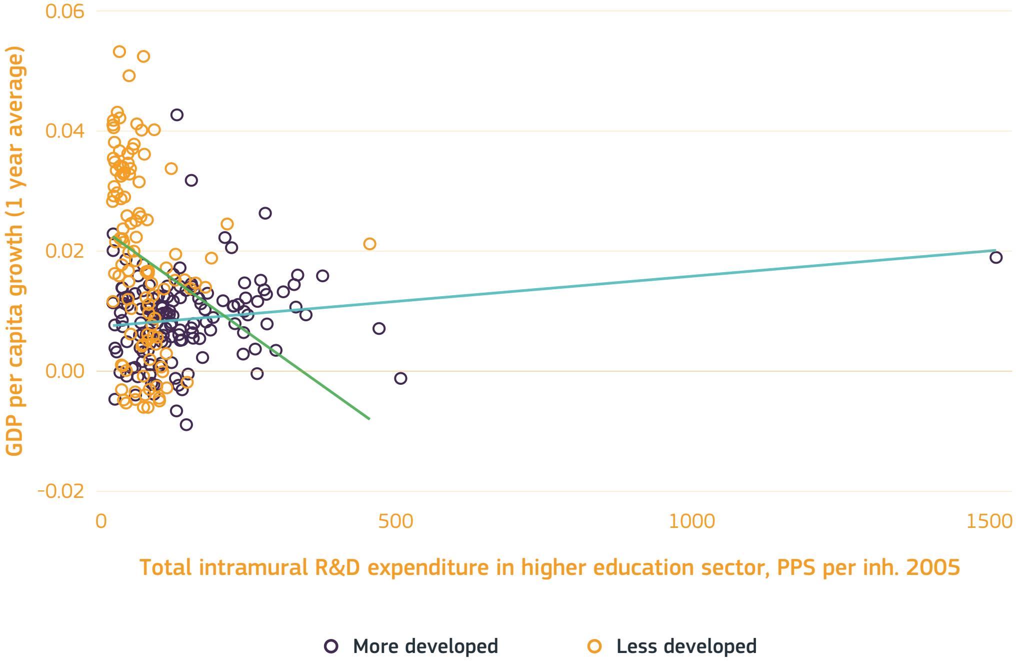
As indicated in the econometric analysis, more investment in R&D has resulted in virtually no additional growth. There is, however, an important difference between the connection between R&D and economic growth in both more- and less-developed regions. In more-developed regions, the regression line between R&D expenditure and economic growth has a slightly positive slope. Regions in the core of Europe with a higher initial level of investment in R&D have achieved a marginally greater degree of economic growth. However, this is not the case in the less-developed regions. A negative regression line reinforces the idea that, in many of these areas, the effort to generate greater innovation has not delivered on the final objective of unleashing greater economic activity and growth.

To what extent is this a consequence of the different types of R&D investment being carried out in both less- and more-developed parts of the EU? Figure 12-11 looks at the connection between R&D investment in the three main sectors – business, government and higher education and economic growth – during the period of analysis.

Figure 12-11 From investment in R&D to economic growth in less- and more-developed regions, by sector of R&D investment







Source: Author's elaboration based on Eurostat data

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/partii/chapter12/figure_12-11.xlsx

While in more developed regions, R&D investment in the business, government, and higher education sector is connected to slightly higher growth, this is far from being the case for less developed regions. All the regression slopes are negative for the less developed category, meaning that the lagging-behind regions that invested the most in R&D have encountered considerable difficulties in transforming this type of innovation input into economic growth. The greatest mismatch concerns the higher education sector. As many less-developed regions lack the advanced business fabric capable of churning out new knowledge generation activities (Rodríguez-Pose, 2001), universities and higher education institutions have acted as substitutes. Indeed, the majority of the growth in R&D investment in the less-developed regions of the EU has taken place in the higher education sector. This additional investment has contributed to an increase in the scientific output in these regions. Both central and eastern Europe and southern Europe have considerably narrowed the gap in scholarly publications relative to the scientific leaders in Europe. Whereas the countries in central and eastern Europe produced only 16 % of the articles of the three European scientific leaders (the UK, Germany and France) in 2000, this share had risen to almost 27 % by 2018 (Figure 12-12). A similar improvement in scientific output was witnessed across southern Europe, where the shift was from 34 % in 2000 to 52 % in 2018 (Figure 12-12). But, as highlighted by Figure 12-11, this considerable leap forward in scientific publications has not resulted in substantial improvements in economic outcomes. Most regions at the economic fringes of the EU have little to show for the increased R&D effort conducted mainly before the crisis.

Figure 12-12 Scientific production in central and eastern and southern Europe relative to the scientific leaders in Europe (%) (2000-2018)

	2000	2010	2018
Scientific leaders[1]	100	100.	100
Central and eastern Europe[2]	16.29	22.57	26.76
Southern Europe[3]	33.87	45.37	51.89

Source: Author's own calculations

Notes: Documents published in journals indexed in the Scimago country rankings. (1)United Kingdom, Germany, France. (2)Bulgaria, Croatia, Czechia, Estonia, Hungary, Latvia, Lithuania, Poland, Romania, Slovakia, Slovenia. (3)Cyprus, Greece, Italy, Malta, Portugal, Spain.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/partii/chapter12/figure_12-12.xlsx

Three key factors may explain this mismatch. First and foremost, a large share of the universities in less-developed regions are far from being knowledge-generation leaders, which means it is often difficult for them to make the most of R&D investment. Second, those university departments in less-developed regions that do manage to produce frontier research often find that they have no viable business partners in the local economy. The structural composition of the economies in these lagging-behind regions is key to this. The lack of a critical mass of innovative firms in most eastern and southern European regions represents a fundamental barrier for the development of networks between universities and public research centres, on the one hand, and firms, on the other. Consequently, new knowledge being generated in these areas does either not percolate locally or, in the worst-case scenario, is lost from an economic point of view. Therefore, the most successful research centres and departments in the EU's less-developed regions are pushed to reach out to business partners in distant locations. Finally, a large share of the research conducted by universities is basic in nature which – although fundamental in leading to innovation further down the road – has less immediate direct impact than the more applied research generally performed by the business sector. Weaker universities and business fabrics in the economic periphery of Europe thus prevent higher education institutions from fulfilling the same role as catalysts of innovation and economic growth as they accomplish, for example, in North America (Rodríguez-Pose and Wilkie, 2019).

Hence, a very modest transformation of R&D into innovation and economic activity in the EU's less-developed regions contributes to what has been called the 'European innovation paradox': the lower capacity of the EU as a whole, relative to, most notably, the United States but also to the Asian Tigers, to convert innovation inputs into greater economic dynamism (Dosi et al., 2006; Argyropoulou et al., 2019). This is possibly because too much attention – especially in the less-developed regions of the EU – has been put on the 'supply-side' of innovation (knowledge generation) at the expense of the capacities of different territories to absorb knowledge and innovation. Similarly, the focus has been on the R (research-side) of R&D rather than on the D (development-side). While more investment in research and the development of the physical scientific infrastructure for it contributed to addressing an investment gap in the first instance, overlooking the D side has contributed to the generation of a significant bottleneck that prevents Europe from making the most, relative to other economies, of its considerable innovation effort (Dosi et al., 2006; Rodríguez-Pose and Wilkie, 2019; Bianchini et al., 2019).

5. Towards a different innovation policy for the EU's less-developed regions

Overall, the EU as a whole, and its economic periphery, in particular, have failed to make the most of policies that follow the linear model of innovation (see also Camagni and Capello, 2013). Low levels of investment but, above all, structural bottlenecks – including deficits in human capital endowments, brain drain, weak economic fabrics, and inadequate institutional ecosystems – have resulted in a low capacity in the EU's less-developed regions to produce new knowledge. But, more fundamentally, this has led to a pervasive inability to translate knowledge into economically feasible innovation. This raises questions about the wisdom of pursing a policy where the main focus is on one aspect of the supply-side of innovation effort: R&D.

Moreover, the incapacity of less-developed European regions to transform new knowledge into viable economic activity is undermining the economic potential of these regions and can lead to an exacerbation of the already significant inequalities in GDP, employment and productivity further down the line. It also limits overall innovation in the EU, as considerable innovation potential remains untapped. But the consequences go well beyond unexploited potential and spill over into the social and political realms. Lack of opportunities and capacity to exploit innovation and, consequently, limited economic growth is a source of tension and discontent on a continent that is naturally averse to inequalities. The outcome is growing social and political tensions, increasingly manifested through the ballot box and the occasional outbursts of violence (e.g. the rise of the '*gilets jaunes*' in France), which threaten the economic and political stability of the EU and which can ultimately also challenge innovation in core areas. Brexit has the potential to be a fundamental example of this (through the flight of innovative firms, brain drain, reduction of investment in R&D, and greater social and political uncertainty) (Rodríguez-Pose, 2018).

Hence, a change in politics in order to promote economically viable innovation in the EU's less-developed regions is on order, as the innovative deficit in less-developed areas of the EU is not necessarily a consequence of limited R&D investment or one of a lack of new scientific knowledge production. Many less-developed regions in the EU have levels of expenditure in R&D which – although still with margins of improvement – are broadly in line with their degree of economic development. Although the emphasis on the research side of R&D has expanded knowledge creation, the benefits in terms of greater economic growth, higher productivity and employment generation have been well below par.

There is therefore a need to go beyond R&D – without neglecting progress in this respect over the last three decades – and to tackle head-on the bottlenecks related to these areas' limited innovative capacity. This implies, at the very least, considering the following areas of intervention:

1. ***Complementing the pursuit of excellence in R&I needs with a greater emphasis on promoting innovation in the EU's less-developed areas***: Although excellence should remain at the heart of the R&I effort, it should be acknowledged that the territorial polarisation of R&I limits the overall innovation potential of the EU. This would imply that unveiling and tapping into R&I potential specifically in the EU's less-developed regions may need to become an explicit and complementary policy objective.

2. ***Putting innovation at centre stage in less-developed regions***: So far, the R&D effort in less-developed regions has been dedicated mainly to improving research outcomes. As shown in Table 12.3, the less-developed countries of the EU periphery have multiplied their scientific output and – at least in number of outputs – closed the scientific gap with the core of the EU. However, improvements in research have not been matched by similar progress in terms of innovation. With a few exceptions, less-developed regions in the EU struggle to transform research into new processes and products developed by local firms – or, often, elsewhere in the EU as well – which means that the impact of the greater research effort on the prosperity and well-being of society is limited.

   This requires an innovation policy that goes well beyond the simple funding of R&D or subsidies to firms in support of R&D and concentrates on: a) enhancing the innovation capacity of firms in the region; and b) creating an adequate ecosystem for innovation to emerge and thrive. More focus on the role of production networks and value chains, as well as on triple and quadruple helix strategies is thus warranted to cement the foundations of favourable innovation systems (Carayannis and Campbell, 2012).

3. ***Promoting pan-European and international networks involving innovation actors***: Recent research has emphasised the importance of extra-local connectivity

as a source of innovation and change. Innovative actors which branch out to other innovative actors outside the local territory not only become more capable of creating new knowledge and innovating themselves, but also turn into catalysts of innovation in their local environments. According to the literature, the results are greatest when these connections are international – the so-called innovation 'pipelines' (Bathelt et al., 2004). Such pipelines facilitate the circulation of new knowledge and reduce the risk of lock-in. There is increasing evidence – from research in Sweden, Norway, Finland, Austria, Portugal and Canada – that dynamic firms in peripheral locations innovate in a different way from those in more innovation-prone environments (Shearmur, 2017; Eder, 2019; Eder and Trippl, 2019). Frequently, innovation is essentially achieved by compensating for the lack of critical mass and for the distance to the technological frontier by engaging in international interaction (Doloreux and Dionne, 2008; Fitjar and Rodríguez-Pose, 2011; Tödtling et al., 2012; Grillitsch and Nilsson, 2015).

Yet the formation of networks for R&I in European policy has fundamentally been limited to the promotion of research consortia within the different Framework Programmes with very limited protagonism for firms. Putting companies at centre stage of the formation of innovation partnerships, first, and networks, later, can represent a huge boost in the innovation capacity of many less-developed regions.

4. ***Aligning EU policies with their potential effects on R&I and territorial inequalities (and better coordination with national innovation policies)***: Lack of an adequate horizontal alignment between the European policies that affect research innovation and territorial inequalities is limiting the impact on investment in innovation. This is not only reducing the returns on the European R&I policy and European Cohesion Policy, but also concerns all efforts to improve education and skills across the EU.

   In addition to these improvements in horizontal coordination, there is also a need for better vertical coordination between European and national R&I policies.

5. ***Tackling poor institutions***: Weak institutions, in general, and poor governance quality, in particular, are important barriers to R&I (Rodríguez-Pose and Di Cataldo, 2015). R&I policies in areas with weak governance are often misguided and almost always lead to significant waste of limited resources. Therefore, improvements in institutional quality must become essential components of any R&I strategy. Interventions targeting institutional bottlenecks, especially in terms of improving efficiency in delivering innovation programmes, increasing transparency and accountability, and combatting corruption will improve the outcomes of any intervention to promote innovation, particularly in the less-developed regions that tend to endure the worst of institutional bottlenecks.

Putting all these factors together requires the development of new, place-sensitive policies: That means policies that are based on strong theory and solid empirical analyses, but which are sensitive to the conditions and problems of specific groups of regions across Europe (Capello and Camagni, 2015; Crescenzi and Giua, 2016; Iammarino et al., 2019). Only in this way can research and innovation policies become versatile enough to make sure that the contrasting objectives of pursuing excellence and maximising the returns on R&I investment, on the one hand, and of mobilising as much innovation potential as possible and achieving more territorially harmonious development, on the other, can be reconciled.

6. Conclusions

The EU suffers from an important innovation divide that is curtailing its capacity to increase its competiveness and economic presence on the world stage, while also undermining the goal of improving the welfare of Europeans regardless of where they live. The tendency of economically viable innovation to concentrate in the more-developed areas is also having considerable consequences on the EU's capacity to close the gap between its economic core and its periphery, further sponsoring a social and political discontent that can have serious consequences – economic and otherwise – for the future of Europe. And the dominant innovation policy emanating from both the Lisbon Strategy (2000-2010) and Europe 2020 of raising the R&D effort to 3% of GDP – despite non-negligible improvements in new knowledge generation – has, so far, failed to trigger the economic dynamism to both increase the competitiveness of the EU as a whole and to close the innovation divide between its more- and less-developed areas.

This demands a thorough re-examination of European innovation policy, especially in the EU's less-developed areas. The R&D-oriented one-size-fits-all, European-wide policies of the past have not led – and, in all likelihood – will not lead to improvements in competitiveness. Nor are they likely to yield significant improvements in economic growth, sustainable employment, and welfare in the EU's less-developed regions. As Sterlacchini emphasises: 'simply investing more public and private resources in the fields of knowledge and education does not guarantee equal growth opportunities among EU regions' (Sterlacchini, 2008: 1106). There is a need, therefore, to go beyond the focus on R&D and adapt policies to the specific characteristics of different territories: a place-sensitive innovation policy for the EU. Such approach must put innovation and innovation absorption at its core, focusing on the mechanisms that would facilitate the generation and absorption of innovation by individual economic actors and firms and contribute to the inclusion of these actors in innovation-generating and diffusing value chains and knowledge, often extending well beyond the local environment (Miguélez and Moreno, 2015).

Recent steps have been taken in this direction at both the EU and national level. In particular, since the reform of the European Cohesion Policy in 2014, the implementation of smart specialisation strategies represents an important step in the right direction. But changes should become bolder and more daring in order to better realise the innovation potential of the whole of Europe and to narrow the innovation and social and economic divide within the EU. The stakes are high as, without better use of the talent and potential for innovation across the entire EU, we will not only be giving up on significant capacities to generate new knowledge, but will also be putting at risk the economic and social stability which has been at the heart of making Europe one of the most prosperous and – despite appearances – equal societies in the world.

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CHAPTER

13

REGULATIONS AND TECHNOLOGY DIFFUSION IN EUROPE: THE ROLE OF INDUSTRY DYNAMICS

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Summary

This chapter focuses on the dynamics of innovation diffusion by analysing the impact of the regulatory framework on the gap between top firms and the followers. It expands on the existing literature by explicitly investigating the relationship between the regulatory frameworks in the labour, goods and capital markets and innovation diffusion, both directly and indirectly through the intermediate effect of business dynamism. This is particularly relevant for small firms engaging in risky activities, such as innovation, for which barriers to access to finance are tighter than for incumbent companies.

The authors developed an original index of potential technology diffusion following a consolidated approach that uses the total factor productivity distance to the technological frontier as proxy, which accounts for the potential transfer of knowledge and technology embodied in trade. The new proposed methodological approach informs on both the mediating and moderating role of business dynamism in the relationship between regulation in product, labour and capital markets and technology diffusion and thereby enriches existing literature on framework conditions and productivity.

This chapter produces evidence to inform reform efforts targeted at product, labour and capital markets while also providing insights on the impact of regulatory frameworks on technology diffusion, the latter being acknowledged recently as a key factor behind productivity dynamics.

1. The issue at stake

Subdued productivity performance has emerged as one of the main challenges facing Europe, and significantly so in the aftermath of the last economic crisis. While the slowdown in productivity growth can be traced back to the second half of the nineties, its severity has worsened in the last decade with zero or negative growth across Europe. European countries have reversed the trend only recently, and with unequal success across their regions, revealing different paths and high heterogeneity also within Member States (Iammarino et al., 2018).

When science and technology are considered to be the engines of growth, how can we rationalise the recent productivity growth slowdown and the concomitant boom in exciting new technologies? Different hypotheses have been put forward. They range from techno-pessimistic views à la Gordon (Gordon, 2012) – claiming that such slowdown is a permanent feature of modern economies that are ‘physiologically’ unable to bring productivity performance back to previous heights – to more optimistic views, which argue that the low growth countries are experiencing is due to the delay in the yet-to-unfold benefits from the digital revolution, caused by the slow transition from a production-oriented towards an intangible-based economy (Brynjolfsson and McAfee, 2011).

Analyses of productivity dynamics at company level provide further insights. Indeed, while productivity growth has generally slowed down, leading technological firms are still able to keep up and continue to grow. A plausible implication of this trend can be the increasing concentration of knowledge and innovation creation among a few actors and places and their lack of diffusion (Andrews et al., 2015; Andrews et al., 2016).

More specifically, innovation benefits are increasingly concentrated among frontier firms, a mechanism continually reinforced by the process of globalisation, which contributes to increasing the productivity gap between the best-performing companies and the rest. Markets tend to be highly concentrated and dominated by a few superstar companies.

At the same time, the process of technology diffusion has stalled, reducing the scope of lagging companies to catch up with the frontier leaders. On the one hand, this is driven by the greater complexity of technology, demanding higher absorption capacity in the form of prior accumulated knowledge and an adequate skills endowment, in order to be able to reap the benefits of technological change. On the other hand, adverse framework conditions may prevent a broader diffusion of innovation across firms, as they can hinder their capacity to invest and create barriers that affect the market entry of new innovative companies (Andrews et al., 2015; Brynjolfsson and McAfee, 2011). Therefore, the innovation gap between frontier firms and the rest grows wider, contributing to divergences in productivity performance.

Against this backdrop, the existing literature has analysed the impact of framework conditions on total factor productivity (TFP) dynamics, focusing mainly on the efficiency of labour, product and capital markets. The standard argument claims that excessive regulation in the product market is constraining productivity growth, as the excessive burden on companies discourages investment (Scarpetta and Tressel, 2002; Scarpetta et al., 2002). Similarly, stringent restrictions regulating hiring and firing may slow down the reallocation of the labour force from less- to more-productive firms, creating a negative effect on aggregate performance while also affecting hiring decisions, especially in downturn periods (Martin and Scarpetta, 2012; McGowan and Andrews, 2015; Thum-Thysen and Raciborski, 2017). Therefore, greater flexibility in the labour market is usually found to be linked to better productivity performance. However, a different perspective suggests that excessive deregulation may reduce firms' incentives to invest in human capital accumulation and training, with negative impacts in the medium and long term (Lucidi, 2012; Egért, 2016). Finally, barriers to access to finance are singled out as a deterrent to companies' investments, in particular for young firms engaging in innovation activities (Hall and Lerner, 2010; Agénor and Canuto, 2017; European Commission, 2018).

This chapter focuses on the dynamics of innovation diffusion by analysing the impact of the regulatory framework on the gap between top firms and the followers. It expands on the existing literature by explicitly investigating the relationship between the regulatory frameworks in the labour, goods and capital markets and innovation diffusion, both directly and indirectly through the intermediate effect of business dynamism. The latter is defined as the sum of shares of firms leaving and entering the market (churn rate) on the total number of active companies. Excessive burdens and bureaucratic barriers tend to discourage new companies from entering the market due to higher entry costs. This is particularly relevant for small firms engaging in risky activities, such as innovation, for which barriers to access to finance are tighter than for incumbent companies (Scarpetta et al., 2002; Acs et al., 2009; Agénor and Canuto, 2017).

The emphasis on the role of firm dynamics (entry and exit) as the main channel through which regulatory reforms may increase productivity growth (European Commission, 2018; de Haan and Parlevliet, 2018), via a greater diffusion of knowledge, is not sufficiently reflected in the existing studies. Hence, this work contributes to the literature in several ways.

First, we develop an original index of potential technology diffusion following a consolidated approach that uses the TFP distance to the technological frontier as the proxy (Nicoletti and Scarpetta, 2003; Buccirossi et al., 2013; Santacreu, 2015; Santacreu, 2017). We account for the potential transfer of knowledge and technology embodied in trade, a dimension that is increasingly relevant as new products, technologies and components are used across different sectors and activities (e.g. dual-use technologies, key enabling technologies, etc.). Specifically, we use a weighted average of the distance between the TFP of a firm i and the TFPs of all frontier firms in sectors that are trade-related to the sector of firm i. We use weights based on the intensity of trade in intermediate inputs between sectors.

Second, we contribute to the existing literature on framework conditions and productivity with a new methodological approach that informs on the mediating and moderating role of business dynamism in the relationship between regulation in product, labour and capital markets and technology diffusion.

Finally, the analysis and its findings are relevant for policy considerations in the European context. The slowdown in productivity growth has affected all European regions, even if with heterogeneous intensity. Member States have been asked to implement structural reforms in order to promote growth in Europe, with a specific focus on innovation as the main lever to boost productivity gains[1]. These reforms target product, labour and capital markets as crucial bottlenecks to the re-boosting of productivity and economic growth performance. This chapter produces evidence to inform those policies, whilst also providing insights into the impact of regulatory frameworks on technology diffusion, the latter being a key factor behind productivity dynamics (Andrews et al., 2016).

2. Technology diffusion

While research and innovation (R&I) are key engines of productivity growth, economies and companies can also grow by importing and adopting innovations produced elsewhere. This is particularly true for countries or regions that are far from the technological frontier and are less likely to produce innovation indigenously. Hence, foreign knowledge is an important source of productivity gains and a leverage for countries' growth, as emphasised in the literature on economic convergence. In his seminal work, Abramovitz (1986) highlighted how the potential gain from technology adoption is greater for those who lag behind, whose potential 'leap' is larger, as the technology imported would replace existing *capital technologically* superannuated. This is usually known as the advantage of backwardness: 'the larger the technological and, therefore, the productivity gap between leader and follower, the stronger the follower's potential for growth in productivity; and, other things being equal, the faster one expects the follower's growth rate to be' (Abramovitz 1986, pp. 386-387). One of the caveats is that the recipient must be able to understand and use the technology, either imported or through technology spillovers. An adequate absorption capacity is needed, which can be built via internal investment in R&I, skills

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[1] See also https://ec.europa.eu/info/business-economy-euro/growth-and-investment/structural-reforms/structural-reforms-economic-growth

and human capital (Falvey et al., 2007; Fu et al., 2011). The analysis in this chapter applies these arguments at the company level.

The evolutionary economics literature led by, among others, Dosi (1982) and Malerba (2002), has put forward the role of sectoral characteristics for differences in productivity. These authors show that productivity differentials are only partially related to innovation diffusion, and they depend on a 'more complex set of structural factors and sector-specific techno-economic conditions'. Castellacci (2007) shows that sectoral differentials in productivity growth in Europe are related to cross-industry differences in terms of technological opportunities, human capital, size of the market, degree of openness and appropriability conditions. In particular, when appropriability conditions are low, i.e. when it is more difficult to protect innovations from imitation, there is a greater opportunity for intra-industry knowledge diffusion and a positive effect on productivity growth.

Technology diffusion can occur via different channels: one is foreign direct investment (FDI) and trade in intermediate goods and machines, in which technology is embedded. Knowledge is diffused and can be translated into products and services as long as the recipient firm has the required absorptive capacity (Rivera and Romer, 1991; Grossman and Helpman, 1991; Santacreu, 2017). This channel is investigated in the international technology diffusion literature, upholding the view that domestic productivity growth is influenced by foreign sources of technology concentrated in a few countries, regions and companies. These actors are responsible for expanding the technological frontier. Countries that are farther from the technological frontier grow by adopting new foreign technologies, while economies closer to it grow by developing new technologies through research and development (R&D) investment (Santacreu, 2015). To this extent, international technology diffusion matters as it determines the pace at which the world's technology frontier may expand in the future (Eaton and Kortum, 1999; Eaton and Kortum, 2001; Keller, 2002; Comin and Mestieri, 2014) and the rate at which laggards can catch up. For instance, Jung and Lee (2010) find that TFP catch-up is more likely in sectors where technology is more explicit and embodied in equipment (such as electronics), and in sectors characterised by more monopolistic market structures. This allowed leading Korean companies to build innovation capacity to converge with Japanese productivity levels.

A second channel is the international knowledge spillovers that are not necessarily linked to any particular transmission form but simply stem from the stock of technology. In other words, current R&D builds on previous R&D performed globally, creating a linkage between national research and the national and global stock of knowledge (Nadiri, 1993; Keller, 2004). Since spillovers cannot be directly observed, the majority of empirical studies measures them by relating the firms' R&D investment to R&D activities, TFP (Keller, 2002), patents (Jaffe et al., 1993; Verspagen, 1993; Mancusi, 2008), or inward FDI (Aitken and Harrison, 1999) of another firm, conditional on the existence of trade flows between the countries to which the two firms belong, in the case of international knowledge spillovers (Coe and Helpmann, 1995).

However, the partially tacit, non-codified nature of technology makes its diffusion incomplete and more geographically localised (Von Hippel, 1994). The larger the tacit component of knowledge, the harder it is to import technology from abroad. In addition, the costs and capabilities needed to absorb knowledge increase with geographical distance. The transfer of tacit knowledge and its positive spillovers are bounded to take place mainly locally, building on personal interactions between or within firms and, as such, are strongly dependent on proximity (Archibugi and Filippetti, 2018).

A trend is also observed when considering innovation diffusion across economies. For instance, Bahar et al. (2014), building on the evidence of the strong decline in knowledge diffusion with geographical distance, empirically test the localised nature of knowledge transfers and confirmed that neighbouring countries share more knowledge and have similar static patterns of comparative advantage.

Knowledge flows between companies, universities and research centres across countries and regions are another source of innovation diffusion. The literature on R&D collaboration sparked by d'Aspremont and Jacquemin (1988) suggests that cooperation among firms or between companies and universities leads to knowledge spillovers, provided that the collaborating parties have a sufficient level of appropriation capabilities (Cassiman and Veugelers, 2002). Technological collaboration allows small and medium-sized enterprises (SMEs) to close the innovation gap with firms at the 'frontier' (Nieto and Santamaria, 2010) and, overall, that 'higher R&D collaboration is associated with a faster catch-up process of laggards firms very far from the national frontier, while firms close to this frontier keep pace with it' (Andrews et al., 2015, p.7). In the case of Europe, the European Research Area initiative has aimed to improve the diffusion of knowledge by promoting its free circulation together with the mobility of researchers, in an effort to maximise the benefits from knowledge spillovers (European Commission, 2018).

3. Framework conditions

Building on the above contributions, substantial literature has explored the role framework conditions have in shaping technology diffusion and differences in productivity and economic growth (Lynn et al., 1996; Nickell, 1993; Blanchard, 2004; Acemoglu et al., 2005; Buccirossi et al., 2013).

The institutions ruling the functioning of the product, labour and capital markets affect companies and their possibility to benefit from innovation outcomes. Framework conditions impact firms' decisions, including how much to invest, how to invest and whether to enter or leave the market. Transaction and entry costs may discourage small and young companies, which tend to be more innovative but are usually unable to get sufficient access to capital or to overcome cost and non-cost barriers to entry. Furthermore, framework conditions also affect the diffusion of technology, influencing the allocation of resources, including skilled workers and intangible capital, and hence companies' absorption capacity.

First, restrictive product market regulations hinder technology transfer and have a negative bearing on productivity (Crafts, 2006; Scarpetta and Tressel, 2002). The study by Scarpetta and Tressel (2002) explores the role of regulations and institutional settings in the products market in explaining TFP growth. They find that stringent regulatory settings in the product market have a negative impact on TFP and, although results are more tentative, on market access by new firms.

As regards labour market regulation, the focus is on non-wage labour costs, wages setting and hiring and firing restrictions for companies. On the one hand, the consensus seems to support the view that regulation that is too strict has negative effects on employment prospects, labour reallocation and eventually on aggregate productivity performance and growth. For instance, Tressel and Scarpetta (2004) analyse labour market institutions affecting labour adjustment costs in 18 Organisation for Economic Co-operation and Development (OECD) countries, finding that high labour adjustment costs (proxied by the strictness of employment protection legislation) decrease industry-level productivity. They argue that, when non-wage labour costs (hiring and firing costs) are high and labour market regulation does not allow for the flexible adjustment of wages, the incentives for innovation and adoption of new technologies are hindered, eventually leading to lower productivity performance. Moreover, these costs tend to discourage the entry of (especially small and medium-sized) firms into most markets (Scarpetta et al., 2002, p. 3). Consistent with this view, Thum-Thysen and Raciborski (2017) find that excessive restrictions in firing and hiring negatively affect TFP in the long term, while Balta and Mohl (2014) report that policies aimed at reducing employment protection legislation may foster productivity growth in economies engaged in a catching-up process.

On the other hand, there is some evidence suggesting that the opposite relationship may be in place. For instance, Lucidi (2012) argues that loose regulation in hiring and firing may provide companies with disincentives to invest in technological upgrade and adoption, opting for cost-competitiveness gains. Similarly, Egert (2016) reports evidence of a positive link between employment protection and TFP, suggesting that stricter restrictions in hiring and firing may incentivise companies to invest in human capital and preserve high-skilled employment. Last but not least, reforms increasing the flexibility of the labour market and reducing workers' bargaining position may have harmful effects in terms of inequality, increasing the gap between the top income shares and the rest (Jaumotte and Buitron, 2015; Dosi et al., 2017).

Among the framework conditions, constraints in accessing finance are singled out as a fundamental barrier to companies' investments, in particular for young firms engaging in innovation activities, and in the aftermath of the last economic crisis (Hall and Lerner, 2010; Agénor and Canuto, 2017; European Commission, 2018). The innovation process is far from being linear and its intrinsically higher probability of failure is a deterrent to provide innovative firms with credit (Mazzucato, 2013; Agénor and Canuto, 2017). Innovative companies may also face greater difficulties in getting access to standard bank-based sources of finance, given that their main value lies in intangible assets, such as human capital and the knowledge created by R&D activities, which are a weak form of collateral (Hall and Lerner, 2010; Brown et al., 2012). Agénor and Canuto (2017) show that the lack of access to finance, together with the high costs of monitoring innovative investments, negatively affect innovation activities whilst also providing firms with adverse incentives to invest in skills, reducing the share of workers able to engage in research activities and the overall absorption capacity. While this issue may be tackled by developed financial markets, such as, for instance, equity markets that do not require collateral, the overall wedge between the rate of return expected by external investors and that required by the entrepreneur may still be large, preventing the financing of innovative investments (Hall and Lerner, 2010). Gorodnichenko and Schnitzer (2013) find that financially constrained companies in developing and transition economies are less innovative and less likely to catch up with the innovation frontier compared to foreign firms. They also reveal a link between financial frictions and aggregate productivity indicators such as TFP and labour productivity.

Finally, business dynamism, measured as entry and exit rates, drive productivity growth as they contribute to the renewal of the business population, with new innovative firms entering the market and challenging incumbents. In turn, these industry dynamics are strongly affected by the regulatory frameworks wherein firms operate.

While studies on industry dynamics and productivity show that the entry and exit of firms makes a significant contribution to aggregate productivity growth (Foster et al., 2006), the available evidence is less conclusive concerning the relationship between business dynamism and framework conditions. Correia and Fontoura Gouveia (2017) find product market regulation has a negative impact on labour productivity, but they reach a different conclusion when employment protection legislation is considered, for which they find either a zero or slightly positive impact on labour productivity growth. Acs et al. (2009) link firms' entry decisions to knowledge spillovers and barriers to entrepreneurship, such as legal and bureaucratic constraints, and labour-market rigidities. Fuentelsaz et al. (2015) incorporate the role of the framework conditions to explore differences between incumbent firms and new entrants. In particular, they show how the informal advantages of being incumbent firms (renowned by investors, trade associations and banks and holding central positions in knowledge networks) provide them with a greater probability of survival and market share advantages. This is especially true in the context of weak market-supporting institutions, including property rights protection or the presence of financial intermediaries facilitating capital and information flows within the market. Indeed, 'in situations where market-supporting institutions are not sufficiently developed, informal ties acquire an important role in supporting economic exchanges. When formal institutions are weak, informal relationships have a greater influence on driving firm strategies and performance' (Fuentelsaz et al., 2015, p. 1782). These mechanisms at play are linked to the phenomenon of the survival of zombie firms in the market, due to their advantage as incumbents (McGowan et al., 2017).

4. Empirical analysis

4.1 Data

This chapter sets itself apart from the existing literature by assessing the impact of regulatory frameworks on technology diffusion, both directly and indirectly through the mediating and moderating effects of firm dynamics. For this purpose, we use balance-sheet information at the company level drawn from the Orbis database (Bureau Van Dijk) to compute TFP. The latter is the building block to construct our measure of technology diffusion. Firm-level data on productivity is matched with country- and sector-level data on business dynamics, human capital, and regulatory frameworks, covering the three dimensions of product, labour and capital (access to finance) market regulation from different sources. Overall, to account for all the dimensions we want to cover, we use a number of datasets at different levels of aggregation: firm-, sector-, and country-level.

TFP is our starting point to produce a measure of innovation diffusion. In order to compute TFP, we use information on turnover, value added, fixed assets, and the number of employees from the online Orbis database. Our final sample is an unbalanced panel of 1.4 million companies, from 2007 to 2017, belonging to 18 EU Member States[2]. Each company is associated

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[2] The countries included in the final sample are BE, BG, CZ, DE, DK, EE, ES, FI, FR, UK, HR, HU, IT, LV, PT, SE, SI and SK. To construct our final sample, we use the online version of Orbis and have restricted our selection to firms reporting balance sheet information on turnover, value added, capital, and employees for at least three consecutive years. Then we compare the coverage of our sample to the official population statistics from Eurostat, in terms of country, year, sector of activity and size class. To increase the representativeness of our data, we keep only those countries for which our sample accounts for either at least 50 % of total employment or 50 % of total gross output.

with a main sector of activity, following the NACE rev.2 classification at the 2-digit level.

Sector-specific information about business dynamics (firm entry and exit rates) is provided by Structural Business Statistics (SBS, Eurostat), covering the business economy for industry, construction, and distributive trades and services. The data are reported at 2-digit level for most of the economic activities, although some are reported as groups (e.g. '05-09' mining and quarrying or '10-12' manufacture of food products, beverages and tobacco products).

Data on the three framework conditions dimensions (product, labour, and capital market regulations) are obtained from different data sources.

To measure the degree of regulation in the product market, we use the Regulatory Impact Indicator developed by Egert and Wanner (2016) for the OECD. The indicator follows the same rationale of the Product Market Regulation indicator developed by the OECD itself, but has the advantage of being disaggregated by sector (NACE rev.2, 2 digits)[3]. Values are normalised as between 0 (low regulation) and 1 (high regulation).

To measure labour market regulation, we use the OECD's Employment Protection Legislation (EPL) indicators. The first one concerns individual and collective dismissals, while the other one is related to the regulation of wage setting. Both indicators take values between 0 and 6, where a higher value indicates stricter rules/procedures for the termination of contracts or for determining employees' wages. From these two indicators, we build a principal component-based weighted index.

Lastly, we include three indicators for the access to capital markets from the Global Competitiveness Index developed by the World Economic Forum. They capture different features of access to credit: (i) ease of access to bank loans; (ii) access to equity funding to finance innovative and risky projects; and (iii) access to finance by issuing bonds or shares on the capital market. The three indicators can take values between 1 and 7, where the higher the value, the better the performance of the capital market. From these three indicators, we build a principal component-based weighted index[4].

In addition to the three dimensions of market regulation, we control for the availability of human capital and absorption capacity, proxied by the growth rate in tertiary graduates and workers in science and technology. Country-level data on human capital is drawn from Eurostat.

Figure 13-1 includes a more detailed description of the variables and data sources, while Figure 13.2 reports the main descriptive statistics for each group of variables. The variables in bold are those used in the estimations.

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[3] The indicator exploits input-output matrices to measure the relevance of regulation in upstream sectors for downstream industries in each country. The rationale is that sectors using intermediate inputs from more regulated sectors are more affected by the rigidities in those sectors. We use the country-weighted version since we include country fixed-effects to account for heterogeneity in the estimates.

[4] The three sub-indicators are part of the Financial Markets Development indicator in the Global Competitiveness Index, to which they contribute via a simple and weighted average. Since the three variables represent different forms of access to finance for companies, in our preliminary analysis, we have used the three indicators separately. However, they all yield similar results to those reported in this chapter.

Figure 13-1 Variables definition

Variable	Definition	Source
TFP	Computed as *Y/(L α))*, where *Y* is value added, L *and* K the number of employees and capital stock. The parameter α is derived as the labour share of output (turnover).	Orbis (Bureau van Dijk), firm-level, 2007-2017
Wage flexibility	In your country, how are wages generally set? [1 = by a centralised bargaining process; 7 = by each individual company].	World Economic Forum, country-level, 2007-2017
Hiring and firing restrictions	In your country, how would you characterise the hiring and firing of workers? [1 = heavily impeded by regulations; 7 = extremely flexible].	
Labour Market Flexibility Index (LabFlex)	Principal component-based weighted index (using 1 component loadings).	Authors' calculations
Product Market Regulation (ProdMarkReg)	The indicator measures the indirect impact of regulatory barriers to firm entry and to competition in the energy, transport and communication (ETC) sectors on all other sectors in the economy (via trade networks). We use the wider definition, including retail trade and professional services, as it is more appropriate for analysis aimed at exploiting cross-country and cross-sector variation in the data.	OECD 2013 REGIMPACT, sector-level, 2007-2016
Entry rate	Number of newly born enterprises over the number of active ones.	Structural Business Statistics (Eurostat), sector-level, 2007-2016
Exit rate	Number of economic enterprise deaths over the number of active ones.	
Churn rate	Sum of entry and exit rates of enterprises. It measures how frequently new firms are created and existing enterprises close down.	
Capital availability	In your country, how easy is it for entrepreneurs with innovative but risky projects to find venture capital? [1 = extremely difficult; 7 = extremely easy].	World Economic Forum, country-level, 2007-2017
Equity financing	In your country, how easy is it for companies to raise money by issuing shares on the stock market? [1 = extremely difficult; 7 = extremely easy].	
Access to finance	In your country, how easy is it to obtain a bank loan with only a good business plan and no collateral? [1 = extremely difficult; 7 = extremely easy].	
Access to Capital Markets Index (CapMkt)	Principal component-based weighted index (using 1 component loadings)	Authors' calculations
Human capital and absorption capacity growth	Growth rate in the number of persons with tertiary education (ISCED) and/or employed in science and technology	Eurostat, 2007-2017, sector-level

Source: Authors' own elaboration

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/partii/chapter13/figure_13-1.xlsx

Figure 13-2 Descriptive statistics

	Average	**Median**	**Std. dev.**	**Min.**	**Max.**
Turnover (EUR, thousands)	14 067	510	538 141	0	363 375 097
Value added (EUR, thousands)	4 423	197	196 281	0	340 034 292
Fixed assets (EUR, thousands)	1 989	30	81 432	0	57 306 763
No. of employees	55	5	1 593	1	648 254
log (TFP)	1.96	1.81	2.116	-19.07	21.08
Wage flexibility	4.1	4	0.82	2.2	6.2
Hiring and firing restrictions	3	2.9	0.5	2.1	6.1
Labour Market Flexibility Index	0	-0.19	1.25	-2.16	4.53
Product Market Regulation	0.12	0.088	0.092	0.0061	0.6
Exit rate	0.086	0.083	0.034	0	0.38
Entry rate	0.086	0.081	0.037	0	0.75
Churn rate	0.17	0.17	0.065	0	0.84
Capital availability	2.9	2.7	0.76	1.8	5.2
Equity financing	3.8	3.5	0.78	2.3	6.2
Access to finance	2.9	2.9	0.97	1.6	5.5
Access to Capital Markets Index	0.01	-0.63	1.64	-2.52	4.74
Human capital growth	0.03	0.02	0.02	-0.05	0.12

Science, research and innovation performance of the EU 2020

Source: Authors' own calculations

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/partii/chapter13/figure_13-2.xlsx

4.2 Methodology

Below, we illustrate the construction of our measure of potential for technology diffusion, which we then use in a mediated and moderated regression to explore the direct and indirect role of framework conditions, along with the increase in the availability of human capital.

We propose a new methodology to measure the potential for technology diffusion that combines the approach of the distance to technology frontier (Nelson and Phelps, 1966; Benhabib and Spiegel, 2005; Santacreu, 2017) with the theoretical foundations of the international trade in intermediate inputs (Caselli and Coleman, 2001; Keller, 2002; Sadik, 2008).

Unlike previous studies on the distance to technology frontier (Bertelsman et al., 2008; Andrews et al., 2016), we explicitly account for the possibility of the transfer of technology that is embodied in intermediate goods and machines (Eaton and Kortum, 1999; Rivera-Batiz and Romer, 1991; Grossman and Helpman, 1993), and that the intensity of technology diffusion is proportional to the intensity of trade between two sectors. Therefore, our measure of potential for technology diffusion is defined as:

$$TT_{ijit} = w_{jkt}\,[\mathrm{ln}(A_{ikt}) — \mathrm{ln}\,(\bar{A}_{jt})] \qquad (1)$$

with

$$\mathrm{w}_{\mathrm{jkt}} = \frac{\mathrm{Z}_{\mathrm{jkt}}}{\Sigma_{\mathrm{j}}\mathrm{Z}_{\mathrm{jkt}}}$$

$$\Sigma_{\mathrm{j}}\,\mathrm{w}_{\mathrm{jkt}\ =\ 1}$$

Where A_{ikt} is TFP of firm i in sector k, $\bar{A}_{jt}$ is the TFP of the leader frontier firm in sector j, w_{jkt} is a weight measuring global intermediate use by sector k of products Z of sector j (of the leader firm) at any time t^5.

Equation (1) can be decomposed as the sum of the traditional distance to the frontier, plus all the other distances to frontiers that are trade-related to firms in sectors that import products in the frontier's sector:

$$TT_{ijit} = w_{jjt}\,[\mathrm{ln}(A_{ijt}) — \mathrm{ln}\,(\bar{A}_{jt})] + \Sigma_{\mathrm{j}\neq\mathrm{k}}\,\mathrm{w}_{\mathrm{jkt}}\,[\mathrm{ln}(A_{ikt}) — \mathrm{ln}\,(\bar{A}_{jt})] \qquad (2)$$

When there is no intersectoral trade ($\mathrm{w}_{\mathrm{jkt}} = 0$), the distance from the frontier is only given by the gap with the leader firm in the same sector, as in the classical distance to the technological frontier in the literature.

Using the intensity of trade in intermediate inputs to weigh the distances to sector-specific frontiers provides a more appropriate measure of the technological gap, as it corrects for the bias arising when considering technologically unrelated sectors, such as, for instance, fishing and air transport. At the same time, it enables firms and frontiers companies operating in two different sectors that are nevertheless trading intermediate products with embodied technology to be related. To give an example of sector relatedness, the manufacturing sector of plastic and rubber products provides on average 11% of its products to the computer, electronic and optical products manufacturing sectors and 12% to the manufacturing of motor vehicles.

Figure 13-3 shows the differences, in 2016, between the trade-weighted and non-weighted distributions of the distance to the technological frontier. Since both measures are based on TFP gaps, observations closer to 0 identify companies with the smaller gap with respect to the frontier. The traditional, non-weighted distribution is more dispersed, with more companies on the two extremes, i.e. both closer (on the left) and farther (on the right) from the frontier.

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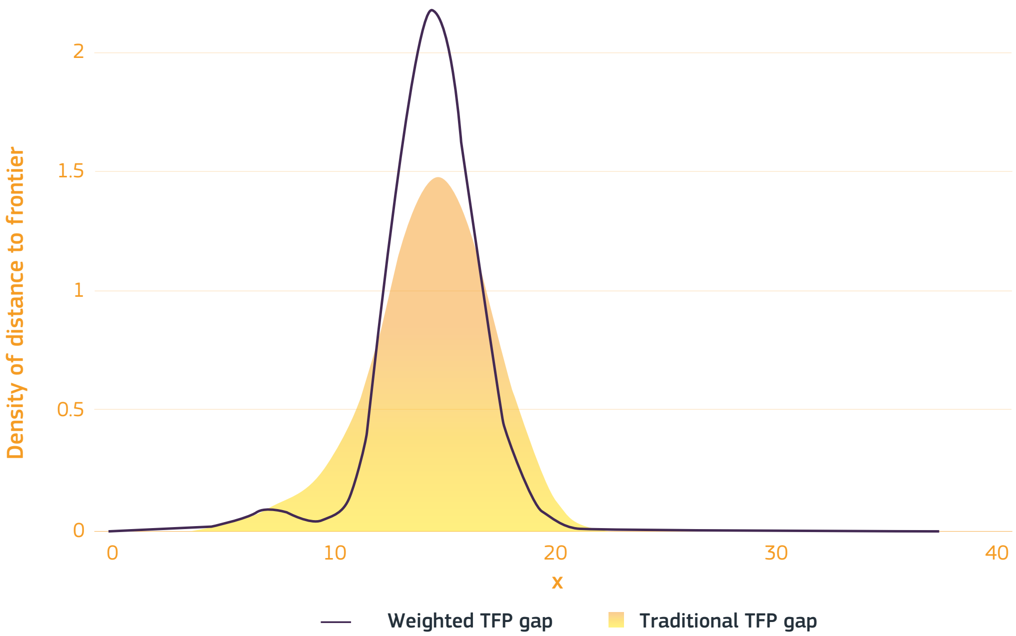
5 Data on the use of intermediate inputs is extracted by the World Input-Output Tables from the World Input-Output Database: http://www.wiod.org/home

Figure 13-3 Weighted vs. traditional distance to the frontier, 2016



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Source: Authors' own calculations

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/partii/chapter13/figure_13-3.xlsx

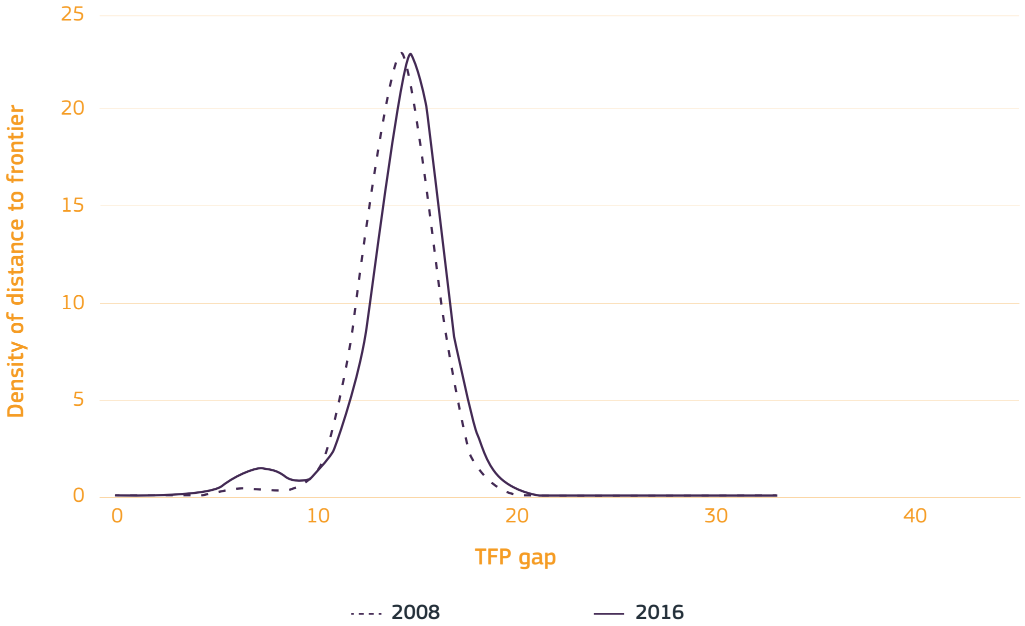
On the other hand, a distinguishing feature of our trade-weighted measure is the presence of a 'bump' of companies closer to the frontier than the rest.

While the unweighted and weighted distances to the frontier have similar overall averages (14.54 versus 14.6), the traditional distances are more dispersed (higher standard deviation and inter-quartile range) than the trade-weighted ones, with variations across sectors. Furthermore, the less the frontier's sector exports intermediate inputs to the other sectors, the smaller the difference between the traditional and the trade-weighted distances.

The evolution of the distribution of trade-weighted distance from 2008 to 2016 is shown in Figure 13-4. Two main features characterise the latest distribution. First, the main mode moves to the right, revealing an increase in the average distance to the TFP frontier. This finding is consistent with recent firm-level studies highlighting the rising gap between frontier companies and laggards which began at the beginning of the 2000s (Andrews et al., 2015). Second, in 2016, the density is characterised by a bump' emerging close to the bottom of the distribution. This new group of companies is getting closer to the frontier, despite the fact that the average economy-wide trend, i.e. the rest of the population, is falling behind. Such a trend may reveal the emergence of a new group of companies able to exploit and put into production cross-cutting technologies produced elsewhere, notably in related sectors or industry[6].

It is worth noting that this distinguishing feature can only be captured when considering the measure of distance with intermediate input trade correction (see also Figure 13-3).

Figure 13-4 Evolution of distances from the frontier



Source: Authors' own calculations
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/partii/chapter13/figure_13-4.xlsx

A first channel through which product, labour and capital market reforms may have an impact on firms' productivity and the process of technology diffusion is companies' dynamics (entry and exit). The latter is often associated with economic growth, as it facilitates the reallocation of resources from less-productive (and eventually exiting) firms to more productive ones. Adverse framework conditions may prevent the entry of adopters of superior technology, hindering innovation diffusion and productivity growth.

To investigate the mediating role of business churning and thus the direct and indirect effects of markets regulations on technology diffusion, we use a mediated regression analysis (Baron and Kenny, 1986; Preacher and Hayes, 2008) which consists of the estimation of two separate regression models:

$$TT_{it} = \beta_0 + \beta_1 TT_{it-1} + \beta_2 Churn_{jt-1} + Reg'_{jct-1}\beta^*_R + \beta_3 HC + e_{it} \tag{3}$$

$$Churn_{jt} = Reg'_{jct-1}\beta_R + u_{jt} \tag{4}$$

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[6] See, for instance, Xiao et al., (2018) for the concept of relatedness.

Where *TT* is the measure of potential for technology diffusion defined above, *Reg* includes the three indicators of labour, capital and product market regulation (*LabFlex, CapMkt, ProdMarkReg*), and *HC* is the growth rate of human capital. Both regression equations include sector, year, and *country* dummies.

Such an approach allows for identification of both the indirect (via the mediating effect of business dynamism, i.e. the churn rate in equation 4) and the direct effect of regulations on technology diffusion. The indirect effect is given by $\beta_2\beta_R$, while the direct effect is given by β_R^*. The sum of the two components gives the total effect[7].

4.3 Results

Figure 13-5 reports the results from the main mediated model (first column), and from a moderating model (second and third column). For the moderating model, we split the sample into firms in low-churn rate sectors and high-churn sectors in order to gauge the effects of regulation at different levels of business dynamism.

Our results suggest that framework conditions have both direct and indirect effects on innovation diffusion.

Labour-market flexibility is found to have a negative direct impact on our measure of technology diffusion: a unit increase in the value of the composite indicator of labour-market flexibility corresponds to a 3.3 % decrease in technology diffusion. The indirect effect is slightly positive, meaning the increased flexibility in the wage-setting regimes and fewer restrictions on hiring and firing are positively related to business dynamism. However, the indirect effect is quite small, leading to a 0.1 % increase in technology diffusion, hence the total relationship is still negative (-3.2 %), being dominated by the direct effect.

The relationship between product market regulation and innovation diffusion is found to be negative. This holds for both its direct and indirect effect, the former being the most relevant channel. Results suggest that a 10 % increase in the indicator corresponds to a 1.58 %, to which the indirect channel contributes only 0.01 %.

Improved conditions for accessing finance in the capital market have a considerably positive and direct effect on technology diffusion, leading to a 10.9 % rise following a unit increase in the indicator. Even in this case, the direct channel is barely affected by the small negative indirect effect of capital accessibility on the churn rate. The weak relationship between access to finance and the churn rate is not surprising, as although easy access to venture, equity or debt financing are related to higher entry rates, they are also negatively related to exit rates. Indeed, if we consider the correlation coefficients relating access to capital markets with entry rate and exit rate separately, the latter is higher (-0.13) in absolute value than the former (0.008). This suggests that, while access to capital is moderately associated with the entry of new firms, it corresponds to a lower churn rate as it increases the probability of survival, hence decreasing the overall churn rate.

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[7] We estimate a system of simultaneous equations with a 3-stage least squares (3SLS), where the error terms e_{it} and u_{jt} are assumed to be correlated.

Figure 13-5 Results of estimations

Dep. var. innovation diffusion (TT)	**Main model**	**Low churn rate**	**High churn rate**
TT, t-1	0.713*** (0.001)	0.564*** (0.002)	0.642*** (0.002)
Labour Market Flexibility Index	-0.033*** (0.001)	-0.041*** (0.002)	0.010*** (0.002)
Product Market Regulation	-0.157*** (0.023)	2.700*** (0.124)	-1.153*** (0.060)
Access to capital markets	0.109*** (0.001)	0.131*** (0.002)	0.217*** (0.002)
Churn rate	0.139*** (0.002)		
Human capital growth	0.009*** (0.001)	0.053*** (0.001)	0.011*** (0.001)
Indirect effects			
Labour Market Flexibility Index	0.001*** (0.000)		
Product Market Regulation	-0.001*** (0.000)		
Access to capital markets	-0.001*** (0.000)		
Number of observations	3 260 637	1 952 775	1 171 121
R-sq	0.57/0.93	0.58	0.63

Source: Authors' own calculations

Note: Significance codes: p<0.001 ***, p<0.01 **, p<0.05 *. Robust standard error in parenthesis. All explanatory variables are lagged by one year. All econometric specifications include year, sector and country dummies.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/partii/chapter13/figure_13-5.xlsx

Finally, business dynamism and human capital growth positively affect the diffusion of technology: a 10% increase in the churn rate or in the human capital growth rate correspond to a 1.39% or a 0.9% increase in technology diffusion, respectively.

How do the above results vary if we consider sectors with different rates of churn rates? Columns 2 and 3 report the results from an alternative specification estimated for two sub-samples: firms in sectors (and countries) with both low churn rates (below the median value) and with high churn rates. The two separate regressions highlight the moderating role of the firm dynamics[8].

For low levels of churn rate, the elasticity of past technology diffusion is smaller, and firms drift away faster from the technological frontier, as suggested by the lower elasticity of current-to-past innovation diffusion. Furthermore, greater

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[8] We obtain similar results from a classical interaction effect between each regulation indicator and the churn rate.

absorption capacity, as measured by the growth rate of human capital, is a more relevant factor for technology diffusion in the context of a low churn rate than in high-churning ones (a 10% higher growth rate in human capital corresponds to a 0.5% and 0.1% increase in the dependent variable, respectively).

We also find that more regulated labour and product markets help the diffusion process. Indeed, more regulated labour markets may favour investments in human capital, as:

'...labour flexibility impacts on training and human capital accumulation. If labour relationships are expected to be short-lived, there is little incentive for firms to invest in both the general and specific training of their workforces [..] Workers, for their part, will be reluctant to acquire firm-specific skills if they do not feel a long-term commitment to their employers' (Lucidi, 2012, p. 266).

In addition, a more regulated product market can stimulate innovation in sectors where technology may be lacking altogether (e.g. environmental technologies) or in sectors that are dominated by a few firms, perhaps due to high entry costs (low-churning sectors tend to be characterised by higher employment costs) or larger economies of agglomeration.

Conversely, the results for firms in high-churning sectors are in line with a more traditional view. Less-regulated product, labour and capital markets increase technology diffusion, especially product and capital markets regulation.

Overall, the results on product (but also labour) market regulation relate to the theoretical framework linking competition and innovation in a non-linear inverted-U-shaped relationship (Aghion et al., 2005). Our findings for product market regulation in the low and high churn rate suggest that when business dynamism is high, markets may be characterised by stronger competition. In this case, more regulation in the product market discourages competition and has a negative effect on innovation diffusion (column 3 in Figure 13-5). On the other hand, when the churn rate is low, a Schumpeterian effect dominates, as the rents appropriable by entrants are low. Therefore, more regulation has a positive effect on technology diffusion (column 2 in Figure 13-2) as the innovation process is mainly driven by incumbent firms.

Finally, more accessible financial markets are always associated with more potential for technological diffusion, independently of the churn rate or the specification used.

5. Discussion and policy implications

In an era of increasing globalisation and new digital technologies that could allow faster-than-ever international knowledge diffusion and technology transfers, the gap in productivity between frontier and other firms is widening, stimulating policy and academic debates on the underlying causes, most notably on those behind the stalling technology diffusion process.

While most of the policy initiatives are aimed at improving technological capabilities and absorption capacity, there are a few which are specifically aimed at changing the speed of technology diffusion, such as the European Research Area, as innovation and knowledge diffusion are strongly affected by public policy (Stoneman and Diederen, 1994).

This chapter investigates the role of labour, capital, and product market regulatory frameworks in technology diffusion, and also accounting for the role of business dynamism in mediating and moderating the impact of regulation on technology diffusion. Under a standard empirical framework with no intermediate role for business dynamics, results match the general findings in the literature: more stringent regulations are associated with lower productivity and less technology diffusion[9] (Scarpetta and Tressel, 2003; Tressel and Scarpetta, 2004). However, the European Central Bank highlights the causal link between business churning, framework conditions and technology adoption/diffusion:

‘Market competition and business churning (i.e. the rate of entry and exit of firms) – which are affected by country-specific framework conditions – influence the incentives and costs for firms to invest in new technology or adapt existing technologies’ (Masuch et al., 2018, p. 110).

Therefore, accounting for both framework conditions and business dynamism, the results of this chapter suggest that greater flexibility in the labour market regulation may benefit technology diffusion as it promotes the creation of new innovative firms and facilitates the restructuring or exit of unproductive ones. However, the direct (and total) effect of labour-market flexibility is negative, suggesting that a more regulated labour market might create incentives for firms to position their absorption capacity and human capital as key elements in their ability to adopt innovations, such as, for instance, by investing in their workers with, for example, on-the-job training (Lucidi, 2012; Egert, 2016). In addition, from a Schumpeterian perspective, given that a more stringent regulatory framework leads to higher fixed costs, this could increase the entry requirements and make competition tougher, igniting the process of creative destruction and favouring the adoption of innovations by firms.

Conversely, access to capital markets has a positive direct impact on technology diffusion, which is offset by the negative indirect effect via business churning. Indeed, while access to sources of finance has been widely recognised as fostering entrepreneurship, it also increases firms’ survival rates, perhaps that of less-productive ones as well, resulting in a slower reallocation of resources, thereby offsetting the positive impact on technology diffusion.

When considering the moderating role of business churning (we estimate a separate model for a low and high level of churning), we find that firms in high-churning sectors catch up faster than in low-churning ones. A faster human capital growth rate is associated with faster technology diffusion for all firms, but particularly for those in low-churning sectors, where human capital may be relatively more important than in high-churning sectors, and where less flexible labour-market regulation may create a favourable environment to invest more in human capital. Furthermore, in line with Andrews et al. (2015) and Aghion et al. (2005), we find that more stringent product market regulation is associated with less technology diffusion for firms in high-churning industries, while this is not the case for low-churning ones. A similar pattern is observed when considering labour-market flexibility, even though the magnitude of the effect is much less prominent, especially when considering greater flexibility in markets with a high churn rate. These results come somewhat in-between the traditional view supporting deregulation of labour relationships in order to boost investment and the alternative argument, which suggests that more secure and regulated labour markets boost investment in skills, innovation and absorptive capacity.

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[9] This estimation has been performed but is not included because of a lack of space.

Overall, this analysis offers an additional perspective to understand the uneven process of technological diffusion and the framework conditions needed to boost the pace of such diffusion. Of course, some caution is needed in interpreting the results as we do not fully control for several factors – such as capital deepening, or the technological or competition level of sectors – which are left for future avenues of research to deepen the understanding of these channels.

In terms of policy implications, our results suggest that:

- a one-size-fits-all regulatory model does not lead to faster technology diffusion, but the specific characteristics in the market and sectoral structure need to be accounted for;

- while excessive product market regulation tends to hinder technology diffusion, this only holds true in industries with vivid business dynamism and high rates of churn rates, where innovation is driven by new entrants;

- a similar argument holds for labour-market regulation, suggesting a more prudent view than merely advocating tout-court deregulation of labour-market relationships;

- human capital and access to finance are confirmed as horizontal drivers of technology catch-up and diffusion. While policies in this domain do not specifically address diffusion directly, they are key in increasing the adoption rate of innovations, enabling local (research and) innovation systems to produce, absorb and implement new knowledge, to keep pace with global technological change.

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CHAPTER

14

DIGITAL ADOPTION IN EUROPE AND THE UNITED STATES[1]

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Summary

The growing digital divide in the global corporate landscape between the technology leaders and laggards has implications for rising productivity polarisation. This raises concerns in policy debates that the EU may be falling behind in the digital technology race, although there is little large-scale, firm-level evidence on digital adoption for the EU and the US. With its innovative approach, this chapter tries to contribute to a more evidence-based policy discussion on the digital divide.

Using a new survey on digital adoption by firms in the EU and the US, this chapter identifies digitalisation profiles based on the current use of digital technologies and future investment plans in digitalisation. The analysis confirms the trend toward digital polarisation and a growing digital divide in the corporate landscape with, on one side, many firms that are not digitally active and, on the other side, a substantial number of digitally active firms forging ahead. Old small firms, with fewer than 50 employees and over 10 years old, are significantly more likely to be persistently digitally non active. They are also less likely to be innovative.

1. Introduction

The adoption of digital technologies in the business sector is spreading rapidly. Because of its transformative impact on the economy and the labour market, from both a creative and a destructive angle, digitalisation is being vigorously discussed by economists and policymakers. On the one hand, there have been numerous optimistic statements that digitalisation will boost growth and productivity. Yet, while digital technologies are expected to be the drivers of economic growth and the Fourth Industrial Revolution, so far there has been little hard evidence of a significant productivity boost. More than 30 years after Robert Solow's (1987) statement 'you can see the computer age everywhere but in productivity statistics', productivity growth in advanced economies remains subdued. At the same time, many people fear that digital technologies can be a source of disruption, leading to a more polarised economic structure, with the benefits concentrated in a few 'superstar firms', while many firms and workers will be on the losing side and will drop out.

Several recent studies provide evidence of this polarisation and 'winner-take-all' markets linked to the use of digital technologies. Andrews, Criscuolo and Gal (2016) show an increasing productivity gap between firms at the global frontier and laggard firms[2]. The superstar firms at the global frontier are typically larger, more innovative and have higher rates of digital-technology adoption. There is also evidence of rising concentration (Autor et al., 2017) and increasing firm mark-ups (De Loecker and Eeckhoudt, 2017). In particular, mark-ups are rising among firms in the highest decile of distribution of mark-ups within their

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[2] Andrews, Criscuolo and Gal (2016) define global frontier firms as the top 5 % of firms in terms of labour productivity levels, within each two-digit sector and in each year, across all countries since the early 2000s. All other firms are defined as laggards.

industry, which is consistent with winner-takes-all patterns (Diez et al., 2018). These trends tend to be more pronounced in the sectors where digital technologies – especially digital services – are developed or intensely adopted (Calligaris, Criscuolo and Marcolin, 2018).

In digital services, the leading companies – including 'big tech' firms, such as Alphabet (Google's parent company), Apple, Facebook, Microsoft, Alibaba, and Huawei – are typically from the United States or China. European firms are not present among either the big tech or the leading digital R&D investors that push the frontier of digital technology (EIB, 2018; Veugelers, 2018). Evidence of the EU lagging behind is mounting, especially in the services sector, which is correlated with subdued productivity growth in the EU (EIB, 2018).

Growing digital polarisation in the global corporate landscape between the technology haves and have-nots has implications for the rising polarisation of productivity. This raises concerns in policy debates that the EU may be falling behind in the digital technology race, being trapped on the wrong side of the digital technology divide. Furthermore, it raises the following questions: Are EU firms stuck as digital-technology-have-nots while US tech firms are forging ahead? What does this imply for the EU's innovation capacity?

Figure 14-1 Survey sampling in the EIB Digital and Skills survey

	Manufacturing	**Services**
Region		
EU28	**456**	**432**
West and North Europe	198	198
South Europe	122	89
Central and East Europe	146	145
US	**411**	**389**
Northeast	93	83
Midwest	126	136
South	106	82
West	86	88
Size		
Micro (5-9)	143	172
Small (10-49)	291	333
Medium (50-249)	287	223
Large (250+)	146	93

Source: Authors' own elaboration

Note: West and North Europe: Austria, Belgium, Denmark, Finland, France, Germany, Ireland, Luxembourg, the Netherlands, Sweden, and the United Kingdom. South Europe: Cyprus, Greece, Italy, Portugal, and Spain. Central and East Europe: Bulgaria, Croatia, Czechia, Estonia, Hungary, Latvia, Lithuania, Poland, Romania, Slovakia, and Slovenia. US regions according to US Census Bureau geography divisions.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/partii/chapter14/figure_14-1.xlsx

While these are first-order concerns, there is little large-scale firm-level evidence on digital adoption for the EU and the United States across different sectors and the position of EU and US firms on the digital divide. Using a new survey on digital adoption of firms in the EU and the United States, this chapter tries to contribute to a more evidence-based policy discussion on the digital divide.

2. Data

In 2018, the European Investment Bank (EIB) Digital and Skills survey interviewed 1 700 companies with at least five employees in manufacturing and services in the EU and United States on their adoption of digital technologies and their plans for future investments. The sample was stratified by industry group (manufacturing and services sector), size class and region. Figure 14-1 gives an overview of the distribution of respondent firms.

To make the sample representative of the economy, the EIB Digital and Skills survey computed weights based on firm size. More specifically, the weights compare the number of employees in the firms included in the survey with data on employment from structural business statistics in specific cells – where the cells are defined by region (four regions in the EU and four in the United States), sector (manufacturing and services) and firm-size class (four firm-size classes)[3].

This chapter identifies digital profiles based on two dimensions:

1. the current adoption of the most prominent state-of-the-art digital technologies in manufacturing and services;
2. future investment plans in digital technologies.

2.1 Adoption of digital technologies

Information on the adoption of digital technologies listed in Figure 14-2 is based on the following survey question:

- ‘Can you tell me for each of the following technologies if (i) not heard about them, (ii) have heard about them but not implemented, (iii) implemented them in parts of your business, or (iv) whether your entire business is organised around them?’.

If companies report that their entire business is organised around one of the four technologies, this chapter labels them as ‘fully digital’. However, if at least one of the technologies is implemented in parts of a firm’s business, they are labelled as ‘partially digital’. All companies

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[3] One of the caveats of the analysis discussed in this chapter is the survey’s relatively small sample size. The survey is representative at the level of three aggregate groups of countries in the EU (and four regions in the United States) but not at individual EU country level. Similarly, it is representative for the manufacturing and services sectors (i.e. representative for two sectors separately in each aggregate group of EU countries or US regions) but does not provide more detailed information on industry classification (e.g. NACE or ISIC classification at two digits that would classify the firms across different sub-industries within the manufacturing sector).

Figure 14-2 State-of-the-art digital technologies in the EIB Digital Survey and Skills Survey

Manufacturing	
a)	3D printing – also known as additive manufacturing
b)	Automation via advanced robotics – a second generation of robots which are more autonomous, flexible and often more easily programmable
c)	Internet of Things – electronic devices that communicate with each other without human assistance
d)	Big data and analytics
Services	
a)	Digitalisation and automation of internal routines, including back-office, purchasing and logistics management – for example, software that automates routine tasks such as billing, accounting, etc.
b)	Web-based applications for marketing and sales – for example, using a specific app through which customers can order goods or services from your company
c)	Provision of digital products and services over the internet – for example, offering automated market intelligence or digital content streaming
d)	Big data and analytics

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Source: Authors' own elaboration

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/partii/chapter14/figure_14-2.xlsx

that have not heard about digital technologies or have heard about them but not implemented them are labelled as 'non-digital'[4].

The state-of-the-art digital technologies considered are different for manufacturing and services. Big data and analytics is the only digital technology firms were asked about in both the manufacturing and services sectors. Firms in services tend to be more digitally active. As this could be partly due to the specific digital technologies listed, manufacturing and services firms are analysed separately throughout the chapter.

The EIB Digital and Skills survey provides unique information compared to other databases providing evidence on the adoption of digital technologies. The Eurostat data used in the Digital Economy and Society Index (DESI) do not include US firms, which is paramount for the analysis of the digital divide discussed

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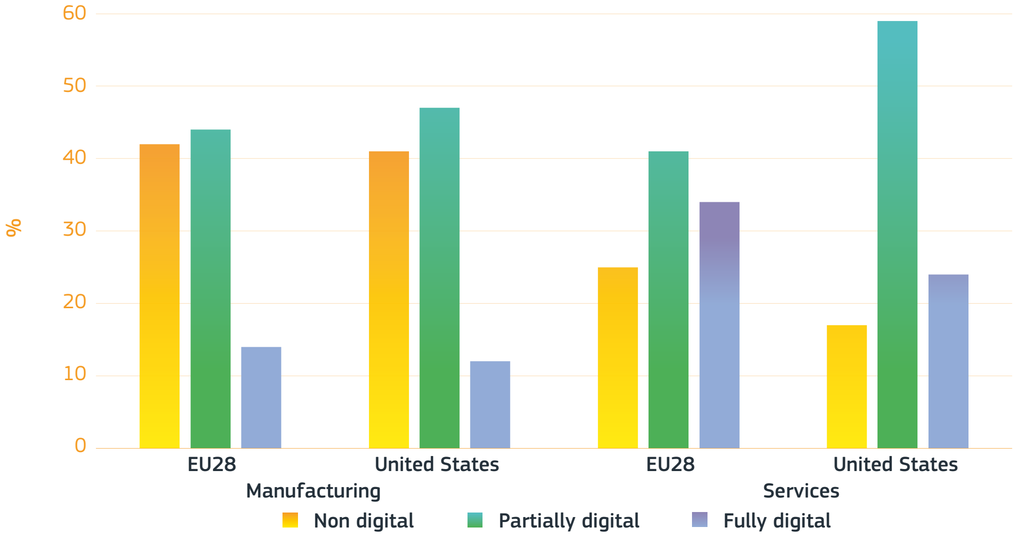
[4] Focusing on firms that have never heard about digital technologies, 22 firms in manufacturing and 19 firms in services have not heard about any of the four technologies. More specifically, few companies in manufacturing have not heard about 3D printing (6 % in both the EU and the United States) and advanced robotics (5 % in the EU and 7 % in the United States), while a larger share of companies has not heard about IoT (18 % in the EU and 22 % in the United States) and big data (21 % in the EU and 18 % in the United States). In services, the share of companies that have not heard about a technology is highest for big data (24 % in the EU and 15 % in the United States), but lower for digitalisation and automation of internal routines (7 % in the EU and 9 % in the United States), web-based applications for marketing and sales (7 % in the EU and 4 % in the United States) and provision of digital products and services online (11 % in the EU and 8 % in the United States). There is no large difference between the United States and the EU, except for the share of firms that have not heard about big data, which is somewhat higher in the EU than the United States, especially in the services sector.

in this chapter[5]. Similarly, Organisation for Co-operation and Development (OECD) statistics on ICT access and usage by businesses provide data on two indicators for the United States but only in 2007 and 2012[6].

Figure 14-3 shows that there are no large differences between the EU and the United States in digital adoption in the manufacturing sector, while the share of EU firms that are non-digital in services is larger than in the United States. However, at the same time, the share of EU firms in services that have organised their entire business around digital technologies is larger than in the United States.

The results of multivariate regression analysis indicate that firm size matters for digital technology adoption: smaller firms (with fewer than 50 employees) are less likely to be digitally active[7]. At the same time, firm age seems to matter less for digitalisation; young firms (less than 10 years old) are not more likely to be digitally active than older firms.

Figure 14-3 **Share of firms that are digitally active (%), by sector and country**



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Source: Authors' calculations based on the EIB Digital and Skills survey 2018

Note: All firms are weighted using employment weights to make them representative of the business population.

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[5] Eurostat provides data on the share of enterprises (with more than 10 employees) using industrial robots (16 % of the enterprises in manufacturing) in the EU in 2018, which is about half the share reported by EU manufacturing firms that have implemented automation via advanced robotics, according to the EIB Digital and Skills survey (29 %). Similarly, the shares of enterprises (with more than 10 employees) using 3D printing or analysing big data are about half the share reported in the EIB Digital and Skills survey. The differences between Eurostat data and the EIB Digital and Skills survey may be driven by the relatively small sample of the survey as well as differences in the questions that the firms were asked (e.g. whether the use of digital technologies is general or very specific to the daily operations of the business or whether it is regular or irregular).

[6] For the United States, the ICT Access and Usage by Businesses database provides data on (i) the share of business with a website or home page (in 2007 and 2012) and (ii) the share of business placing orders (i.e. making purchases) over computer networks (in 2007).

[7] The multivariate regression analysis is based on marginal effects in a probit model and considers the likelihood of being digitally active after controlling for the effects of country (United States, EU), sector (manufacturing, services), firm size (micro, small, medium, large) and firm age (young, old). An alternative specification combines the information on firm age and size to create four categories: young small, old small, young large and old large. The findings are qualitatively similar using the alternative specification.

2.2 Digital investment plans

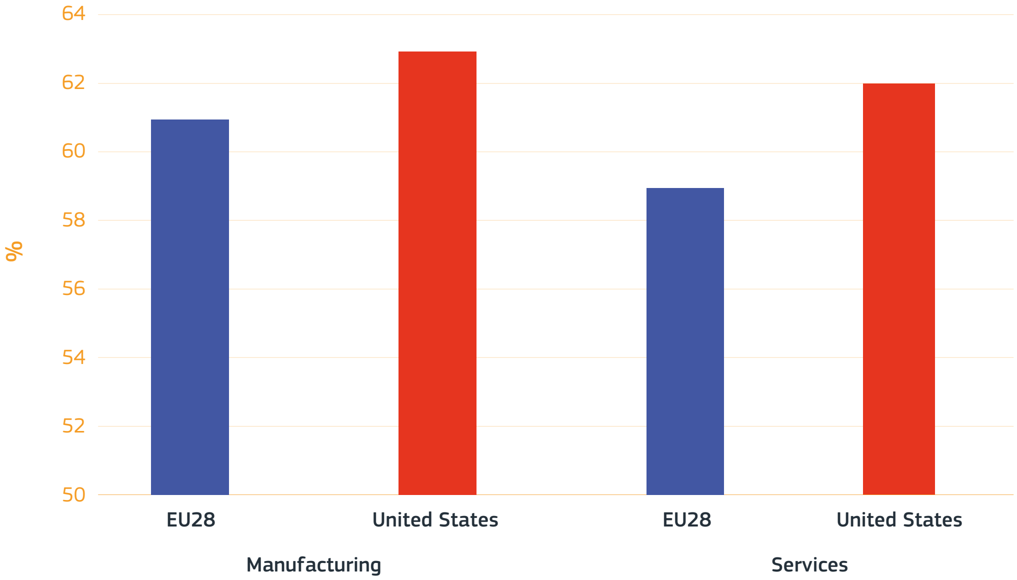
The second dimension of the digital divide profiles, namely the digital investment outlook, is based on the following two survey questions:

- For firms that have already implemented one of the digital technologies:
  - 'Over the next three years, do you expect your investment spend in digital technologies to (i) increase, (ii) stay around the same, (iii) decrease, (iv) no investment planned in digital technologies?'
- For firms that are non-digital:
  - 'Looking ahead to the next three years, do you plan to invest in digital technologies?'

Companies are considered as 'increasing' if they plan to increase their investment or, for those that have yet to invest, if they plan to start investing in digital technologies. All other firms are labelled as 'stable/inactive/reduced'. Figure 14-4 shows that around 60% of the firms have plans to raise investment in digital technologies in the next three years. Although EU firms score slightly lower than US firms, in both the manufacturing and services sectors, the difference between the EU and the United States with respect to future digital investment plans is small.

Multivariate regression analysis confirms that there is no significant difference between the EU and the United States or between the manufacturing and services sectors with respect to the digital investment outlook. However, it shows a firm-size effect for digital investment plans: larger firms are not only more likely to be currently digitally active, but they are also more likely to expand their digital investments in the future. Within the EU, firms from central and eastern Europe have a significantly lower probability of planning to increase their digital investments.

Figure 14-4 Share of firms that plan to increase investment in digital technologies in the next 3 years (%)



Source: Authors' calculations based on the EIB Digital and Skills survey 2018

Note: All firms are weighted using employment weights to make them representative of the business population.

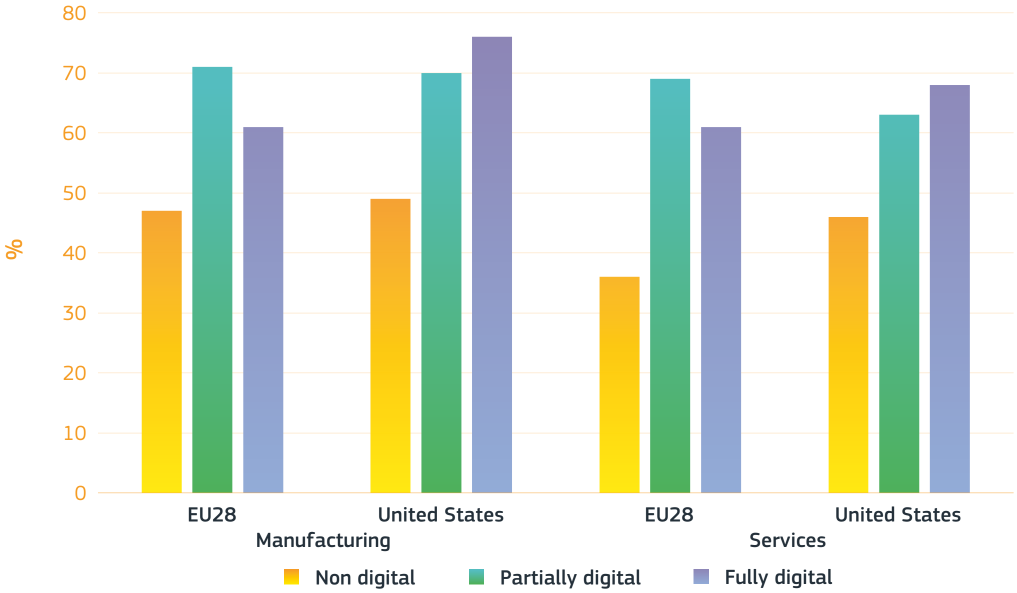
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/partii/chapter14/figure_14-4.xlsx

3. Is there a corporate digital divide?

A first glance at a corporate digital divide, with some firms pushing ahead and others falling behind, is provided by Figure 14-5, which links the share of firms that are digitally active with the share that have plans to further increase their digital investments. Digitally active firms (either partially or fully digital) are significantly more likely to have plans to expand their digital investment further. This holds true in both the EU and the United States as well as in the manufacturing and services sectors.

Multivariate regression analysis confirms that firms that are already digitally active have a significantly higher probability (20% higher) of having digital investment expansion plans, everything else being equal[8]. This result provides evidence of a corporate digital divide: firms that are not (yet) digitally active are significantly less likely to have digital investment expansion plans compared to those that are already digitally active. This trend is likely to exacerbate the digital divide across firms, in both the EU and the United States. This digital polarisation is a general phenomenon: the digital divide is not significantly larger in the EU than in the United States or in services compared to the manufacturing services.

Figure 14-5 Share of firms that plan to increase investment in digital technologies in the next 3 years (%), by digital intensity



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Source: Authors' calculations based on the EIB Digital and Skills survey 2018

Note: All firms are weighted using employment weights to make them representative of the business population.

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[8] Multivariate regression analysis is based on marginal effects in a probit model and considers the likelihood of having digital-investment expansion plans depending on whether the firm is currently digitally active (yes or no), and controlling for the effects of the country (United States, EU), sector (manufacturing, services), firm size (micro, small, medium, large) and firm age (young, old). The marginal effect for digitally active firms is 0.201 (with a standard error of 0.041).

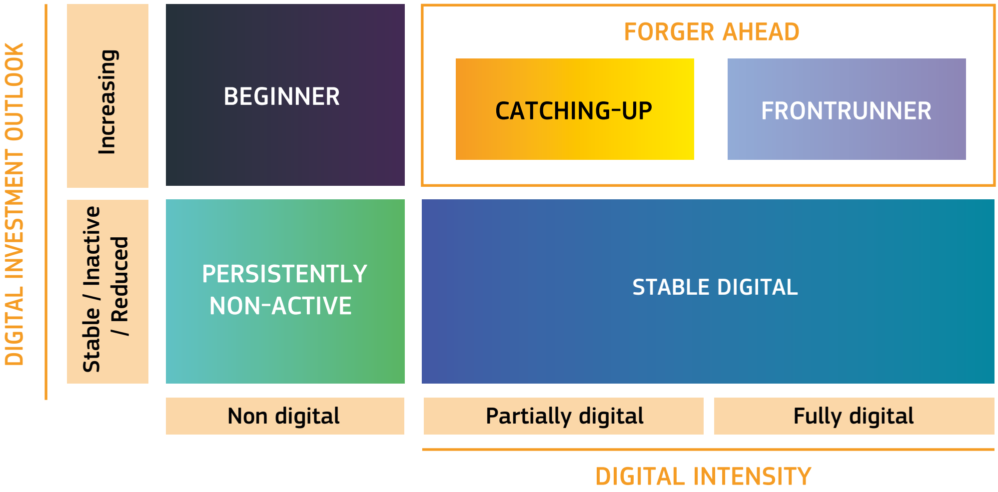
4. Which firms are falling behind and which are forging ahead?

The previous section has identified a significant corporate digital divide. The next step is to identify and characterise the firms on each side of the divide. Which companies are falling behind and which are forging ahead? To address this question, Figure 14-6 positions firms on the digital-divide grid, based on the combination of their current digital-technology intensity and their digital investment outlook.

The first group of firms to identify are those that have not implemented any digital technology and do not plan to invest in digital technologies in the next three years: these companies are falling behind on the digital-divide grid and are labelled as 'persistently non-active'. Companies that are currently non-digital but have plans to invest in digital technologies are labelled 'beginners'.

Within the group of firms that have implemented digital technologies, there are those that are already digital but do not intend to increase investment in digital technologies in the coming three years: they are labelled as 'stable digital'. Digital firms that are planning to further invest in digital technologies are labelled 'forgers ahead' which can be further divided depending on whether they have implemented a digital technology in parts of their business or whether their entire business is organised around digital technologies. 'Catching-up' firms are partially digital and plan to increase their digital investments further, while 'frontrunners' are already fully digital and continue to increase their investment spend on digital technologies.

Figure 14-6 The corporate digital divide categories



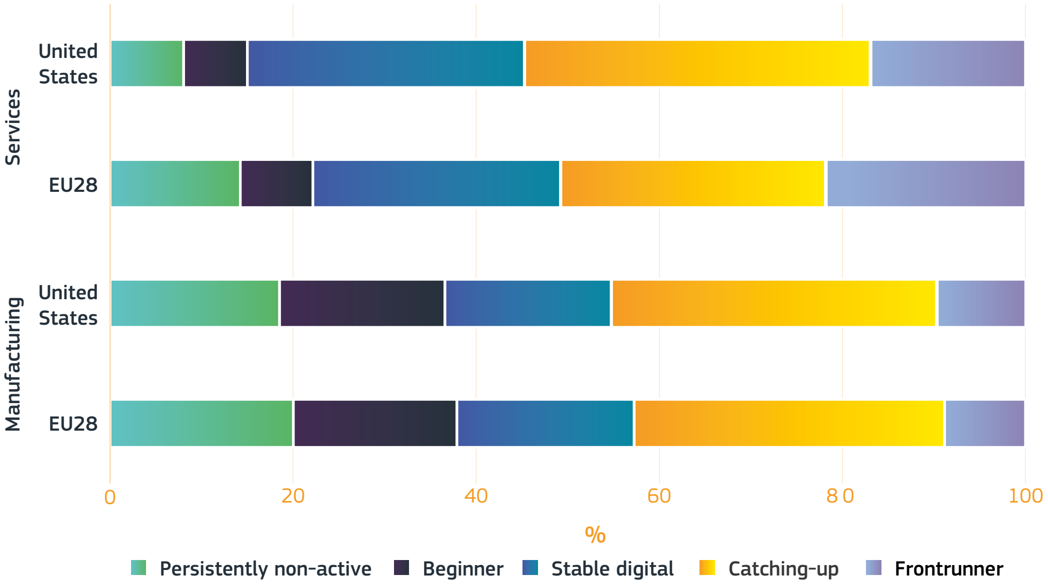
Source: Authors' own elaboration

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/partii/chapter14/figure_14-6.xlsx

Figure 14-7 shows the share of companies in the EU and the United States, for manufacturing and services, in each of the digital-divide profiles, depending on their position on the grid. There are more persistently non-active firms in services in the EU than in the United States: this category refers to firms that have not implemented any digital technology and do not plan to invest in them over the next three years. At the same time, EU firms in the manufacturing sector are not significantly more likely to be persistently non-active than in the United States.

On the other side of the corporate digital divide, there are no large differences between the EU and the United States in manufacturing for forgers ahead (catching-up and frontrunner). Even though the difference on forgers ahead is not significant in services either, the EU has somewhat more frontrunners compared to the United States. Together with the higher share of persistently non-active firms, this suggests that the EU may have a deeper and more polarised digital divide in services compared to the United States.

Figure 14-7 Digital divide, share of firms (in %), by sector and country



Source: Authors' calculations based on the EIB Digital and Skills survey 2018

Note: Digital profiles defined as in Figure 14-6. All firms are weighted using employment weights to make them representative of the business population.

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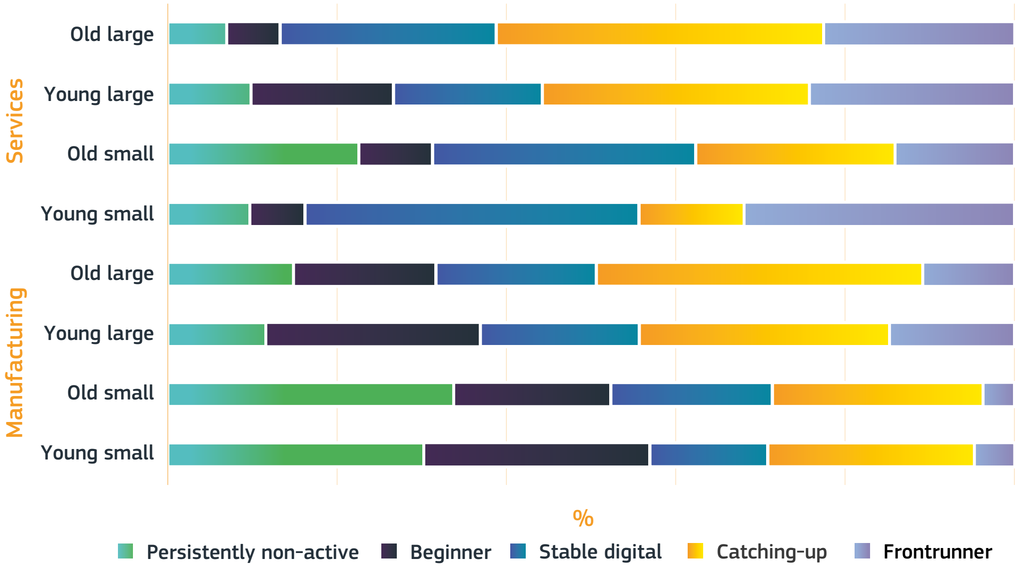
Figure 14-8 shows that old small firms, i.e. firms with fewer than 50 employees and older than 10 years, are significantly more likely to be on the wrong side of the digital divide[9]. Old small firms, which represent a significant share of the corporate landscape – especially in the EU – are more likely to be persistently non-active and less likely to be forging ahead (catching-up and frontrunner), in both services and manufacturing.

Figure 14-9 confirms the importance of firm size for positioning on the digital-divide grid in manufacturing. Small manufacturing firms (with fewer than 50 employees) are more likely to be persistently non-active. This holds true for both young small and, in particular, old small firms: they have, respectively, a 15 % and 19 % higher probability of being non-active compared to large firms. In the services sector, only old small firms are significantly more likely to be persistently non-active: they have a 15 % higher probability compared to large firms. Small services firms which are young are not significantly more likely to be digitally left behind.

Figure 14-8 Digital divide, share of firms (%), by sector and age-size categories



Source: Authors' calculations based on the EIB Digital and Skills survey 2018

Note: Young: less than 10 years old. Small: less than 50 employees. Digital profiles defined as in Figure 14-6. All firms are weighted using employment weights to make them representative of the business population.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/partii/chapter14/figure_14-8.xlsx

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[9] Because of the relatively small sample sizes, the figure includes both EU and US firms. The results are also qualitatively similar when disaggregating the sample by country, in addition to sector and age-size categories.

Similarly, on the other side of the digital divide, small firms are significantly less likely to be forging ahead. In the manufacturing sector, both young and old small firms are significantly less likely to be forging ahead (a 21 % lower probability compared to large firms, and a 7 % lower probability of being a frontrunner). In services, young small, and especially old small firms are significantly less likely to be forging ahead (17 % and 23 % lower probability, respectively). In addition, old small firms are significantly less likely to be frontrunners. All these results confirm that old small firms are clearly a problematic category on the corporate digital-divide grid.

Figure 14-9 Probability of being persistently non-active or forging ahead or frontrunner

	Persistent non-active		**Forging ahead**		**Frontrunner**	
	Manuf.	Services	Manuf.	Services	Manuf.	Services
Age-size category (omitted category: large firms, young or old)						
Old small	0.191*** (0.039)	0.146*** (0.043)	-0.205*** (0.044)	-0.234*** (0.056)	-0.074*** (0.022)	-0.098** (0.042)
Young small	0.155** (0.075)	0.021 (0.061)	-0.199*** (0.074)	-0.166* (0.095)	-0.063* (0.033)	0.082 (0.089)
Country group (omitted category: US)						
EU28	0.014 (0.037)	0.030 (0.033)	-0.020 (0.048)	0.016 (0.051)	-0.007 (0.029)	0.066* (0.039)
Sample size	773	770	773	770	773	770
Pseudo R-squared	0.038	0.060	0.024	0.035	0.022	0.021

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Source: Authors' calculations based on the EIB Digital and Skills survey 2018

Note: Marginal effects in a Probit model. The coefficients can be interpreted as marginal effects on the probability to be 'persistently non active', 'forging ahead' or 'frontrunner'. *** p<0.01, ** p<0.05, * p<0.1. Young: less than 10 years old. Small: fewer than 50 employees. All firms are weighted using employment weights to make them representative of the business population.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/partii/chapter14/figure_14-9.xlsx

Which companies escape the digital-non-active trap? Comparing the probability of being persistently non-active as opposed to beginners enables a check to be carried out among the firms that have not implemented digital technologies to establish which ones are likely to become digitally active in the next three years. The multivariate analysis in Figure 14-10 confirms once again that firm size matters: in particular, old small firms appear to be a problematic group. They are significantly less likely to 'begin' to be digitally active if they were initially non-active (19 % lower probability compared to large firms in manufacturing and 21 % in services). Young small firms also have a lower probability to start investing although the differences are not significant.

Similarly, the probability of forging ahead, as opposed to remaining stable digital, is a way to verify among those firms that have already implemented digital technologies which ones are likely to further increase their digital investments. Once again, old small firms belong to the problematic category. Even when they are already digitally active, old small firms are significantly less likely to increase their digital investments, both in manufacturing and services. In services, young small firms that are already digitally active are also less likely to increase their digital investments.

Figure 14-10 Probability of starting or increasing investment in digital technologies, by current digital intensity

	Beginner vs. persistently non-active		Forging ahead vs. stable digital		Frontrunner vs. fully digital stable	
	Manuf.	Services	Manuf.	Services	Manuf.	Services
Age-size category (omitted category: large firms, young or old)						
Old small	-0.187** (0.074)	-0.214* (0.126)	-0.122** (0.058)	-0.173*** (0.063)	-0.218* (0.128)	-0.244** (0.098)
Young small	-0.071 (0.114)	-0.098 (0.219)	-0.045 (0.114)	-0.189* (0.105)	-0.256 (0.243)	-0.150 (0.142)
Country group (omitted category: US)						
EU28	-0.018 (0.078)	-0.052 (0.113)	-0.023 (0.056)	0.050 (0.055)	-0.135 (0.123)	0.000 (0.094)
Sample size	322	160	451	610	92	235
Pseudo R-squared	0.020	0.039	0.008	0.023	0.044	0.040

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Source: Authors' calculations based on the EIB Digital and Skills survey 2018

Note: Marginal effects in a Probit model. The coefficients can be interpreted as marginal effects on the probability to be 'beginner', 'forging ahead' or 'frontrunner'. *** p<0.01, ** p<0.05, * p<0.1. Young: less than 10 years old. Small: fewer than 50 employees. All firms are weighted using employment weights to make them representative of the business population.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/partii/chapter14/figure_14-10.xlsx

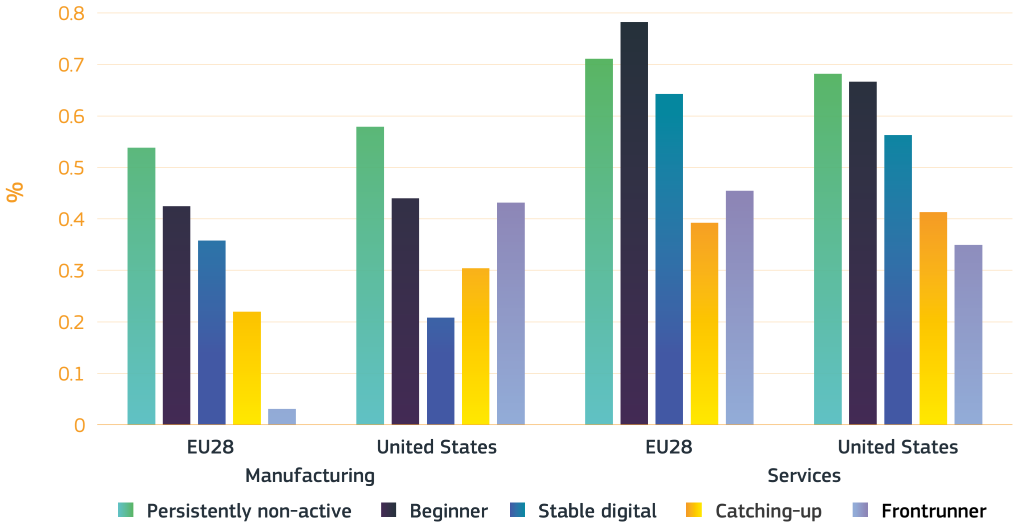
5. Innovation profiles along the digital-divide grid

Does it matter to the innovation capacity of the EU economy whether firms are falling behind as persistent non-digitally active or forging ahead and running in front? Digital technologies are likely to be empowering innovation. Therefore, digitally-active profiles are expected to be active in innovation. If that is the case, any digital investment polarisation would also be associated with an innovation divide gap.

Following EIB (2017), the data from the EIB Digital and Skills survey can be used to identify innovation profiles based on current R&D expenditure and whether firms invest to introduce new products, processes or services (which can be new to the company only or new to the market). The companies are identified as basic firms (or 'non-innovation-active') if they are neither engaged in R&D nor innovate (developing themselves or adopting innovations already developed elsewhere). Figure 14-11 confirms that non-digitally-active firms are also more likely to be non-innovation-active. This holds true for beginners but also for the persistently-non-active firms, especially in the services sector.

Results of the multivariate regression analysis reported in Figure 14-12 confirm these findings and show that, with the exception of the beginners, all categories of firms are more likely to be innovation active than the persistently-non-active firms[10]. In particular, the forgers

Figure 14-11 Share of non-innovation-active firms (%), by digital profile



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Source: Authors' calculations based on the EIB Digital and Skills survey 2018

Note: Non-innovation active firms are firms that do not invest in R&D and do not introduce new products, processes or services. All firms are weighted using employment weights to make them representative of the business population.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/partii/chapter14/figure_14-11.xlsx

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[10] The regression analysis in Table 14.5 combines firms in the manufacturing and services sectors. The results are qualitatively similar when the sectors are considered separately.

ahead, both catching-up and frontrunners, are significantly more likely to be innovation active. Catching-up and frontrunners are also significantly more likely to be 'leading innovators', i.e. they invest in R&D and introduce innovations that are new to the market. Thus, the polarisation of digital investment appears to be associated with an innovation divide gap.

Figure 14-12 **Digital divide and innovation performance**

	Non-innovator	Leading innovator
Digitalisation profiles (omitted category: non-digital)		
Beginner	-0.077 (0.081)	-0.103 (0.043)
Stable	-0.182*** (0.068)	0.075 (0.049)
Catch-up	-0.284*** (0.064)	0.076* (0.042)
Frontrunner	-0.292*** (0.081)	0.102* (0.059)
Age-size category (omitted category: large firms, young or old)		
Old and small	0.067 (0.044)	-0.060** (0.030)
Young and small	0.100 (0.080)	-0.081** (0.034)
Sector (omitted category: manufacturing)		
Services	0.203*** (0.043)	-0.158*** (0.026)
Country group (omitted category: US)		
EU	-0.023 (0.043)	-0.008 (0.031)
Sample size	1,023	1,023
Pseudo R-squared	0.068	0.111

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Source: Authors' calculations based on the EIB Digital and Skills survey 2018

Note: Marginal effects in a probit model. The coefficients can be interpreted as marginal effects on the probability of being non-innovator or leading innovator. *** p<0.01, ** p<0.05, * p<0.1. Young: less than 10 years old; small: fewer than 50 employees. Non-innovator: no investment in R&D in the previous financial year and no introduction of new products, processes or services. Leading innovator: significant investment in R&D in the previous financial year and introduction of new products, processes or services that are new to the market (not only new to the company). All firms are weighted using employment weights to make them representative of the business population.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/partii/chapter14/figure_14-12.xlsx

6. Conclusions

Overall, the results of the analysis using data from the EIB Digital and Skills survey confirm the trend toward digital polarisation and a growing digital divide on the corporate landscape. On the one hand, a substantial number of firms do not implement any state-of-the-art digital technology and are also less likely to have plans to start investing digitally in the next three years. On the other hand, there are firms that are already partially or even fully implementing state-of-the-art digital technologies in their businesses. In addition, they are also more likely to plan to further increase their digital investments in the future and to become leading innovators. The analysis further shows that persistently-non-digitally-active firms are less likely to be innovative, while digital frontrunners are more likely to be leading innovators.

The survey does not provide any evidence for significant differences between the EU and the United States. The prevalence of persistently-non-digitally-active firms versus frontrunners in economies is significantly correlated to the firm size and age composition of their business population. Small firms in manufacturing and old small firms in services – with fewer than 50 employees and more than 10 years old – are significantly more likely to be persistently digitally non active.

The findings in this chapter do not recover causal relationships. Further research should aim at investigating what policies could fast-track the adoption of digital technologies by EU firms, in particular old small firms, to help them catch up and grow. In this respect, the issues that tend to affect the investment activities of small firms in the EU, such as the lack of access to finance, poor management practices or a difficult business environment, are likely to play important roles.

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CHAPTER
15

SCANNING THE INNOVATION HORIZON

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European Commission

Summary

This chapter is dedicated to efforts gathering wide-ranging intelligence to identify new signs of emerging issues, trends and challenges for the future. It describes in detail the practice of horizon scanning, which can be seen as the basic groundwork of foresight projects, or as an important strategic function in its own right.

It presents the European Commission's latest research and innovation (R&I) foresight exercises which are essential in the context of the increasing emphasis being placed by the EU's R&I policy on directionality, in particular towards sustainable development. The need for informed policy priorities results in demand for more systematic, continuous and comprehensive scans to feed into decision-making processes.

1. Introduction

The European Union makes substantial investments in research, science, technology and innovation, aiming at lowering technical and commercial risks associated with innovation to make its economy more competitive and to enable its society to achieve goals such as prosperity, sustainability and quality of life. European strength in science, technology and industry is necessary to ensure that Europe is able to achieve its objectives. To be competitive, Europe needs to maximise the value and productivity of its investments in R&I, and this requires appropriate intelligence and coordination between relevant policies and strategies at EU, national and regional levels. These investments may follow Europe's strengths or weaknesses and concentrate on areas where the greatest impacts can be expected and where the most benefits would lie. A good understanding of capacities and aspirations for future innovations is an invaluable basis for reflection and debate on potential impacts of different investment decisions, and on the normative and strategic considerations that should guide those investment decisions.

This paper presents a brief overview of how horizon scanning took hold in EU efforts to improve priority-setting in science and technology. It begins with the history of the development of priority setting in R&I policy and the analytical methodologies used to support it, showing the hand-in-hand evolution of political and analytical developments. Despite being practised for many years, especially in Japan, horizon scanning in science and technology (S&T) really took off with the publication of the Chinese Roadmaps for 2050. The close coupling between understanding the horizon, the policy goals and the commitment to achieving them that seemed to drive the modernisation of China incentivised other governments to undertake R&I horizon scanning, and to use it in priority setting. The paper reviews some key national projects before describing the European Commission's experience with horizon scanning. Its conclusions simply appraise this experience and point at questions and possible improvements that could determine whether horizon scanning becomes a regular part of the EU policymaking toolbox or remains an experiment from which lessons are applied elsewhere.

2. Horizon scanning in R&I policy

A great deal of modern S&T has its roots in the efforts to sustain the technological leadership of the US military and the commercial advantages these generated for US firms (Bush, 1945; McDougall, 1985; Gholz, 2011; Mazzucato, 2011). The EU's R&I efforts originated in an effort to catch up with the USA in certain fields of S&T (EC 1970, 1985; Patel and Pavitt, 1987; Sharp, 1989). The EU was not alone in this effort. Japan, the Soviet Union and, increasingly, other parts of the world began to invest heavily in R&D and to seek to compete with the USA in S&T. During the 1980s, it became clear that no country could afford to be the world leader in all fields of S&T and strategic R&I programming became prominent.

Japan led the way with the launch of the Very large-scale integration (VLSI) programme in 1976. The ALVEY Programme in the UK and the ESPRIT programme in the European Community were reactions to Japan's VLSI. More and more countries set off to develop capacities in key technologies (Rothwel and Zegveld, 1985), which 'when effectively controlled, offer keys to economic success' (Revermann and Sonntag, 1989, p. 1). The effort to devise priorities led to the development of disciplines such as scientometrics (De Sola Price, 1978), technometrics (Sahal, 1985) and to the application of foresight in S&T (Martin and Irvine, 1984, 1989; Urashima, Yokoo and Nagano, 2012). The foundations of these disciplines lie in the belief that priority-setting in S&T can benefit from on an informed understanding of capabilities and aspirations, which can be revealed by the study of expert communities and their communication.

The practice of horizon scanning evolved in this context and can be seen either as the basic groundwork of foresight projects, or as an important strategic function in its own right. It signifies an effort to gather wide-ranging intelligence that goes beyond the normal intelligence practice, to identify new signals of emerging issues, trends and challenges that could help preparedness for the future (Cuhls, van der Giessen and Toivanen, 2015). In S&T, horizon scanning provides intelligence about capacities and aspirations which could push forward the frontiers of knowledge and innovation. For contemporary R&I policymaking, this intelligence is an essential part of the strategic context of policy decisions. It allows informed evaluations of expected costs, benefits, challenges and opportunities associated with particular R&I policy options and directions (ibid.). Again, Japan led the way. Regular foresight studies in science and technology, with a broad horizon scan, began in the 1970s, and since 1996 they have been integrated into the revision of the Basic Plan, the basis of Japanese S&T policy that is reviewed every five years (Urashima, Yokoo and Nagano, 2012).

The need for a more strategic approach to R&I policy underpins the European Commission's recent efforts to develop a more systematic understanding of the innovation horizon. These efforts build on two foundations: the first is the development of strategic foresight in the EU's R&I policy during Horizon 2020 (EFFLA 2013; Burgelman et al., 2014; Kastrinos, 2018). In the practice of strategic foresight, some of the most powerful context is provided by megatrends[1] (Gore, 2013; EEA 2010, 2015; OECD 2016; ESPAS 2015, 2019), described as inescapably powerful forces). However, in their content megatrends invariably resemble significant debates about the future rather than determined historical destinies. The interplay between determinism and strategies to change the future requires foresight to decompose megatrends, to juxtapose established trends with emerging

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[1] In 2018, the JRC developed an online megatrends hub: https://ec.europa.eu/knowledge4policy/foresight/about_en and a set of methodologies for using it as the context for decision-making games.

trends, and to debate the significance of different phenomena. Scanning the horizon for signals of new trends is a way of compensating for the power of megatrend discourses over both likely and unlikely alternative futures.

Trends are sequences of events in time that imply an underlying cause. The horizon is scanned for 'signals'. These are significant observations (events) which may or may not signify a trend. Horizon scanning relates such observations to one another to develop 'signposts". Signposts are conditions that could signify a trend within underlying causal theories. By accumulating signposts, trends become more visible and different causal theories build and lose predictive value. And as we begin to discern trends, the future becomes more predictable.

The second foundation of the European Commission's horizon-scanning effort lies with the international experience that is demonstrating more and more clearly the feasibility of scanning that is useful for policy. Studies aiming to produce representations of the scientific and technological frontier began in the 1980s (Sahal, 1985; Callon et al., 1983; Callon, Rip and Law, 1986) but really took off in the 21st century with the growing importance of the internet and the development of text-mining algorithms (Porter, Kongthon, Lu, 2002; Kostoff, 2012; Kim and Chen, 2015). Early studies built on the framework of the key technologies of the 1980s: ICT, biotechnology, industrial technology and new materials and energy technologies (Revermann and Sonntag, 1989). Later, the frameworks became more elaborate. Two phenomena probably played a role: the first is technological convergence and cross-fertilisation (Roco and Bainbridge, 2003). An important part of convergence was tied to what they saw as the unification of S&T:

'The sciences have reached a watershed at which they must unify if they are to continue to advance rapidly. Convergence of the sciences can initiate a new renaissance, embodying a holistic view of technology based on transformative tools, the mathematics of complex systems, and unified cause-and-effect understanding of the physical world from the nanoscale to the planetary scale' (ibid. p. x).

R&I policies have gradually moved from discipline-based work towards a systems-oriented policy. In the EU, key technologies and key application areas continued to be the framework (see Cahil and Scapolo, 1999) until the Fifth Framework Programme (FP5) put its focus on key actions for particular socio-economic systems, such as the cities of the future, industry, etc. Whilst this was very well received, evaluation of FP5 centred around the EU's relative inability to coordinate national R&D policies:

'Our panel is convinced that the required changes need to be conceived within an overall strategy for Europe, articulated at the level of the EU and supported by all the Member States' (Majo et al., 2000 p. i).

The ability of the Union to coordinate national programmes and policies became a key political issue of the decade, with the European Research Area (Kastrinos, 2010), whilst the thematic structure of the framework programme remained stable.

3. Horizons and roadmaps

In 2010, the Chinese Academy of Sciences published a Roadmap for Science and Technology in China to 2050 (Lu, 2010). This signalled China's resolution to move from imitation to innovation with Chinese characteristics, rooted in domestic efforts and integrating global innovation resources. The roadmap was based on an analysis of key systems for China's socio-economic development and strategic capabilities, which framed its priority-setting process. Through this lens, China set out what it saw as the horizon of R&I challenges for the coming 40 years.

Roadmap for Chinese S&T 2050

Strategic systems for China's socio-economic development

- a. The system of sustainable energy resources
- b. The green system of advanced materials and intelligent manufacturing
- c. The system of ecological and high-value agriculture and the biological industry
- d. The generally applicable health-assurance system
- e. The system of ecological and environmental conservation development
- f. The expanded system of space and ocean-exploration capability
- g. The national and public security system

S&T initiatives of strategic importance for China's modernisation

1. Six S&T initiatives of strategic importance to international competitiveness:
   - a. New principles and technologies of Post-IP Network and its test beds
   - b. Green manufacturing of high-quality raw materials
   - c. Process engineering of highly efficient, cleaner and recycling utilisation of resources
   - d. Ubiquitous sensing-based informationised manufacturing systems
   - e. Exa (1018) supercomputing technology
   - f. Molecular design of animal and plant strains and products
2. Seven S&T initiatives of strategic importance to China's sustainability:
   - a. 4000-metre transparency underground programme
   - b. New renewable energy power systems
   - c. Deep geothermal energy power generation
   - d. A new nuclear energy system
   - e. Marine capacity expansion plan
   - f. Stem cells and regenerative medicine
   - g. Early diagnosis and systematic intervention of major chronic diseases
3. Two S&T initiatives of strategic importance to China's national and public security:
   - a. Space situation awareness network (SSAN)
   - b. Social computing and parallel management systems
4. Four basic science initiatives likely to make transformative breakthroughs:
   - a. Exploration of dark matter and dark energy
   - b. Controlling the structure of matter
   - c. Artificial life and synthetic biology
   - d. A mechanism of photosynthesis
5. Three emerging initiatives of cross-disciplinary and cutting-edge research:
   - a. Nanoscience and technology
   - b. Space science and exploration satellite series
   - c. Mathematics and complex systems

The defining difference between the Chinese Roadmap and all other priority-setting exercises is its expansionary nature. It was not a plan for the efficient use of resources in a steady state. It was the expansion plan which, over a decade, built the current competitive position of Chinese R&I and its future prospects.

Soon after the Chinese Roadmap was published, the Parliament of Finland launched the project '100 opportunities for Finland and the world' (Linturi, Kuusi and Alqvist, 2014), and the Russian prime minister launched the project 'Russia 2030: Science and Technology Foresight' (Gokhberg, 2016). Both projects benchmarked national capabilities in S&T in relation to key areas which were identified through some form of horizon scanning. The Russian study used a literature-based approach to its horizon scanning, whilst the Finnish one used an expert conversation-based methodology. The Russian study presented its findings in seven categories. The first three were the traditional generic technologies of the 1980s: ICT, biotechnology, and new materials (and nanotechnology), whilst the other four were application areas: healthcare and medicine, environmental management, transport and space systems, and energy efficiency and energy savings. In those four categories, the report catalogues about 200 important research areas, characterising Russian S&T as world class in a very small number of them (a handful of areas in medicine and energy, one area in space and one area in materials). However, the report made no case for the need for Russia to be world class in some areas. It simply developed an assessment on which government agencies and public and private companies could base their decisions about what they wanted to achieve.

The Finnish study explicitly took the view that Finland would have to adapt to whatever the world economy becomes. Thus, it defined future global value networks in which Finland would have to play a role if it were to sustain its standard of living. The study carried out a broad expert consultation on trends in S&T that would affect the global value networks and evaluated the importance of those trends in relation to their potential effects on such networks. The 100 trends with the biggest potential impact were labelled 100 opportunities for Finland and the world and were used by the study to benchmark the capacity of Finland in relation to the world standard. The Finnish study was revisited during 2017 with a similar methodology and was published under the title Societal Transformation 2018-2037 (Linturi and Kuusi, 2019). There were a few changes between the two studies. The global value networks terminology became more austere and some of the areas identified changed. The earlier study defined sensors, functional materials and intelligent goods as emerging global value chains, while the later work emphasised more social areas related to work, education and meaningful life. There was also some change in the framing of areas of innovation that constitute breakthroughs, as can be seen in the box below.

The figure below traces the evolution of the view on future global value networks of interest to Finland.

Figure 15-1 Horizon scanning of the Parliament of Finland: global value networks and areas of technological breakthroughs[2]

100 opportunities for Finland and the world (published in 2014)	Societal transformation 2018-2037 (published in 2019)
Global value networks	
Automation of passenger-vehicle traffic	Passenger transport
Automation of commodity transport	Logistics
Manufacturing close to customers	Manufacturing of goods
Virtualisation of retail trade and services	Exchange
Local or functional food	Sustenance
Distance presence and remote control of tools	Remote impact
Individualisation of learning and guidance	Acquiring information
Self-care based and personalised healthcare	Healthcare
New capabilities for those who have lost their functional health	Redressing disabilities
Sustainable energy technologies	Energy supply
Raw materials from untapped areas of the earth and space	Materials
Participatory forms of entertainment, culture and influence	Producing experiences
National defence and anti-terrorism	Safety and security
Functionalisation of spaces and structures	Built environment
Operation models for self-organising communities	Collaboration and trust
Virtualisation of identities and social structures	Existential meaning
Democracy, freedom and social cohesion	Power structures
Equipment that increases awareness of the environment	*Automation of work*
Functional materials and new material technologies	*Work and income*
Functional added value of intelligent goods	*Proficiency and its proof*
Areas of technological breakthroughs	
Control of metabolisms of human beings and other organisms	Biotechnology and pharmacology
Social innovations	Digital crowdsourcing platforms
Algorithms and systemic solutions based on IT	Artificial intelligence and algorithmic reduction
Measurement and picturing	Digitisation of sensory data and processing
Moving and transportation	Transport, mobility and logistics
Robotics	Production of products and services
Key enabling materials and industrial raw materials	Material technology
Energy technology	Energy technology
Messaging technologies and protocols	Instrumentation and telecommunication
Human machine interface technologies	*Globalising technology interfaces*
Imitation of nature and cyborgs	

Science, research and innovation performance of the EU 2020

Source: Author's elaboration based on Linturi at al., 2014; Linturi and Kuusi, 2019

Note: The placing of areas next to each other indicates the continuity from one report to the other, unless in italics, which indicates discontinuities.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/partii/chapter15/figure_15-1.xlsx

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[2] The placement of areas next to each other indicates the continuity from one report to the other, unless in italics, which indicates discontinuities.

4. Horizon scanning in the European Commission: the Radical Innovation Breakthrough Inquirer

The European Commission's Radical Innovation Breakthrough Inquirer (RIBRI) project was inspired by the Finnish study in two ways. First, having realised the importance of values in foresight and R&I policy (Remotti et al., 2016; Webber et al., 2018), the Commission came to appreciate the Finnish study's emphasis on values and the concomitant interest in social innovation. Second, the idea of using values as a means of evaluating the potential impact of radical innovations was consistent with the rising emphasis on directionality in EU R&I policy, in particular towards the Sustainable Development Goals in the UN Agenda 2030.

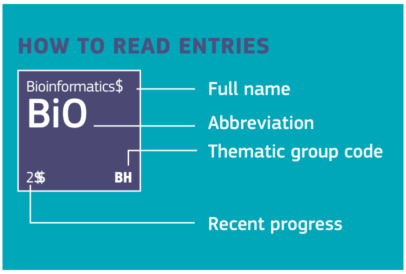
The RIBRI study used a mixed approach to identify radical innovation breakthroughs. For the most part, a massive bibliometric study used specially trained algorithms to mine scientific and technical publications for emerging concepts. Signals identified by the algorithms went through expert refereeing, after which they were written up as Radical Innovation Breakthroughs (RIBs). These were compared to and enhanced with other RIBs identified by other recent foresight studies, including surveys of social innovations. The 100 most important ones were selected through expert assessment procedures for their potential for widespread use by 2038, their level of maturity, and the EU's relative position in patents and publications.

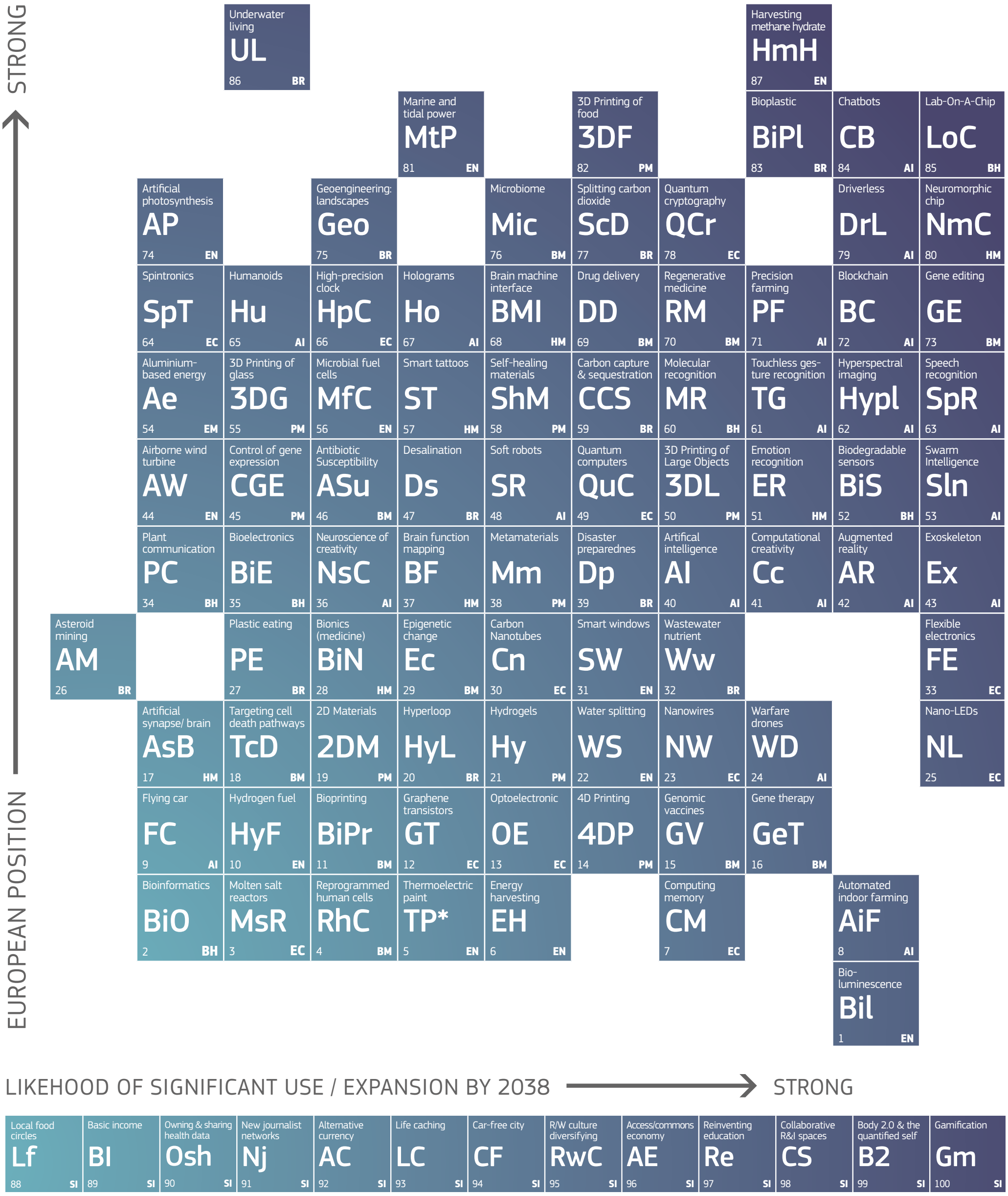
The 100 RIBs were clustered ex post into nine areas: Artificial Intelligence and robotics (AI&R); electronics and computing (E&C); bio-medicine (BM); human-machine interaction and biomimetics (HMI&B); printing and materials (P&M); resource boundaries (RB); energy (E); bio-hybrids (BH); and social innovations (SI). In all areas other than social innovations, the collections include mature topics that have been around for a while (breakthroughs waiting to happen) and emerging new areas of fundamental research (high potential – high uncertainty breakthroughs). All social innovations depicted are areas of existing social activity and thus of considerable maturity. Having ranked the RIBs in terms of their potential for significant use in 20 years and the current relative strength of the EU in the global system, the RIBs can be portrayed as presented in the figure below:

Figure 15-2 Table of radical innovation breakthroughs

TABLE OF RADICAL INNOVATIONS BREAKTHROUGHS

A dashboard of 100 emerging developments offering strong impact on global value creation and potential solutions to societal needs





		Underwater living UL 86 BR						Harvesting methane hydrate HmH 87 EN		
				Marine and tidal power MtP 81 EN		3D Printing of food 3DF 82 PM		Bioplastic BiPl 83 BR	Chatbots CB 84 AI	Lab-On-A-Chip LoC 85 BH
	Artificial photosynthesis AP 74 EN		Geoengineering: landscapes Geo 75 BR		Microbiome Mic 76 BM	Splitting carbon dioxide ScD 77 BR	Quantum cryptography QCr 78 EC		Driverless DrL 79 AI	Neuromorphic chip NmC 80 HM
	Spintronics SpT 64 EC	Humanoids Hu 65 AI	High-precision clock HpC 66 EC	Holograms Ho 67 AI	Brain machine interface BMI 68 HM	Drug delivery DD 69 BM	Regenerative medicine RM 70 BM	Precision farming PF 71 AI	Blockchain BC 72 AI	Gene editing GE 73 BM
	Aluminium-based energy Ae 54 EM	3D Printing of glass 3DG 55 PM	Microbial fuel cells MfC 56 EN	Smart tattoos ST 57 HM	Self-healing materials ShM 58 PM	Carbon capture & sequestration CCS 59 BR	Molecular recognition MR 60 BH	Touchless gesture recognition TG 61 AI	Hyperspectral imaging HypI 62 AI	Speech recognition SpR 63 AI
	Airborne wind turbine AW 44 EN	Control of gene expression CGE 45 PM	Antibiotic Susceptibility ASu 46 BM	Desalination Ds 47 BR	Soft robots SR 48 AI	Quantum computers QuC 49 EC	3D Printing of Large Objects 3DL 50 PM	Emotion recognition ER 51 HM	Biodegradable sensors BiS 52 BH	Swarm Intelligence SIn 53 AI
	Plant communication PC 34 BH	Bioelectronics BiE 35 BH	Neuroscience of creativity NsC 36 AI	Brain function mapping BF 37 HM	Metamaterials Mm 38 PM	Disaster preparednes Dp 39 BR	Artifical intelligence AI 40 AI	Computational creativity Cc 41 AI	Augmented reality AR 42 AI	Exoskeleton Ex 43 AI
Asteroid mining AM 26 BR		Plastic eating PE 27 BR	Bionics (medicine) BiN 28 HM	Epigenetic change Ec 29 BM	Carbon Nanotubes Cn 30 EC	Smart windows SW 31 EN	Wastewater nutrient Ww 32 BR			Flexible electronics FE 33 EC
	Artificial synapse/ brain AsB 17 HM	Targeting cell death pathways TcD 18 BM	2D Materials 2DM 19 PM	Hyperloop HyL 20 BR	Hydrogels Hy 21 PM	Water splitting WS 22 EN	Nanowires NW 23 EC	Warfare drones WD 24 AI		Nano-LEDs NL 25 EC
	Flying car FC 9 AI	Hydrogen fuel HyF 10 EN	Bioprinting BiPr 11 BM	Graphene transistors GT 12 EC	Optoelectronic OE 13 EC	4D Printing 4DP 14 PM	Genomic vaccines GV 15 BM	Gene therapy GeT 16 BM		
	Bioinformatics BiO 2 BH	Molten salt reactors MsR 3 EC	Reprogrammed human cells RhC 4 BM	Thermoelectric paint TP* 5 EN	Energy harvesting EH 6 EN		Computing memory CM 7 EC		Automated indoor farming AiF 8 AI	
									Bio-luminescence BiI 1 EN	

Local food circles Lf 88 SI	Basic income BI 89 SI	Owning & sharing health data Osh 90 SI	New journalist networks Nj 91 SI	Alternative currency AC 92 SI	Life caching LC 93 SI	Car-free city CF 94 SI	R/W culture diversifying RwC 95 SI	Access/commons economy AE 96 SI	Reinventing education Re 97 SI	Collaborative R&I spaces CS 98 SI	Body 2.0 & the quantified self B2 99 SI	Gamification Gm 100 SI

THEMATIC GROUPS

AI Artificial Intelligence and Robots
BH Biohybrids
BR Breaking Resource Boundaries
HM Human-Machine Interaction & Biomimetics
BM Biomedicine
EN Energy
EC Electronics & Computing
PM Printing & Materials
SI Social Innovations

1 Glowing plants, Visualization of gene expression
2 Biohybrid
3 Waste-burning with lithiumflouride/thoriumfloride material, Collaborative efforts in Canada, Protoypes in China
4 Destruction of cancer cells, Macrophages to kill the Tuberculosis pathogen
5 (*No value for European position) - Thermoelectric paint, Harvest of electriciy from waste heat
6 Biological motion, Other sources (wind, heat, radio, chemical)
7 In-memory algorithms, Faster phase-shifting computer memory
8 Techno farming in extreme conditions
9 Personal autonomous drones and rockets, Coordinated flying taxi services
10 Production, Storage, Hydrogen-powered vehicles
11 Bones, tissue, skin, blood vessels and other human parts, 3D-printed models
12 Microprocessors, Neuromorphic chips, Next-generation electronics
13 Optical computing, 5D optical data storage, Photonic chips
14 Exposure to heat, Water contact
15 Clinical trials, DNA vaccines for animals, Better delivery pathways
16 Disease areas, Treatments
17 Atomristors, ENODe, Junction-based artificial synaptic device, epiRAM
18 Targeting new pathways to trigger cell death
19 2D Semiconductors, 2D Magnets, Black phosphorous ink
20 Section of Hyperloop Track finalised in NL, Further tests under way at several sites
21 Regenerative medicine, Soft robots, Biothreat detection devices, Optogenetics
22 New Catalysts, Fertilizers
23 Batteries, Nanosensors, Electrochromic devices, FET, Heat dissipators
24 Intelligence, Fuel autonomy, Microdrones, Defense against drones
25 Multitasking LED displays, Deep UVC, Optical Data Communication
26 Asteroid detection, Examination and mining technologies
27 Plastic-colonizing fungi, Micro-to-macro: plastic-munching worms
28 Exoskeleton, Upper limbs, Internal organs
29 Epigenetic technologies for diagnosis and other technologies
30 Nanotubes with fullerenes, On-chip light sources, Liquid biopsy chip
31 Electrochromic materials, Liquid crystal sandwich, Nanocrystals
32 Nutrient recovery from wastewater, Biological phosphate removal
33 Transistors, Displays, Energy storage, Sensors, Health monitoring, 3D printing
34 Senses of plants, Parasites involved in plant communication
35 Biochip, Biological computer, Biological computer parts, Bio interface
36 Testing and Influencing imagination and creativity
37 Brain electrical activity and biomarker mapping, Improving cognitive functions
38 Cloaking devices, Photovoltaic devices, Medical imaging
39 Submarine (smart-)cable network, Robots & AI emergency response
40 Duelling Networks, Capsule Networks, One Shot Image Recognition
41 Computational Creativity
42 Synchronization with the physical world, Live instructions, Therapy
43 Medical applications, Military applications, Industrial applications
44 Ground- and flying Generator Airborne Energy Systems
45 Epitranscriptomics, Embryo development
46 AST Micro-assay, Lab-on-a-Stick, Microfluidic devices, AST Gadget
47 Nanofiltration, New distillation solutions
48 Pneumatic, Living muscle tissue, Hydrogel, Mechanical
49 Quantum systems, Quasiparticle control
50 Energy: 3D-printed turbine prototype, 3D-printing robots for building
51 Interpreting facial expressions and text, voice, heartbeat, breathing
52 Medical uses, Food/medication tracking, Environmental sensing
53 The Swarm-Organ project, Unmanned Aerial Vehicles
54 Aluminium-ion batteries, Aluminium-air batteries
55 Fused filament fabrication, Stereolitography
56 New catalysts, Cheap material for electrodes, Wearable energy devices
57 Medical technologies, Environmental monitoring, Marketing
58 Civil engineering, Protective clothing, Energy storage, Soft robotics
59 Exploring new storage solutions, New uses for CO_2
60 Portable diagnostic devices, Electrodiagnosis, Screening (medicine)
61 Ultrasonic gesture sensing, Optical cameras and sensors, Gesture decoding equipment
62 Medical imaging, Food quality, Mining, Recycling, Security, Hardware & Software
63 Dedicated chipsets and algorithms, Systems and devices
64 Spin relaxation and spin transport, Combination with Claytronics
65 Mimicking humans, Application demonstrators, Control
66 Attophysics, Ultra-precise time measurement for GPS applications VoIP
67 Acoustic holograms, Touchable/printable holograms
68 Electroencephalography (EEG, ECoG, fNIRS, fMRI)
69 Breaking the Blood-Brain-Barrier, New- and nano-materials, Genetically-engineered devices
70 Cellular therapies, Tissue engineering and artificial tissues or organs
71 Agrobots, Internet of Things in precision farming, In-field devices
72 Trust, Notarization, Smart contracts, Corporate blockchain networks
73 CRISPR as revolution in health, CRISPR in agriculture
74 Drug production, Fuel processing, Renewable energy, Air purification
75 Changing landscapes and climate, Climate Engineering: greenhouse gas removal
76 Gut bacteria and immunotherapy and gene activity, Probiotic bacteria and depression
77 Low-cost carbon dioxide splitting
78 Quantum key distribution from orbit, Faster data rates, Blockchain
79 New-generation sensors, Man-machine synergy, Legislation, Connectivity
80 Neuromorphic chips for object recognition
81 New technologies for tidal and wave energy harvesting
82 Soup with 3D-printed twist, Technology to help people with dysphagia
83 Bioplasics for Skin contact, Wound repair, electronics
84 Unscripted chatbots, Reuse & integration with major platforms, Enterprise & Customer Service Applications
85 Sepsis detection, Lab-on-a-stick, Cheap lab-on-a-chip manufacturing
86 Aquanaut technologies for hotels, Entering a sustainable underwater future
87 Methane Hydrate Gas in China, Energy from methane hydrate gas on a large scale
88 Community and indoor Gardening, Localised Food Systems, Permaculture
89 Unconditional Minimum Basic Income, National Referendum on unconditional basic income
90 Healthbank for Health information, Sharing scientific health data for money
91 Large-scale investigative journalism
92 Crypto-currencies traded world-wide, Giving up cash
93 Live caching as an industry, Scrapbooking
94 Banning cars from cities, New cities without cars
95 Breakdown of established gatekeepers, Ownership disruption
96 Online mediated sharing, Rise of the Commons, Based-peer production
97 Increase in diversity of actors in and forms of education
98 Makerspaces on the rise
99 Tools for tracking common devices, Body 2.0 – monitoring at the workplace
100 Data generation combined with participation via gaming, Physical Education and Health

Source: European Commission, DG Research and Innovation based on Warnke, P et al., 2019

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/partii/chapter15/figure_15-2.xlsx

Comparing the extremes of the different distributions provides the following highlights:

1. The AI and robotics revolution

AI&R form a cluster of innovations that will have a huge impact on the future world economy and society. It is the most populous cluster of RIBs identified and the one with the highest average potential for significant use in 20 years' time.

Emotion recognition

Emotion recognition has been about applying advanced image-processing algorithms to images (or videos) of the human face. Recent developments have extended the field to include other means of gauging emotions (text analysis, tone of voice, heartbeat and breathing patterns, etc.) and even extending them to other species. Applications cover areas such as marketing (detecting minute, subconscious reactions to advertising or products), smart devices that adapt to our mood, and law enforcement (improved lie detectors).

In some areas of the AI&R cluster, such as chatbots, Europe is strong while in other areas, like computing memory, Europe's capacities are relatively weak. Consolidating the application pathways emerging from the surge of innovations in algorithms and hardware in sectors such as mobility, health, education and food seems at least as important as fostering the further emergence of upcoming innovations. It is vital for Europe to pursue trajectories that unlock the potential of these technologies to support better solutions able to meet citizens' needs.

2. Fast-emerging innovations

The results include 45 RIBs currently at a low level of maturity which are expected to develop quickly and find important use in the coming 20 years. Among these, seven RIBs are expected to be particularly fast moving:

- Neuromorphic chip
- Biodegradable sensors
- Hyperspectral imaging
- Warfare drones
- Harvesting methane hydrate
- Thermoelectric paint
- Neuroscience of creativity and imagination
- 4D printing

Neuromorphic chip

Modelled on biological brains, neuromorphic chips are less flexible and powerful than the best general-purpose chips, but highly efficient for specialised tasks. They can boost the development of AI-based systems for specific purposes such as object recognition, voice and gesture recognition, emotion analytics, health analytics or robot motion, and can moderate their power consumption.

Among the 45 potentially fast-moving RIBs, relative weaknesses in Europe were found in the following:

- 4D printing
- Bioluminescence
- Automated indoor farming
- Water splitting
- Computing memory
- Molten salt reactors
- Graphene transistors
- Energy harvesting
- Hyperloop

4D printing

4D printing adds an additional element of time to 3D printing/additive manufacturing. 4D-printed objects can change shape or self-assemble over time if exposed to a stimulus – heat, light, water, magnetic field or another form of energy – which activates the process of change. Among the ground-breaking applications foreseen are drug devices reacting to heat changes in the body, shape-memory materials enabling solar panels to auto-rotate towards the sun, and self-repairing infrastructures.

Amongst the 45 potentially fast-growing RIBs, relative strengths in Europe were found in:

- Harvesting methane hydrate
- Underwater living
- Bioplastics
- 3D printing of food
- Lab-on-a-chip
- Chatbots
- Quantum cryptography
- Marine and tidal-power technologies

Interestingly, in the field of quantum cryptography, the EU leads in terms of patents but China is the leader in publications.

Lab-on-a-chip

A lab-on-a-chip integrates laboratory functions into a single device of small dimensions. It promises better and faster diagnostics, especially in areas with poor healthcare infrastructure, a more active role for patients in monitoring their own health, as well as enabling citizens to engage in environmental monitoring.

3. Highly speculative areas

The following highly speculative topics made it into the 100 RIBs:

- Neuromorphic chip
- Neuroscience of creativity and imagination
- Plant communication
- Spintronics
- Bioelectronics
- Aluminium-based energy
- Airborne wind turbine
- Artificial photosynthesis
- *4D printing*
- *Asteroid mining*
- *Thermoelectric paint*
- *Artificial synapse/brain*
- *Flying car*

Bioelectronics

Bioelectronics is the use of biological materials and architectures inspired by biological systems to design and build information-processing machinery and related devices. Researchers hope to develop bio-inspired materials (e.g. capable of self-assembly or self-repair) and bio-inspired hardware architectures (e.g. massive parallelism) to be used in new sensors, actuators and information-processing systems that are smaller, work faster/better and require less power.

In the first eight RIBs on this list, Europe has noteworthy capacities. In the other five (indicated in italics) its position is either unclear or weak as regards maintaining and further advancing its position as a pioneering actor in newly emerging technologies. The neuromorphic chip also deserves special attention because, in spite of its low maturity, expectations on its widespread use in 2038 are very high.

4. Mature, yet radical

Some of the RIBs identified are quite mature – they have been known for a while and have been subjects of R&D and patenting. At the same time, they have a great deal of unexploited growth potential in the perspective of 2038. Their relative technological maturity places them at the junction between R&I policy and industry policy concerns. Such RIBs are found, for example, in the area of nanotechnology (nano-LEDs, nanowires, carbon nanotubes). Hydrogels and holograms also fall into this category. Their further development is not so much a matter of R&I policy but more a subject for industry policy or other policies concerned with the respective domains. Given their potential, it is worth asking whether appropriate regulatory frameworks are in place and if complementary social innovations are needed for the successful and beneficial exploitation of these RIBs, or whether an industry policy is required to strengthen Europe's position in the areas of carbon nanotubes, nanowires and hydrogels, where currently it is not world-leading.

Hydrogels

These natural or synthetic polymeric networks are capable of holding large volumes of water that can replicate the dynamic signalling involved in biological processes, such as cell/tissue development. In the near future, hydrogels will provide the basis for first-aid kits and innovative drug-development concepts. In the longer term, we can imagine curative soft robots performing surgery at microscopic and sub-microscopic levels, and hydrogels in mobile-phone screens sensing environmental pollutants and informing an app.

5. A view from Europe's Research and Technology Organisations (RTOs)

During a workshop entitled 'Future technology for prosperity – horizon scanning' in Oslo on 2-3 July 2019[3], we asked a number of Europe's RTOs and funding bodies[4] the question: 'What are the next emerging technologies Europe should invest in?'. The workshop was part of a wide public consultation on the draft strategic plan for the next EU Research and Innovation Programme, Horizon Europe.

RTOs play a very important role in the European Innovation system, intermediating between science, technology, industry and government. Based on their special position, we asked the directors of participating RTOs and funding bodies to single out the technology they thought was the most important for future prosperity.

Current policy debate in the EU already focuses a lot on information and communication technologies, including AI, the digital transformation[5] and Industry 4.0[6]. Participants were asked to focus on areas 'other than digital only'.

The result was a collection of emerging technologies considered to have particularly strong potential, in their opinion, to create prosperity, including economic growth and broader benefits. An essential factor was the contribution of the technologies to society and the transition towards sustainability.

The technologies presented can be clustered into five areas, technological frameworks: biological transformation; smart materials; marine technologies; low-energy data transmission; and 'power to X'.

1. **Biological transformation** includes the increasing exploitation of biological knowledge as well as the increasing spread of biomimetic design. Biological transformation brings together the basic disciplines of biotechnology, engineering and information technology. Methods of adaptive data processing (machine-learning algorithms) are just as important as biotechnological production processes. Their combination and intelligent networking, including biological components and principles for their optimisation were considered key to a bio-intelligent economy that enables prosperity and healthy and sustainable (qualitative rather than quantitative) growth. The areas discussed in the workshop included Human-Machine Interaction, smart farming, gene technology and neuro-technologies.

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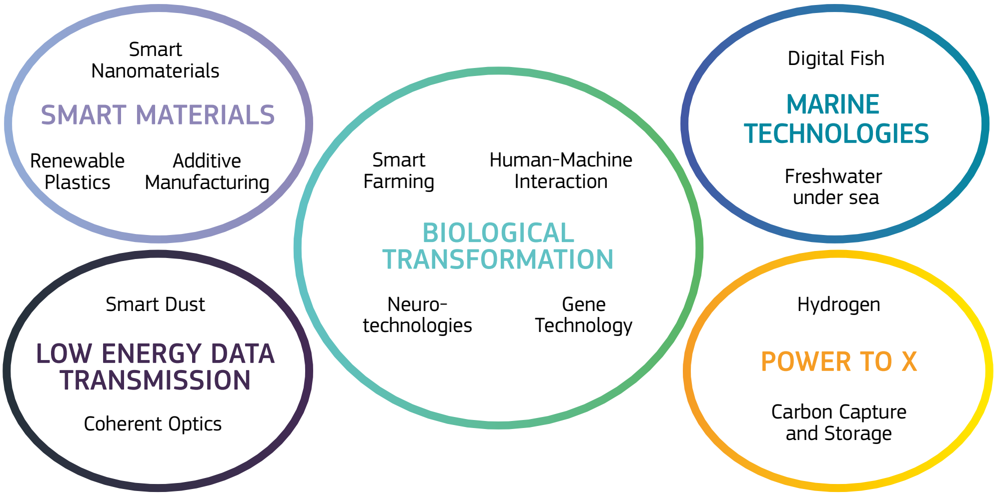
[3] The workshop was organised by the Directorate for Prosperity in the European Commission's Directorate-General for Research and Innovation and the Research Council of Norway. https://ec.europa.eu/info/sites/info/files/research_and_innovation/ki-03-19-551-en-n.pdf

[4] Organisations represented: Agency for Higher Education, Science and Innovation Funding in Romania; Austrian Institute of Technology; CEA Tech; Cenate AS; CSEM; Enterprise Ireland; European Commission Directorate-General Research & Innovation and the Joint Research Centre; Firda AS; European Association of Research & Technology Organisations; Flanders Make vzw; Fraunhofer Gesellschaft; International Iberian Nanotechnology Laboratory; Innovate UK; J. Stefan Institute; Luxembourg Institute of Science and Technology; Łukasiewicz Research Network; National Research Council of Italy; Norwegian Research Centre; Norwegian Biotechnology Advisory Board; Research Council of Norway; Research Institutes of Sweden; Research Institute on Computer Science and Control at the Hungarian Academy of Sciences; SINTEF; State Secretary to the Minister of Research and Higher Education of Norway; Technology Agency of Czechia; Tecnalia Research & Innovation; TNO; University of Malta; University of Applied Sciences Salzburg; VTT Ltd.

[5] https://ec.europa.eu/growth/industry/policy/digital-transformation_en

[6] https://www.europarl.europa.eu/RegData/etudes/STUD/2016/570007/IPOL_STU(2016)570007_EN.pdf

Figure 15-3 Overview of technology frameworks and technologies



Science, research and innovation performance of the EU 2020

Source: Müller, J and L Potters (2019) Future technology for prosperity: Horizon scanning by Europe's technology leaders, European Commission

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/2020/partii/chapter15/figure_15-3.xlsx

2. **Smart materials** (e.g. renewable plastics, smart nanomaterials and additive manufacturing) build on technology that provides them with additional functionalities, capacities, and features in bulk and/or at the interface, including adaptability and the capacity to be both sensors and actuators, or to create new structures even on a very small scale. Further development of smart materials can contribute to environmental sustainability (enabling, recycling, repair and self-healing or sensing) and find important uses in healthcare (e.g. thanks to their properties, some smart materials can be used in medical applications that enable better treatment of patients and new forms of therapy) as well as other areas of application.

3. **Low-energy data transmission** will be important as data networks are expected to expand massively in the next few years. The two technologies discussed in the workshop include coherent optics, which allow the transmission of larger volumes of data over longer distances, with lower energy consumption on the existing fibre-optic infrastructure; and smart dust, which is a completely different way of transmitting and receiving data opening up completely different application domains. Smart dust combines systems for ubiquitous Internet of Things (IoT) with ultra-low power consumption or energy autonomy. It encompasses intelligent sensors that are degradable and able to communicate among one another.

4. **Power to X** refers to the electrification of industrial processes and the transition in the way heavy industries, and especially the chemical industry, use power. The two technologies discussed in the workshop are hydrogen and carbon capture and storage. The long-term vision is to turn natural sources of energy, such as sunlight, directly into heat, fuels and further chemical products, which could massively increase the efficiency of the chemical industry through direct power conversion, also closely aligned with carbon capture and storage technologies.

5. **Marine technologies** emphasise the potential of the seas. Digital fish, the monitoring of fish via sensors, enables a digital twin of fish to be created. This enables the lives of fish to be tracked and studied, hunger mitigated, disease stress and further stress factors to reduce diseases, fish mortality to be improved, and the optimisation of feeding processes and fish well-being. The other area discussed concerns the potential to discover and exploit large amounts of fresh water below the ocean surface, often hidden in caves. This water could be used to irrigate regions with low precipitation, for example, for farming or to provide communities with fresh water.

All areas have in common the fact that they relate to societal challenges and have the potential for systemic changes. They involve the need to better understand the underlying systems, a combination of disciplines and collaboration and co-creation of all main actors, with industry taking a leading role in this. The role of policymakers is seen as shaping the conditions for a strong innovation ecosystem whereby all actors in the innovation process are connected and can create value, creating critical mass to tackle strategic economic and societal domains, and to deploy favourable regulation and financial instruments as an impetus for collective innovation. Participants also emphasised active engagement with civil society and citizens from the very start of technology development.

6. In conclusion: waves of change and horizon scanning

Which areas should Europe prioritise? How should strengths and weaknesses be dealt with? Such strategic questions cannot be answered by horizon scanning, although it can inform us about the implications of one or other of the choices. A scan of the horizon at a specific point in time raises our awareness of potentially important areas of R&I and provides for a better-informed R&I strategy. In its simplest form, it enables us to ask ourselves whether or not we need to invest in all these areas and why, and to better understand the opportunity cost of our choices.

While this is an important strategic function, it is also important to note that a complete scan of the horizon is very costly, and the picture of the horizon is a moving one. The Finnish experience with the two successive studies provides some insight into the speed of change. New understandings and experiments change people's views of what is doable and worth doing, while societal values, norms and beliefs also influence the pursuits of scientists and engineers.

The waves of change associated with the functioning of economic expectations have, since the Second World War, combined with notions of technological performance associated with military concerns to drive technological innovation in domains that have massively increased economic productivity. Several authors (Mazzucato and Perez, 2014; Mazzucato, 2018; Perez, 2016) have argued that humanity needs to shift towards different sets of technological aspirations that reflect humanistic ideals and the value of our ecosystem – such as the UN Sustainable Development Goals. The workshop in Oslo related technologies clearly to a 'purpose'. In RIBRI, we see some signs of such waves of change. The most visible innovation drive related to the 'digital revolution' is expected to be followed by a more diverse wave of innovations that address broader concerns of life and the ecosystem. For many (Kastrinos and Vercruysse, 2019; Messerli et al., 2019), and the EU has expressed commitments in this respect, the SDGs will, to a considerable degree, shape the value-creating structures and processes of the future.

However, this is neither a clear case nor a finished battle. Although mining methane hydrate – to use an obvious example of an area where Europe appears to be strong – could solve resource problems, it also poses significant environmental risks. The values of sustainability and environmental performance are not clear-cut. While science, technology, research and innovation can enable and contribute to sustainability pursuits, they cannot alone provide a new green wave. What they can do is to provide answers to those who claim that such a wave is impossible and that sustainability cannot be achieved. They must show that it is doable and provide the tools for achieving it. It is society's duty to decide that it is worth doing.

In this context, it is the duty of horizon scanning to showcase different alternatives and to allow for the continuous assessment of those alternatives as routes towards sustainability. This does not necessarily mean that only the most efficient routes must be followed. Often short-term efficiency is a long-term liability. Priorities and choices must be informed and to achieve that, scans of the horizon need to be systematic, continuous and comprehensive, feeding into decision-making processes that are both engaging and participative, involving broad sets of stakeholders and the concerned public, in a new EU R&I policy that will successfully pave the way to sustainability.

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