CHAPTER
I.4

SCIENTIFIC, TECHNOLOGICAL AND INNOVATION PRODUCTION

Scientific and technological production is the very basis of innovation outputs and reflects the efficiency and effectiveness of a research system in transforming investment in knowledge-creation activities into tangible and intangible assets that enable higher value-added activities. For innovation, the quest for excellence in scientific and technological activities is particularly important to ensure high-impact innovations, as well as favourable conditions for a thick weave of knowledge to flow.

Against this backdrop, and using a set of different measures, this chapter assesses the EU's scientific, technological and innovation performance in an international context as well as the robustness of knowledge flows across different innovation stakeholders.

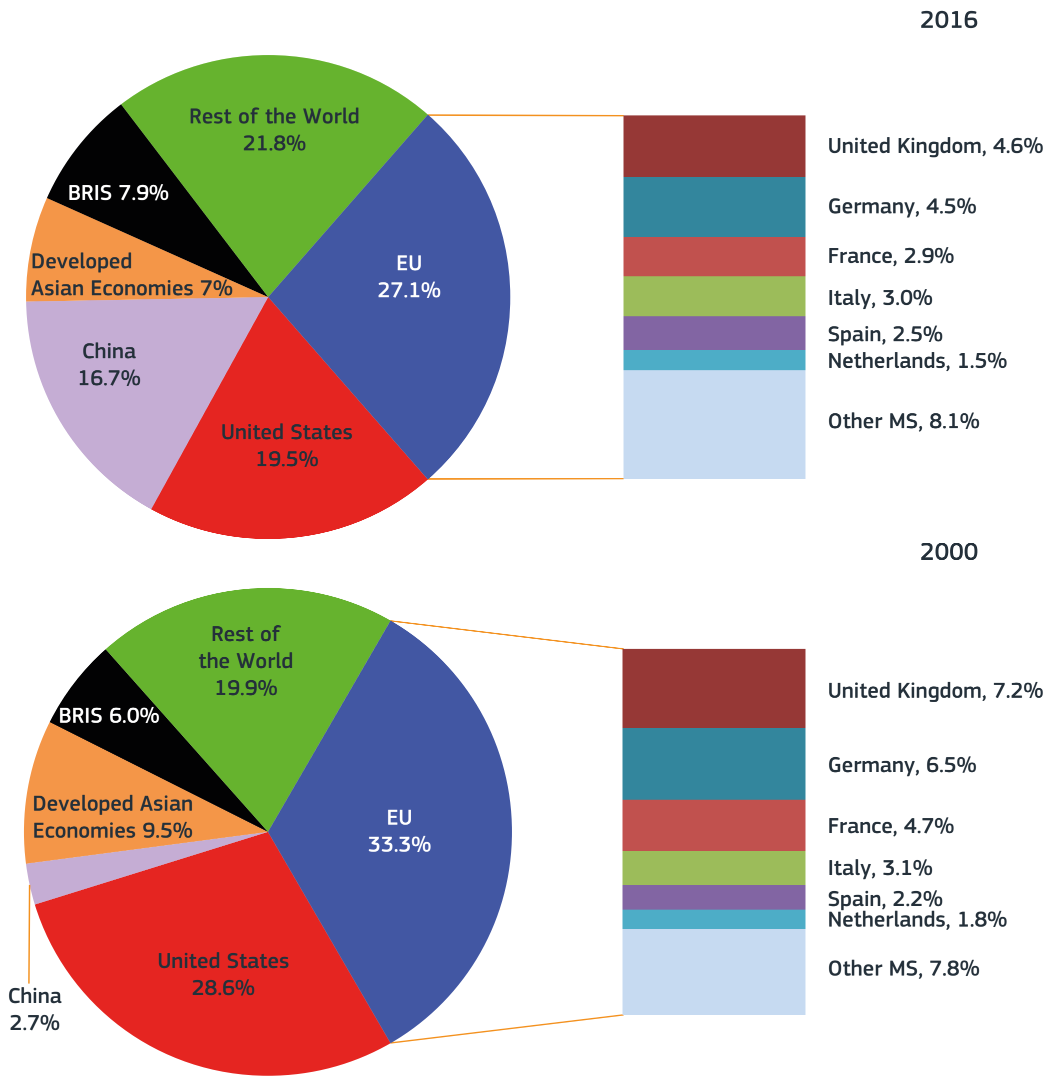
CHAPTER I.4-A SCIENTIFIC PRODUCTION AND SCIENTIFIC EXCELLENCE

Science is recognised at the global scale as an indispensable asset to understand and address today's economic and societal challenges, embrace emerging opportunities, and create technologies and innovations that benefit humanity and create wealth.

In terms of overall scientific production, Europe is in the lead, ahead of the United States and China; a lead that has been maintained over time despite the emergence of an increasingly multipolar scientific landscape.

Back in 2000, the EU and the United States dominated global knowledge production, together being the home for almost two-thirds of scientific publications worldwide. However, China's significant investment in science over the last two decades has started to pay off and the country's world share of scientific publications has risen exponentially from 2.7 % in 2000 to 16.7 % in 2016. This has assured China a solid third position in the global ranking. Simultaneously, the United States' world share of scientific publications shrank from 28.6 % in 2000 to 19.5 % in 2016, increasing the gap with the EU, which managed to preserve its global leadership with over 27 % of the world's knowledge production (see Figure I.4-A.1).

Figure I.4-A.1 World share of scientific publications[1], 2000 and 2016



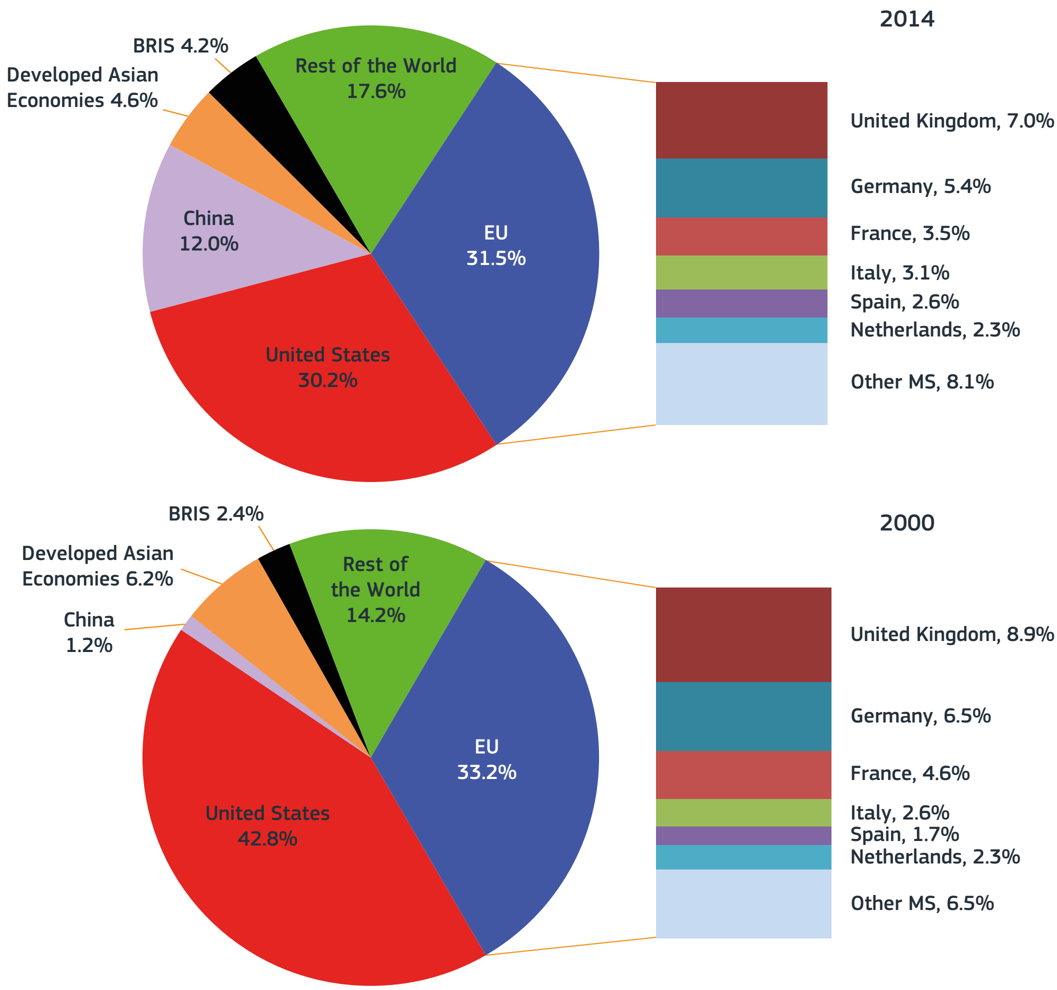
Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research and Innovation Policies
Data: CWTS based on Web of Science database
Note: [1]Fractional counting method.
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/parti/i_4-a_figures/f_i_4-a_1.xlsx

Europe has also maintained its global share in terms of highly cited publications. It has managed to overcome the United States as the world leader, despite China's sharp rise as a scientific superpower.

In times of increasingly competitive global research dynamics, the EU has succeeded in steadily maintaining its world share of highly cited scientific publications (within 10 % most cited) and has replaced the United States as the world leader. The United States experienced a heavy decline in the number of highly cited scientific publications, from 42.8 % in 2000 to 30.2 % in 2014, while China increased its share tenfold from 1.2 % in 2000 to 12.0 % in 2014. The share of other developed Asian economies in worldwide highly cited publications has also been falling (see Figure I.4-A.2).

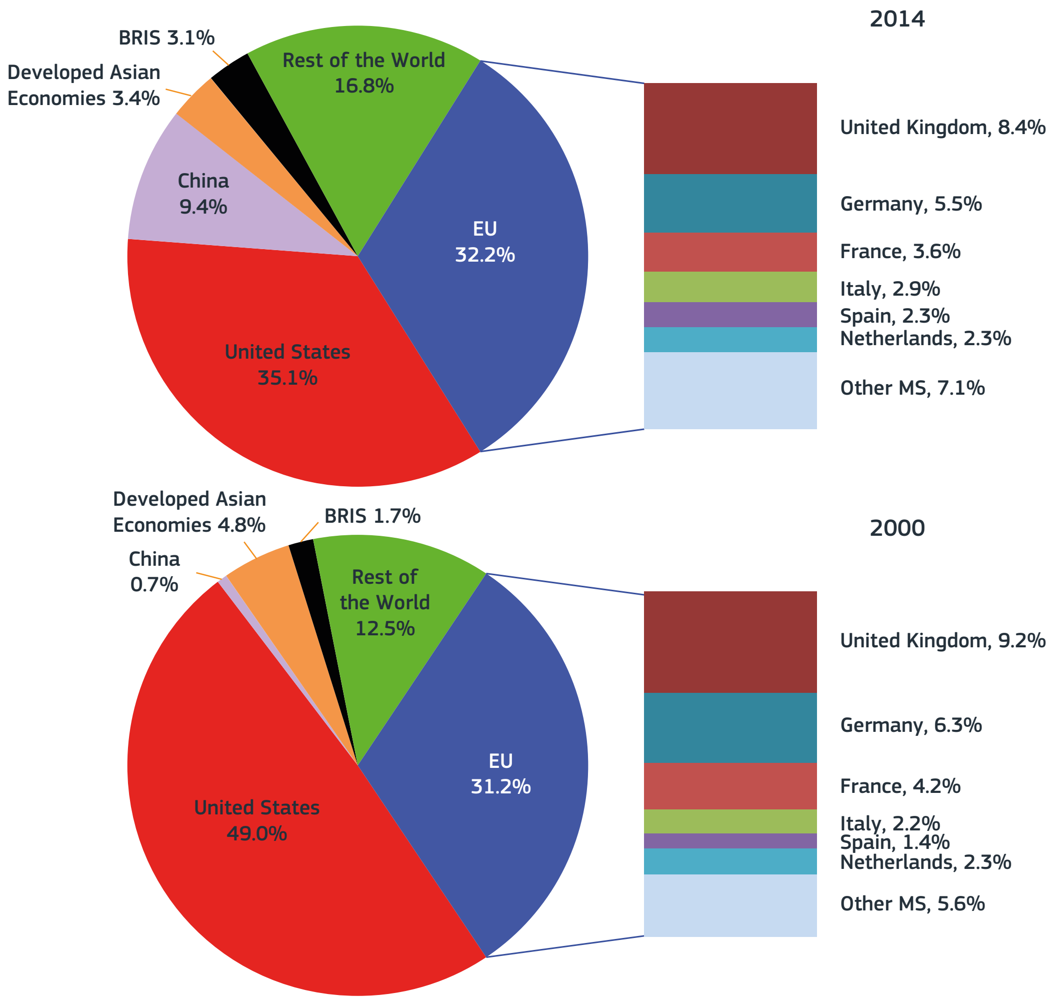
A similar trend is observed for the top 1 % of most-cited articles. However, despite the strong fall noted for top-cited American publications from 2000 to 2014 (from 49.0 % to 35.1 %) and Europe's ability to slightly improve its global share of top-cited publications over the last decade, the United States remains the global leader in top science although the gap with the EU has substantially narrowed (see Figure I.4-A.3).

Figure I.4-A.2 World share of top 10% highly cited scientific publications[1], 2000 (citation window: 2000-2002) and 2014 (citation window: 2014-2016)



Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research and Innovation Policies
Data: CWTS based on Web of Science database
Note: [1]Scientific publications within the 10% most-cited scientific publications worldwide as % of total scientific publications of the country; fractional counting method.
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/parti/i_4-a_figures/f_i_4-a_2.xlsx

Figure I.4-A.3 World share of top 1% highly cited scientific publications[1], 2000 (citation window: 2000-2002) and 2014 (citation window: 2014-2016)



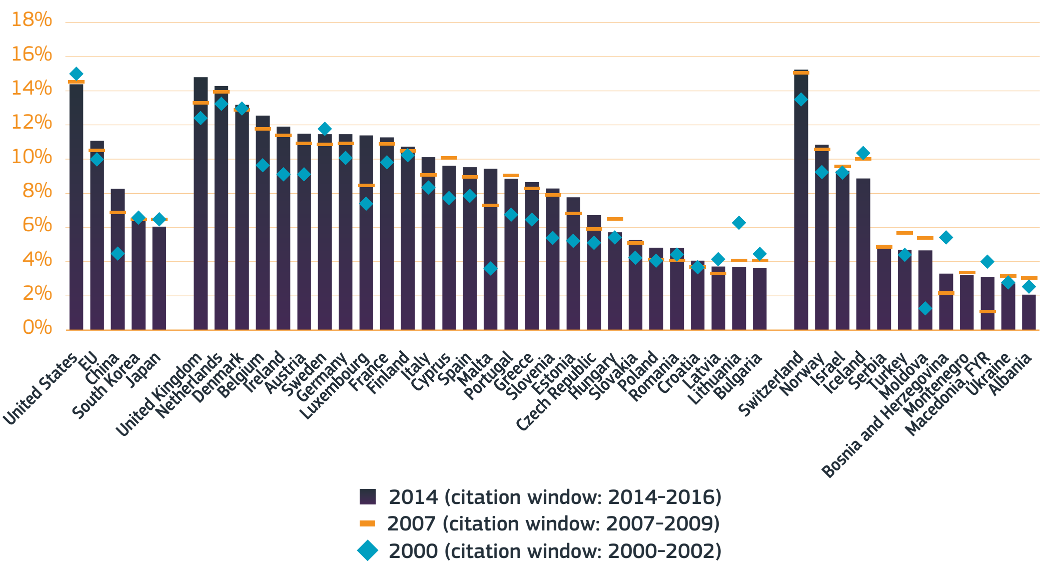
Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research and Innovation Policies
Data: CWTS based on Web of Science database
Note: [1]Scientific publications within the 1% most-cited scientific publications worldwide as % of total scientific publications of the country; fractional counting method.
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/parti/i_4-a_figures/f_i_4-a_3.xlsx

In relative terms, Europe lags behind the United States in the share of the top 10% highly cited publications of total publications. In dynamic terms, Europe has advanced in making its science more excellent. Although large national differences exist across Member States, overall, most countries are making significant progress.

Despite a slight fall in the share of total publications among the 10% most-cited worldwide since 2000 (see Figure I-4-A.4), the United States still outperforms the EU, which has more publications than the former but with a lower impact in terms of citations. Moreover, China is quickly bridging the gap with the EU since its top 10% most-cited publications have almost doubled since 2000.

Inside the European Research Area, strong differences among countries' performances persist. Switzerland confirms its leading global position, while as from 2014, the United Kingdom has managed to surpass the United States in terms of high-impact scientific publications, with the Netherlands following closely behind. Numerous Western European and Scandinavian countries have continued to raise their scientific performance since 2000 (e.g. Denmark, Belgium, Ireland, Norway, Germany, Austria, Luxembourg and France). While several Mediterranean and Eastern European countries like Malta, Italy, Spain, Greece and Slovenia have managed to raise their scientific output significantly compared to 2000 and 2007, a post-2007 drop has been noted for Cyprus, Hungary, Bulgaria and Lithuania. Iceland experienced the largest fall in highly cited publications over the period 2000-2014. It should be noted that the scientific performance among the Eastern Partnership and Balkan countries has been volatile over the last decade.

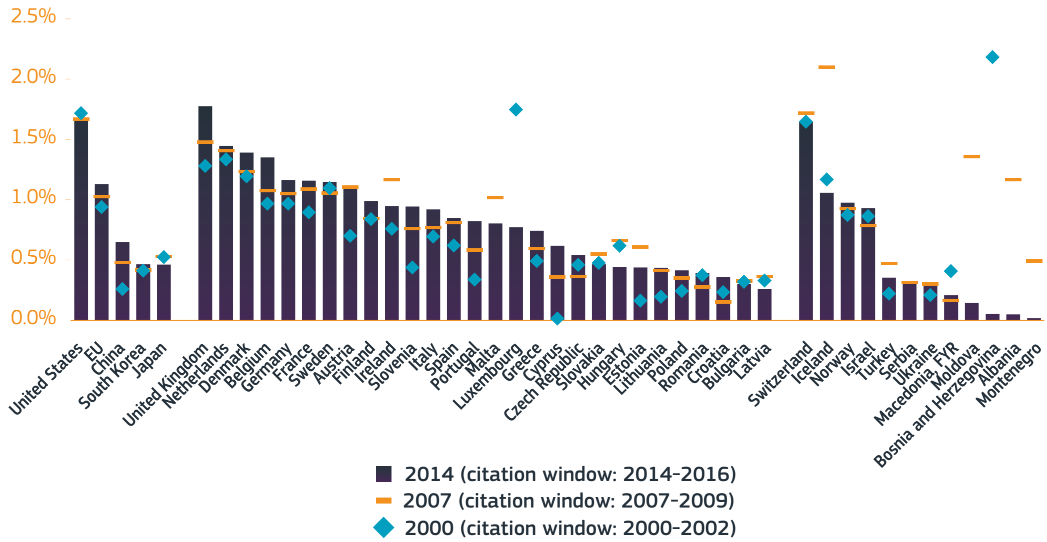
Figure I.4-A.4 Top 10% highly cited scientific publications[1], 2000, 2007 and 2014



Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research and Innovation Policies
Data: CWTS based on Web of Science database
Note: [1]Scientific publications within the 10% most cited scientific publications worldwide as % of total scientific publications of the country; fractional counting method.
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/parti/i_4-a_figures/f_i_4-a_4.xlsx

Overall, and despite persisting differences between the Member States, the EU is raising its scientific impact as well as progressing in relative terms when examining the top 1 % of highly cited scientific publications as a percentage of total scientific production (see Figure I.4-A.5), a proxy for top scientific excellence. This indicator confirms the trends presented above: while the United States and Japan declined, the performance of the EU and China increased steadily. The UK is the world top performer in science where the top 1 % of articles is concerned, ahead of the United States, and followed by Switzerland, the Netherlands, Denmark, Belgium, Germany, France and Sweden, which all score above the EU average.

Figure I.4-A.5 Top 1% highly cited scientific publications[1], 2000, 2007 and 2014



Science, Research and Innovation performance of the EU 2018

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research and Innovation Policies

Data: CWTS based on Web of Science database

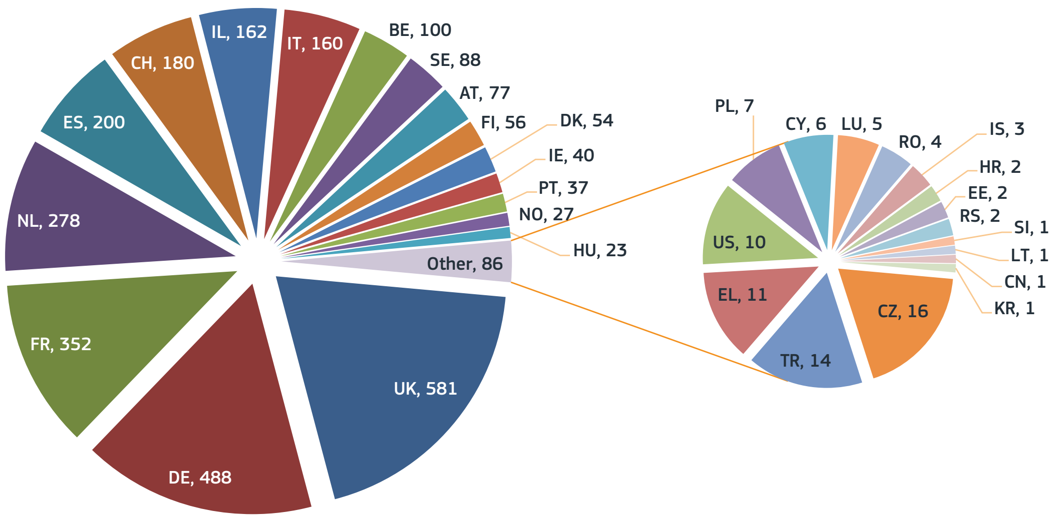
Note: [1]Scientific publications within the 1% most cited scientific publications worldwide as % of total scientific publications of the country; fractional counting method.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/parti/i_4-a_figures/f_i_4-a_5.xlsx

European Research Council (ERC) grantees are increasingly recognised as a measure of excellence. The UK and the Netherlands perform particularly strongly in ERC grantees, notably in comparison to their overall level of public R&D investment.

Shortly after its establishment in 2007, the ERC became a reference for the funding of international, excellent, frontier research conducted on the basis of Europe-wide competition. The ERC is continuously improving its high-quality evaluation systems, including under the current Horizon 2020 Framework Programme. By 2017, researchers based in the UK, Germany, France and the Netherlands had been awarded most ERC grants under Horizon 2020. The grants are focused on research-intensive countries since almost 90% of those distributed are concentrated in 10 countries, while half of the 20 remaining European Research Area (ERA) countries have less than 10 grants (see Figure I.4-A.6).

Figure I.4-A.6 Number of European Research Council (ERC) grants by country, 2017

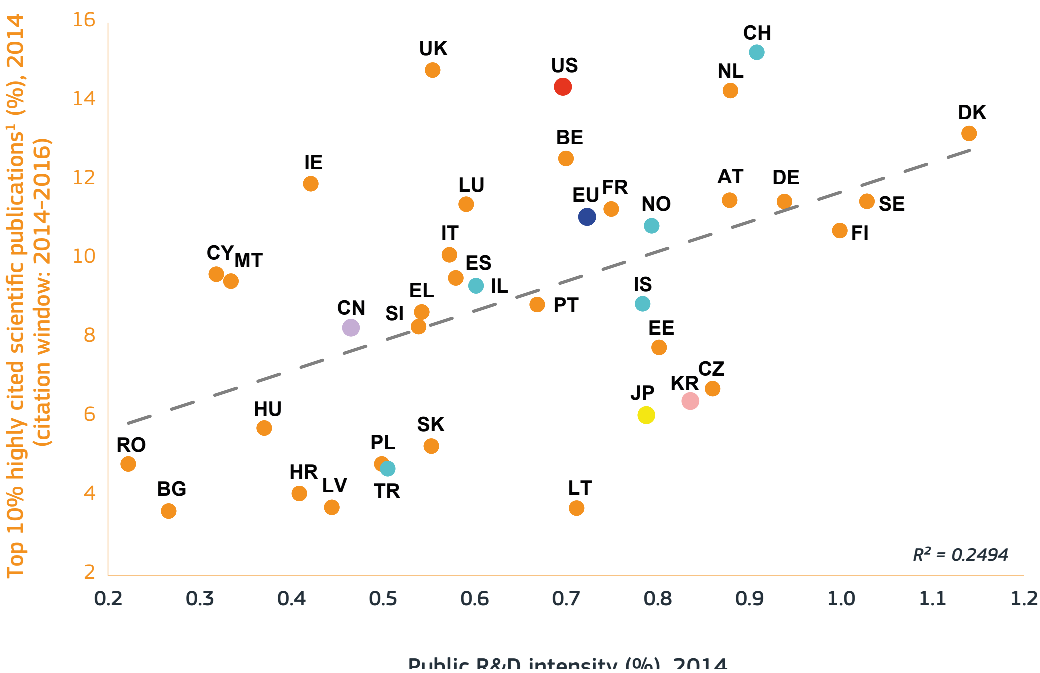


Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research and Innovation Policies
Data: DG Research and Innovation (CORDA database)
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/parti/i_4-a_figures/f_i_4-a_6.xlsx

Despite progress in building up excellence in EU science, numerous ERA countries punch below their public R&D weight, suggesting persistent weaknesses in building more impactful research excellence which requires sustained investments and efficient reforms of the public research systems to increase the quality and impact.

At the global level, where the share of total publications among the 10% most-cited worldwide is concerned, the United States makes a higher scientific impact than the EU, despite its slightly lower public R&D intensity, while South Korea and Japan show relatively low levels of scientific quality in relation to their public investments (see Figure I.4-A.7). In Europe, weaker research excellence in Central and Eastern European countries confirms the persistence of an East-West science divide, with Mediterranean countries ranked just in the middle (although below the EU average). Simultaneously, a positive correlation between investments and scientific quality is evident for most countries. Switzerland, Denmark, Sweden, Germany, the Netherlands, Austria and France enjoy higher levels of public investments in R&D than the EU average, as well as better scientific results. Eastern European countries have below-EU-average investment levels matched with equally low levels of scientific excellence.

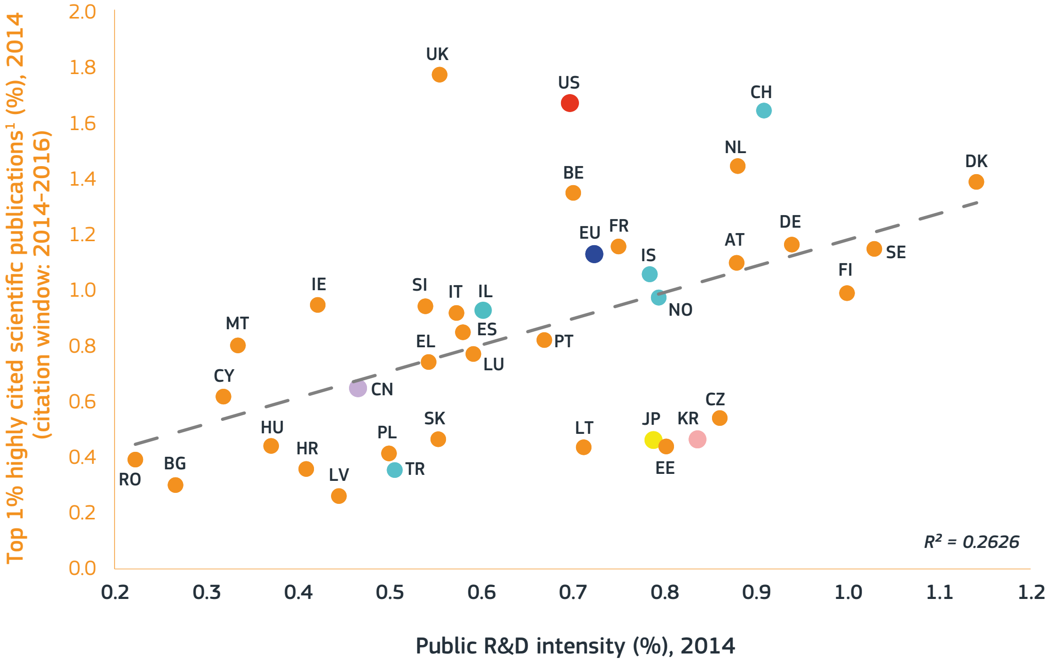
Figure I.4-A.7 Public R&D intensity, 2014 and top 10% highly cited scientific publications[1] 2014 (citation window: 2014-2016)



Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research and Innovation Policies
Data: CWTS based on Web of Science database
Note: [1]Scientific publications within the 10% most cited scientific publications worldwide as % of total scientific publications of the country; fractional counting method.
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/parti/i_4-a_figures/f_i_4-a_7.xlsx

However, it should also be noted that the UK, Belgium and Ireland perform significantly better than would be expected from their public R&D investment levels. Conversely, the resources put into public research in countries like Estonia, the Czech Republic, Lithuania or Iceland do not appear to lead to sufficiently high-quality results. Interestingly, the trends described above are confirmed by looking at the top 1% of highly cited publications in relation to countries' public investments (see Figure I.4-A.8).

Figure I.4-A.8 Public R&D intensity, 2014 and top 1% highly cited scientific publications[1] 2014 (citation window: 2014-2016)



Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research and Innovation Policies
Data: CWTS based on Web of Science database
Note: [1]Scientific publications within the 1% most cited scientific publications worldwide as % of total scientific publications of the country; fractional counting method.
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/parti/i_4-a_figures/f_i_4-a_8.xlsx

The diversity of the European research landscape is explained not only by the levels of national R&D investment but also by their effectiveness. Countries which systematically pursue a better quality and impact of their public science base through sustained public investments and structural reforms of their national science and innovation systems[1] tend to be those that extract the maximum from their public R&D investments. The Horizon 2020 Policy Support Facility supports the design, evaluation and implementation of such national reforms[2].

Since the globalisation of research has intensified over the last decade, particularly collaborative research, international co-publications are becoming increasingly significant in fostering the production of new knowledge worldwide and stimulating positive impacts in scientific performance.

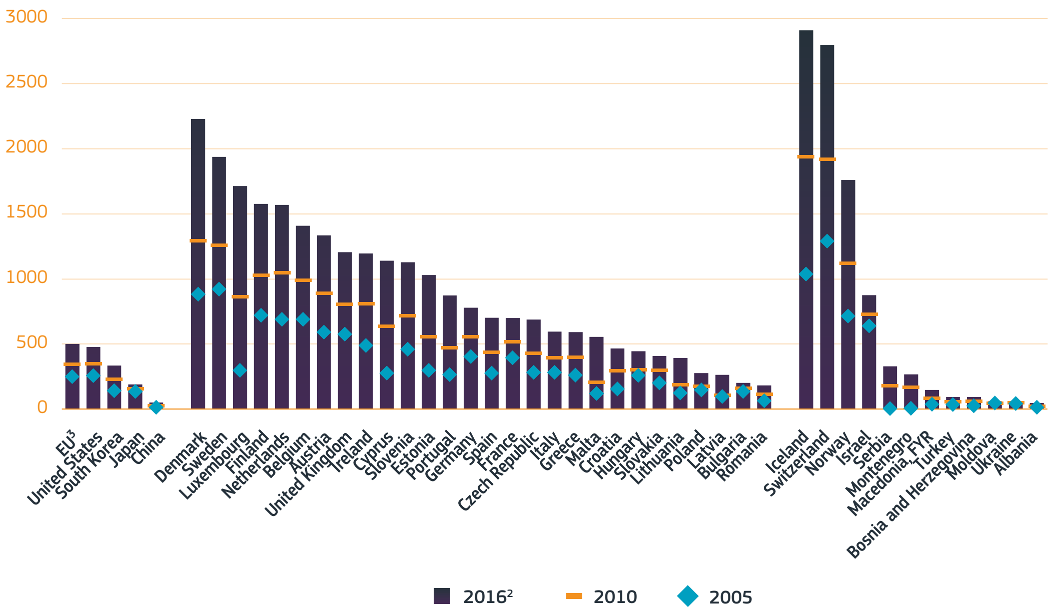
All ERA countries have steadily increased their share of international co-publications since 2000, a trend that is also confirmed at the global level for the United States and Asian economies (see Figure I.4-A.9). Several Eastern European countries (Poland, Slovakia, Romania and Bulgaria) have lower levels of international exposure and collaboration, and some of their researchers enjoy less international mobility. While the low level of excellence in some of these countries does not provide opportunities for international collaboration, it is also clear that the low level of internationalisation has an impact on the level of scientific excellence, leading to lower scores in highly cited scientific publications in these countries. On the other hand, research-intensive countries, both large (such as the United States, UK, Germany and France) and small (like the Netherlands, Switzerland and Denmark) enjoy higher levels of international collaboration coupled with higher scores in quality science. In short, open research systems perform better in scientific quality since scientists achieve greater impact from their international collaborations.

International collaboration in science is becoming increasingly important and leads to improved scientific quality, as measured by the publications' citation impact. This is confirmed by the fact that the citation impact of international co-publications is greater than that of single-country publications for all countries (see Figure I.4-A.10).

1 Such reforms include aspects such as: the establishment of adequate mechanisms to reward, through public funding, a higher research performance by institutions; effective incentives for researchers and institutions to perform high-quality and impactful research; policies that combat the fragmentation of national science and higher education systems; optimisation of the institutional environment of public institutions performing R&D to facilitate collaborative research and cooperation with industry; strategies to improve international scientific collaboration and researcher mobility; and public action in support of knowledge transfer.

2 The Horizon 2020 Policy Support Facility (PSF) gives Member States and countries associated to Horizon 2020 practical support to design, implement and evaluate reforms that enhance the quality of their R&I investments, policies and systems (https://rio.jrc.ec.europa.eu/en/policy-support-facility).

Figure I.4-A.9 International scientific co-publications[1] per million population, 2005, 2010 and 2016



Science, Research and Innovation performance of the EU 2018

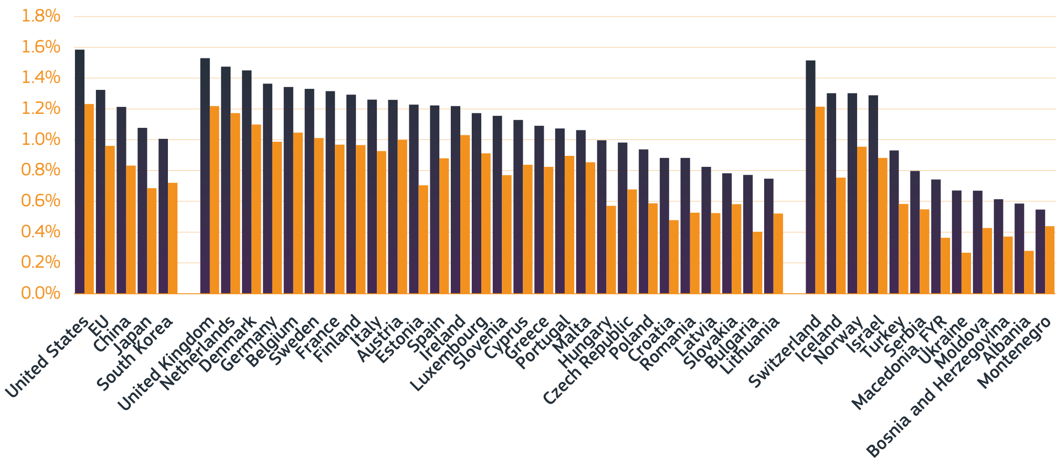
Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research and Innovation Policies

Data: CWTS based on Web of Science database

Notes: [1]Scientific publications with at least one co-author based abroad. [2]AL, BA, UA, IL, US, JP, CN, KR: 2015.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/parti/i_4-a_figures/f_i_4-a_9.xlsx

Figure I.4-A.10 Citation impact[1] of scientific publications, 2014 (citation window: 2014-2016)



Science, Research and Innovation performance of the EU 2018

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research and Innovation Policies
Data: CWTS based on Web of Science database
Note: [1]Citation impact normalised by field and publication year (ratio of the average number of citations received by the considered papers 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/parti/i_4-a_figures/f_i_4-a_10.xlsx

Global higher education rankings are increasingly perceived and used as the international measure of impactful scientific research and teaching quality. The EU has more 'world-class' universities among the top 500 institutions while the United States still leads in the top 100, as measured by the two most popular rankings.

After periods of strong massification of higher education institutions, and with the advance of their globalisation and marketization, over the last 15 years, more and more attention has been paid to their internationally measured performance. The Academic Ranking of World Universities[3] (ARWU), also called the Shanghai Ranking, and the Times Higher Education (THE) ranking are currently the most-quoted university rankings in the world.

Although the validity and impact of a growing number of league tables with international university rankings is still being debated, many higher education institutions use them to inform strategic decisions or shape priorities, and being in the 'top 100' is widely defined as a national or institutional strategy. Visibility in international rankings is naturally associated with universities' capability to conduct globally impactful, excellent scientific research, and gives them 'world-class' status.

According to ARWU, 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), the EU has more universities (182) in the top 500 than the United States (135), a number which has been stable since 2005 (see Figure I.4-A.11). However, the United States still slightly outperforms the EU in the top 500 universities per million population, has a higher number of universities in the top 100, and holds 8 of the top 10 ranks. The EU, on the other hand, outperforms South Korea, Japan and China (which in the ARWU includes Hong Kong, Macao and Taiwan) in terms of top institutions per million population (see Figure I.4-A.12). Leading EU countries in terms of the ARWU top 500 institutions per million inhabitants are Sweden, Finland and Denmark. Portugal has improved its performance most since 2010, while the performance of Finland, Austria, Italy and Hungary has declined. The Baltic States (except Estonia), Bulgaria, Romania, Croatia, Cyprus, Luxembourg, Malta[4] and Slovakia do not have a university among the top 500 worldwide, while Romania, Croatia, Luxembourg, Slovakia and Lithuania have institutions ranked in the top 800 of the ARWU.

The THE, established in 2004, has a broader scope and also includes indicators on teaching, international outlook and industry income (and hence knowledge transfer). As regards research, it includes subjective factors, too, such as reputation. As a result, while international performance patterns are broadly similar compared to the ARWU, the EU comes out better than the United States in areas like teaching and internationalisation.

In the THE ranking, the EU has nearly twice as many top 500 institutions as the United States which still outperforms the EU in the top 100 of the ranking (see Figure I.4-A.13). However, while two American institutions (Harvard and Stanford) are in the lead in the ARWU, the THE ranking lists Oxford and Cambridge as the world's top universities.

According to the THE ranking, Luxembourg is the best EU performer in the top 500 universities per million population (with one institution), followed by Ireland, Finland, Denmark and Sweden (see Figure I.4-A.14). The majority of Central and Eastern European Member States do not have universities in the THE top 500 (Estonia and Hungary being the only exceptions).

3 The Academic Ranking of World Universities (ARWU) was first published by the Graduate School of Education of the Shanghai Jiao Tong University in June 2003 and has been updated since on an annual basis.

4 It should be noted that Malta and Luxembourg have only one university (Malta has two higher education institutions). In total, there are about 3300 higher education institutions in the EU.

Figure I.4-A.11 Number of top 100 and top 500 universities in the Shanghai ranking

	Top 100 universities				Top 500 universities			
	2005	2010	2015	2017	2005	2010	2015	2017
EU[1]	30	28	29	28	191	191	192	182
United States	53	54	51	48	168	154	146	135
China	-	-	-	2	18	34	44	57
Japan	5	5	4	3	34	25	18	17
South Korea	-	-	-	-	8	10	12	12

Science, Research and Innovation performance of the EU 2018

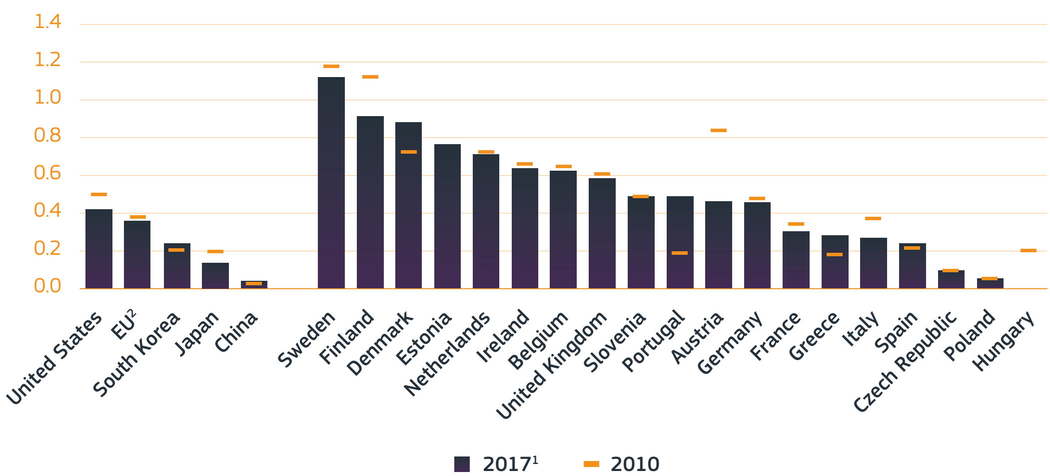
Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research and Innovation Policies

Data: Shanghai rankings (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/parti/i_4-a_figures/f_i_4-a_11.xlsx

Figure I.4-A.12 Number of top 500 universities in the Shanghai ranking per million population[1], 2010 and 2017



Science, Research and Innovation performance of the EU 2018

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research and Innovation Policies

Data: Shanghai rankings (http://www.shanghairanking.com/)

Notes: [1]Population refers to 2016 for all countries except US, JP, CN, and KR in respect of which population refers to 2015.

[2]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/parti/i_4-a_figures/f_i_4-a_12.xlsx

Figure I.4-A.13 Number of top 100 and top 500 universities in the Times Higher Education World university rankings

	Top 100 universities			Top 500 universities		
	2016	2017	2018	2016	2017	2018
EU[1]	40	36	35	228	226	225
United States	39	41	43	122	120	125
China	2	2	2	11	12	12
Japan	2	2	2	11	12	10
South Korea	1	2	2	11	11	11

Science, Research and Innovation performance of the EU 2018

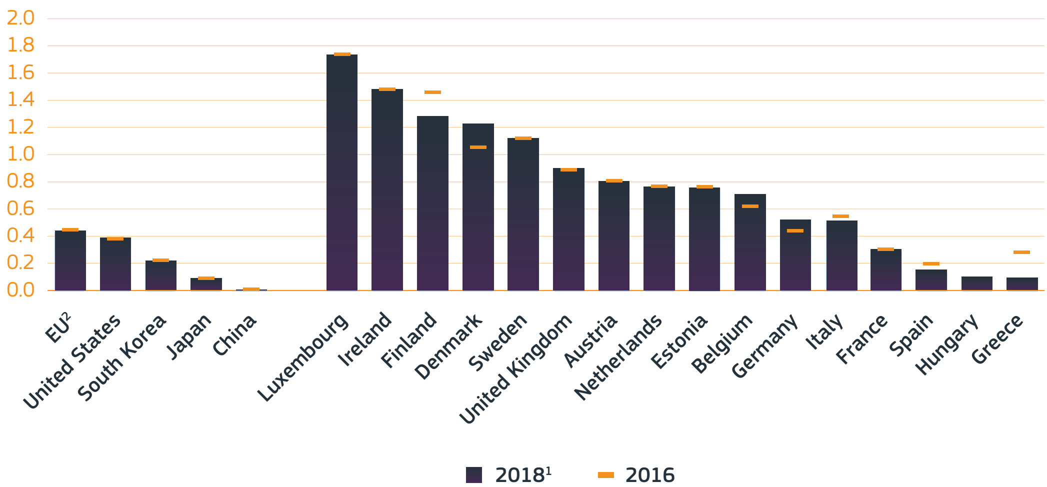
Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research and Innovation Policies

Data: Times Higher Education - World university rankings (https://www.timeshighereducation.com/world-university-rankings/2018)

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/parti/i_4-a_figures/f_i_4-a_13.xlsx

Figure I.4-A.14 Number of top 500 universities in the Times Higher Education World university rankings per million population[1], 2016 and 2018



Science, Research and Innovation performance of the EU 2018

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research and Innovation Policies

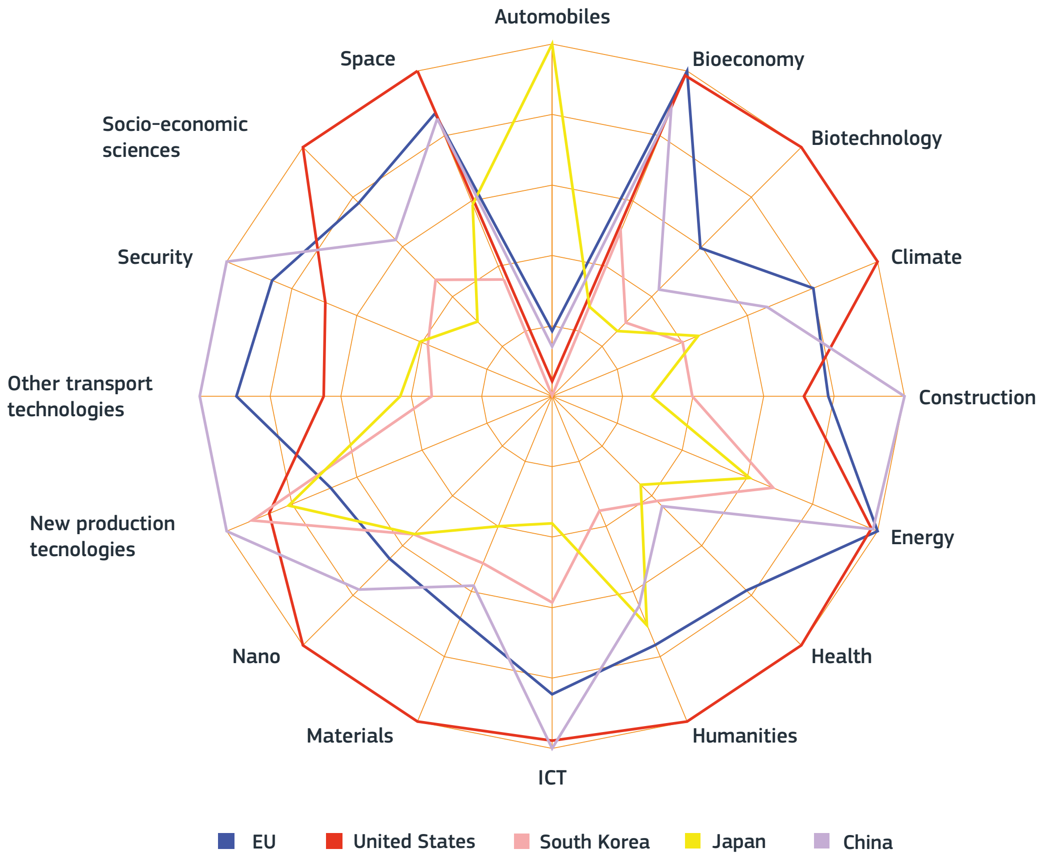
Data: Times Higher Education - World university rankings (https://www.timeshighereducation.com/world-university-rankings/2018)

Notes: [1]Population refers to 2016 for all countries except US, JP, CN, and KR in respect of which population refers to 2015.

[2]EU was estimated by DG Research and Innovation based on the data available for the Member States.

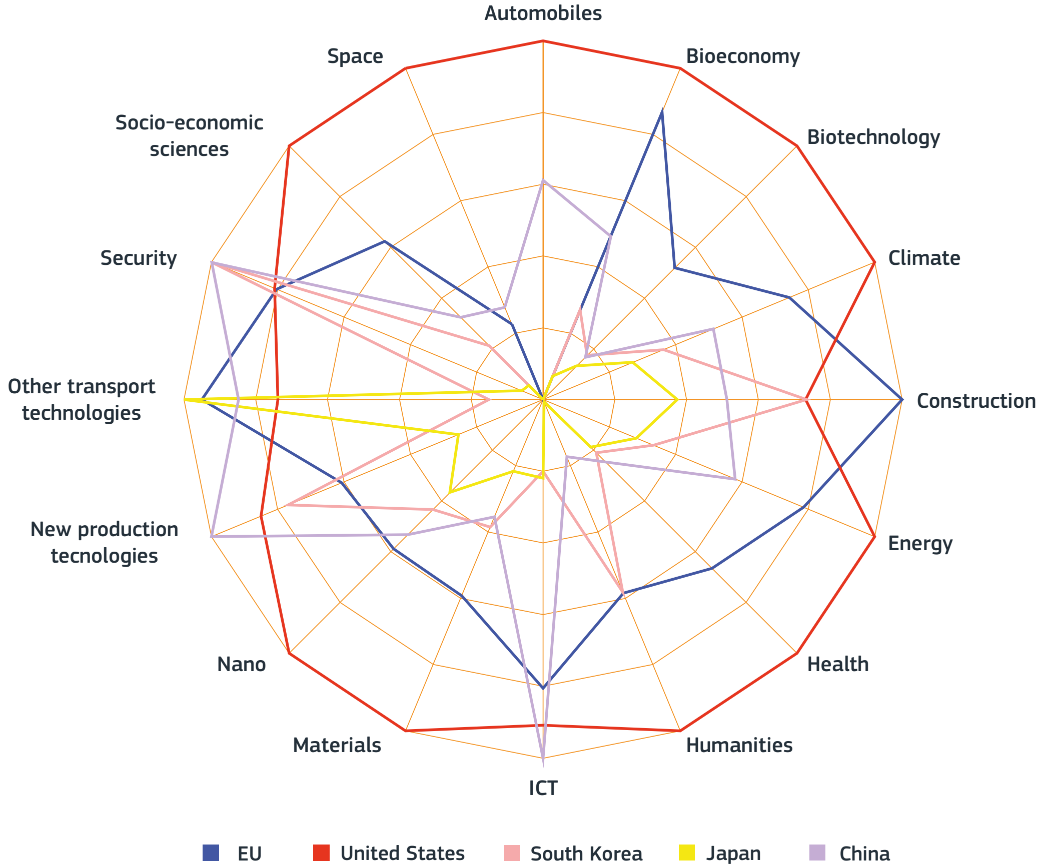
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/parti/i_4-a_figures/f_i_4-a_14.xlsx

Figure I.4-A.15 Top 10% highly cited scientific publications[1], by sector, 2014 (citation window: 2014-2016)



Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research and Innovation Policies
Data: CWTS based on Web of Science database
Note: [1]Scientific publications within the 10% most cited scientific publications worldwide as a % of total scientific publications of the country; fractional counting method.
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/parti/i_4-a_figures/f_i_4-a_15.xlsx

Figure I.4-A.16 Top 1% highly cited scientific publications[1], by sector, 2014 (citation window: 2014-2016)



Science, Research and Innovation performance of the EU 2018

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research and Innovation Policies

Data: CWTS based on Web of Science database

Note: [1]Scientific publications within the 1% most cited scientific publications worldwide as a % of total scientific publications of the country; fractional counting method.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/parti/i_4-a_figures/f_i_4-a_16.xlsx

CHAPTER I.4-B: KNOWLEDGE FLOWS

Knowledge diffusion has always been crucial to support the creation and dissemination of innovation across companies, sectors and countries. Against a backdrop where innovation diffusion from leading to laggard firms seems to stall our economies' productivity, knowledge flows become even more important.

Recent work by the OECD (2015)[5] shows that over the past decade the productivity gap between frontier and laggard firms has widened. One of the main reasons for this is the persistently insufficient diffusion of technologies and innovations across firms and countries, both between and within sectors. Consequently, understanding the dynamics of knowledge diffusion is critical to make a proper assessment of innovation performance.

Innovation diffusion depends on three principles: (i) Open Science (ii) Open Innovation and (iii) Open to the World.

This chapter analyses how knowledge is disseminated in the EU through different channels. More precisely, innovation diffusion depends on three principles: (1) *Open Science*, with scientific outputs being used and integrated more and more widely to produce faster and more impactful scientific advances; (2) *Open Innovation*, with robust and strong science-business linkages; and (3) *Open to the World*, with knowledge flowing freely and not limited to territorial boundaries. These principles guide the European research[6] policy and will form the basis of the analyses of knowledge flows presented in this chapter.

Open Science

This section looks at the progress achieved in making science more open in Europe, notably through better open access to scientific publications and greater mobility of researchers across institutions. In an ever-more globalised and knowledge-driven world, in which data is increasingly valuable and considered as a competitive advantage[7], it is key to ensure that advances in science and technology are open as far as possible. This makes the scientific discovery process increasingly robust as, for example, it allows for an easier verification and replication of research results.

Overall, and despite still lagging behind the United States, European science is becoming increasingly more open-access oriented, with significant progress across all Member States.

The trend towards providing a wider audience with access to scientific output has continued for decades, driven by the growth of ICT, amongst others, making data and knowledge increasingly accessible beyond national

5 OECD (2015), The Future of Productivity, OECD Publishing, Paris. See also, Chapter II.1 of this report for a recent update on the work by the OECD in this field.

6 European Commission (2016a). Open Innovation, Open Science, Open to the World - a Vision for Europe. DG Research and Innovation.

7 http://europa.eu/rapid/press-release_SPEECH-11-872_en.htm?locale=en

boundaries. For years, the European Commission has actively supported creating the right conditions for open access in Europe, e.g. via the creation of a European Open Science Cloud or the 2012 Recommendation on open access policies relating to scientific research funded by public funds[8]. This was also reinforced by the Amsterdam Call for Action on Open Science in 2016[9,10]. The EU distinguished between two forms of open access: gold (open access publishing) and green (not published in an open access journal but self-archived)[11].

As shown in figure I.4-B.1, although EU scientific publications are becoming increasingly open, the EU is still lagging behind the United States and a few associated countries such as Switzerland, Iceland, Norway, Macedonia, Serbia and Bosnia and Herzegovina. This is mainly driven by the differences between the Member States, given that central European and Nordic countries report a larger share of open access publications than the rest of the EU. However, overall a positive trend can be observed across all countries, with the exception of Croatia, Bosnia and Herzegovina and Montenegro. The graph also shows differences in the relative share of gold versus green open access publications, with a higher relative share of gold open access in the lower-performing countries, both in the EU and internationally.

Another relevant channel for scientific diffusion is linked to the mobility of researchers and scientists. When moving from one job to the next, the knowledge acquired by individuals is disseminated in the new workplace. Every year, Eurostat collects statistics related to the mobility of human resources in science and technology (HRST)[12] via the EU Labour Force Survey. Figure I.4-B.2 presents the number of scientists who changed jobs in two consecutive time periods as a share of the total human resources in science and technology available in a country in the initial period.

8 European Commission (2012a). Commission Recommendation of 17.7.2012 on access to and preservation of scientific information. C(2012) 4890 final.

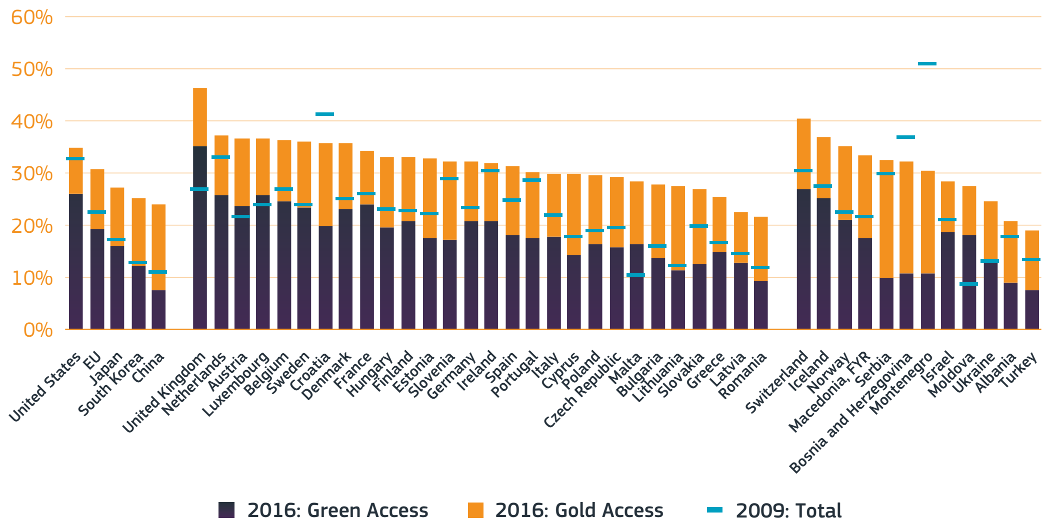
9 European Commission (2016b) European Cloud Initiative: Building a competitive data and knowledge economy in Europe.

10 See also Amsterdam Call for Action on Open Science, 2016: https://www.government.nl/documents/reports/2016/04/04/amsterdam-call-for-action-on-open-science

11 European Commission (2012b). Towards better access to scientific information: Boosting the benefits of public investments in research. COM(2012) 401 final.

12 Job-to-job mobility HRST are individuals who have changed employers during the last year, and fulfil the condition of being employed HRST, i.e. (1) they have successfully completed education at the third level and are employed in any kind of job; or (2) they are not formally qualified as above but are employed in an occupation where the above qualifications are normally required – for more details: http://ec.europa.eu/eurostat/statistics-explained/index.php/Glossary:Human_resources_in_science_and_technology_(HRST).

Figure I.4-B.1 Open access scientific publications[1] with digital object identifier (DOI) as % of total scientific publications with DOI, 2009 and 2016



Science, Research and Innovation performance of the EU 2018

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research and Innovation Policies

Data: CWTS based on Web of Science database

Note: [1]Open access publications are online publications that are freely available to the reader.

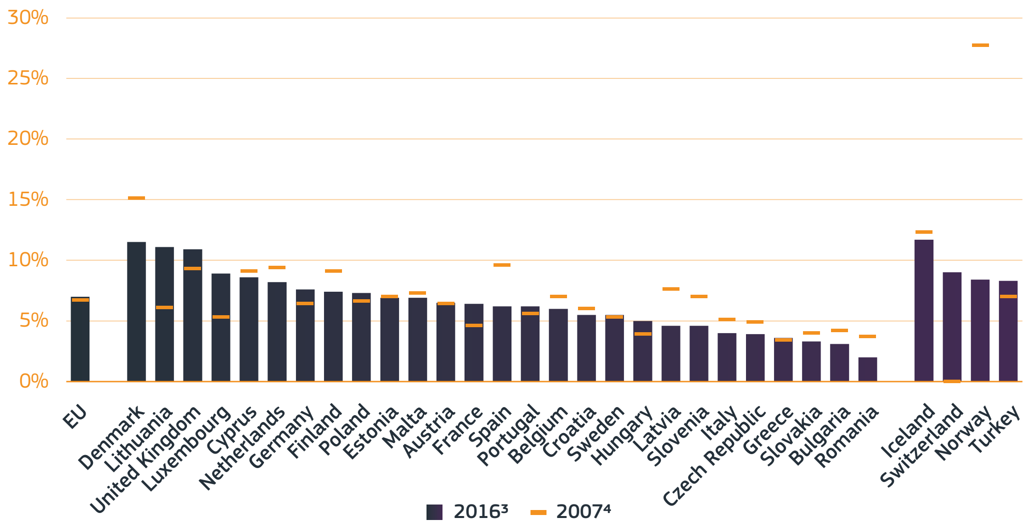
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/parti/i_4-b_figures/f_i_4-b_1.xlsx

While HRST mobility has remained broadly stable at the EU level, there are significant differences across Member States where a mixed pattern can be observed, suggesting a divide between the core and the periphery, which appears to widen over time.

Between 2007 and 2016, most of the decline in job-to-job mobility of HRST can be observed in Eastern and some Southern Member States, while remaining roughly stable for the EU as a whole. As can be seen in Figure I.4-B.2, Member States which already had a lower share of mobile researchers reduced that share even further, with the exception of a few countries where increased mobility can be observed. In some cases, the share of mobile researchers declined significantly in countries where mobility was relatively high, such as Denmark, Spain and Norway. Conversely, research mobility increased more significantly in Lithuania, Luxembourg, the UK, Germany, France and Hungary. In general, a divide can be detected between the core and the periphery, with a widening trend over time. These patterns might be the result of various factors, including the effects of the crisis or brain-drain phenomena – the latter notably in Bulgaria, Romania and Slovakia – which has been attributed to, amongst others, increased competition linked to the opening of labour markets[13,14]. Thus, finding a good balance between flexible and secure labour markets is an important precondition to enable workers to overcome obstacles to mobility between jobs and sectors, as well as creating attractive conditions for research and science to encourage mobile workers to return to their home countries to take full advantage of this exchange of knowledge. Public policy has proven to be a catalyst of such mobility, as discussed in Chapter I.5. on Framework Conditions.

At the European level, the Marie Skłodowska-Curie Actions (MSCA) are relevant in supporting the attraction and mobility of highly skilled researchers by providing more high-quality training and career development for researchers and their career mobility between academia and non-academia.

Figure I.4-B.2 Job-to-job mobility[1] of human resources in science and technology (HRST)[2] as % of total HRST, 2007 and 2016



Science, Research and Innovation performance of the EU 2018

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research and Innovation Policies
Data: Eurostat
Notes: [1]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: Persons with tertiary education and/or employed in science and technology. [3]CH: 2015. [4]BG: 2008.
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/parti/i_4-b_figures/f_i_4-b_2.xlsx

13 Doria Arrieta, O., Pammolli, F. and Petersen, A. (2017). Quantifying the negative impact of brain drain on the integration of European science. Science Advances. 3. 10.1126/sciadv.1602232.
14 European Commission (2016c). European Research Area Progress Reports: Technical Report. DG Research and Innovation.

Open innovation

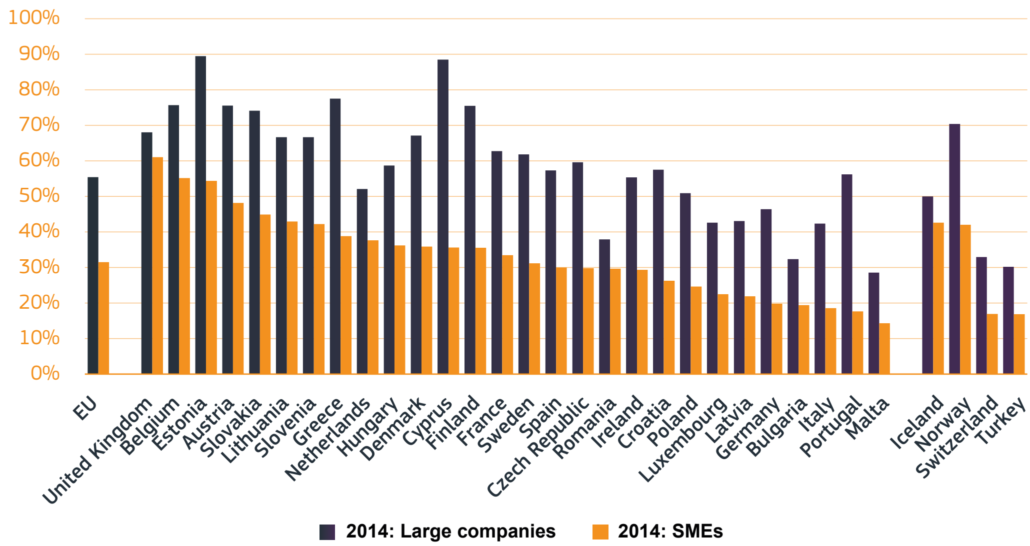
One of the most impactful channels for knowledge diffusion is the cooperation between businesses and other businesses and science. Eurostat produces the Community Innovation Survey which asks companies if in the past three years they were engaged with third parties in cooperation related to the introduction of product or process innovations, and what type of partners were involved in these cooperations.

Across the EU, large companies engage more in cooperation activities with third parties than SMEs. However, the degree of cooperation varies widely across Member States.

Figure I.4-B.3 provides an overview of business cooperation, showing the overall share of innovative enterprises involved in any type of cooperation with other enterprises or organisations[15]. However, while there are many forms of cooperative activities, the below analysis will focus mostly on business cooperation with research institutions, such as (i) universities or other higher education institutions; (ii) governments, public and private research institutes; as well as (iii) their competitors. It is not surprising to note that SMEs have a lower cooperation rate with third parties than large companies. However, the differences between Member States are striking. When examining whether companies are cooperating at all, no general pattern is observed. Indeed, while Germany and Luxembourg are surprisingly underperforming compared to other Member States, Estonia, Slovakia, Lithuania, Slovenia and Greece have relatively high levels of cooperation. In general, in countries with higher levels of cooperation among large companies, SMEs also cooperate more.

15 This includes cooperation with (1) enterprises from the same group; (2) suppliers of equipment, materials, components or software, with customers from the; (3) private; or (4) public sectors; with (5) competitors or other enterprises from the same sector; with (6) consultants or commercial labs; with (7) universities or other higher education institutes; and with (8) government, public or private research institutes.

Figure I.4-B.3 % share of innovative enterprises[1] involved in any type of cooperation, 2014



Science, Research and Innovation performance of the EU 2018

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research and Innovation Policies

Data: Eurostat (CIS 2014)

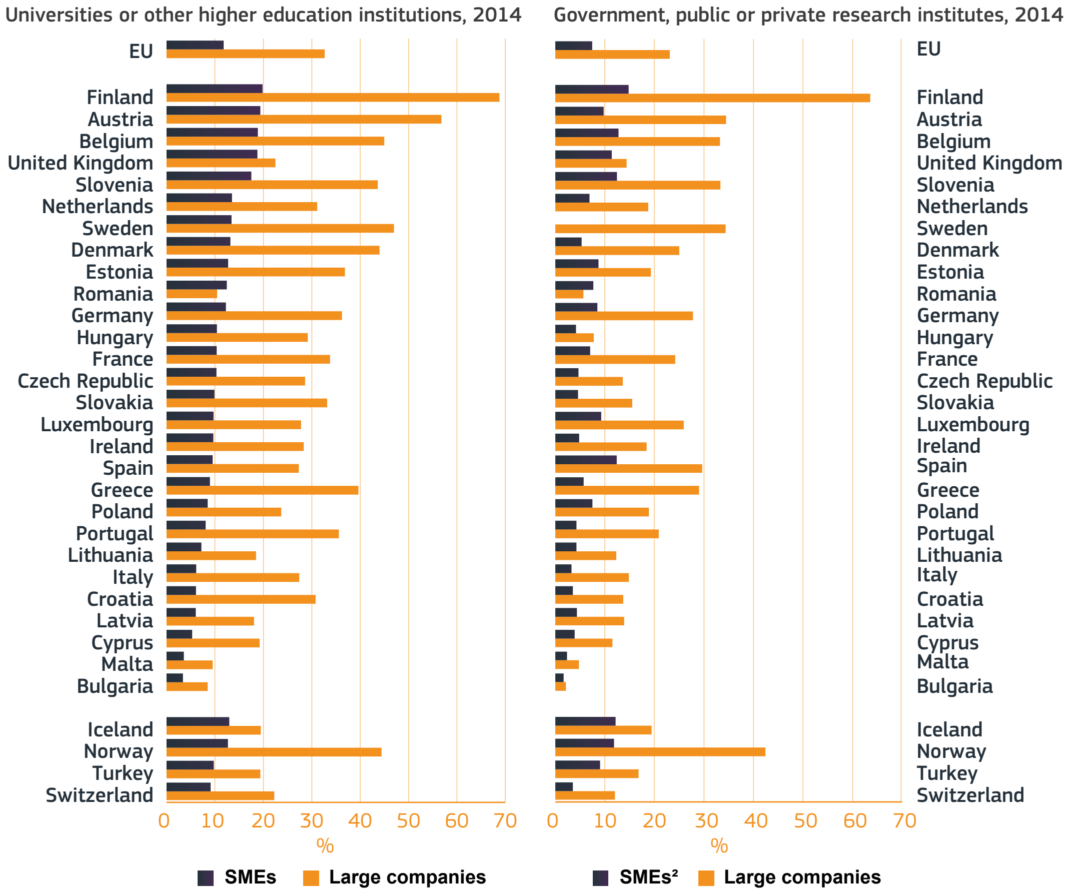
Note: [1]Product and/or process innovative enterprises, regardless of organisational or marketing innovation (including enterprises with abandoned/suspended or ongoing innovation activities).

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/parti/i_4-b_figures/f_i_4-b_3.xlsx

Although not clear-cut, a divide between the EU's core and periphery appears to be emerging when focusing on cooperation patterns with universities and higher education institutions, as well as with governments and public and private research institutions. This is also true for business cooperation with competitors or other enterprises in the same sector.

Countries such as Finland, Belgium, Austria and the UK report the highest cooperation shares between SMEs and universities and higher education institutes, as well as government, public and private research institutions. Many Eastern European countries also report relatively high cooperation levels, such as Slovenia, Estonia, Romania and Hungary. The bottom of the distribution is made up of a mix of Eastern and Southern European countries, with Malta and Bulgaria reporting the lowest values (see Figure I.4-B.4). A similar pattern can be observed when looking at the share of cooperation with competitors or other enterprises in the same sector, with some notable exceptions, such as Greece, which has a relatively high share of this kind of cooperation among SMEs, while Germany is at the bottom of the distribution (see Figure I.4-B.5).

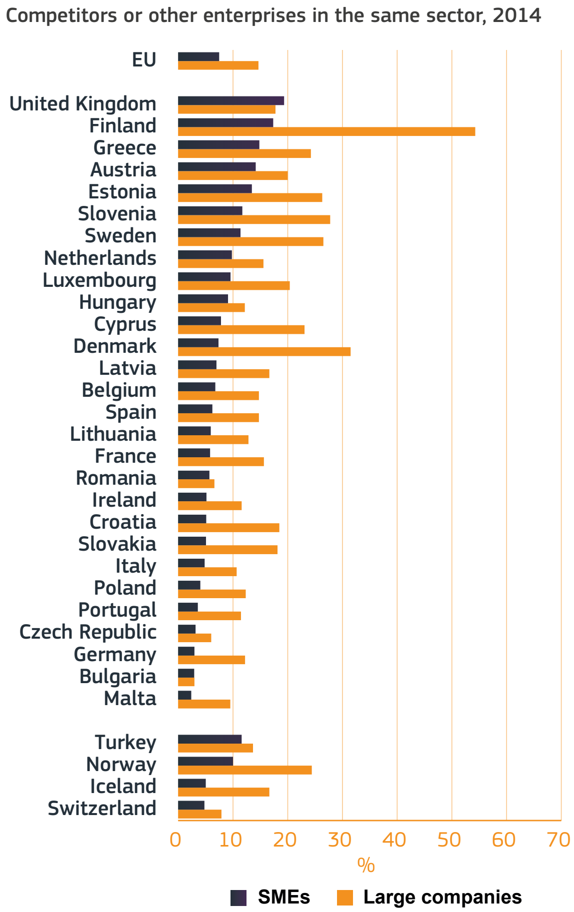
Figure I.4-B.4 % share of innovative enterprises[1] cooperating with:



Science, Research and Innovation performance of the EU 2018

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research and Innovation Policies
Data: Eurostat (CIS 2014)
Notes: [1]Product and/or process innovative enterprises, regardless of organisational or marketing innovation (including enterprises with abandoned/suspended or ongoing innovation activities). [2]EU average does not include Sweden.
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/parti/i_4-b_figures/f_i_4-b_4.xlsx

Figure I.4-B.5 % share of enterprises cooperating with:



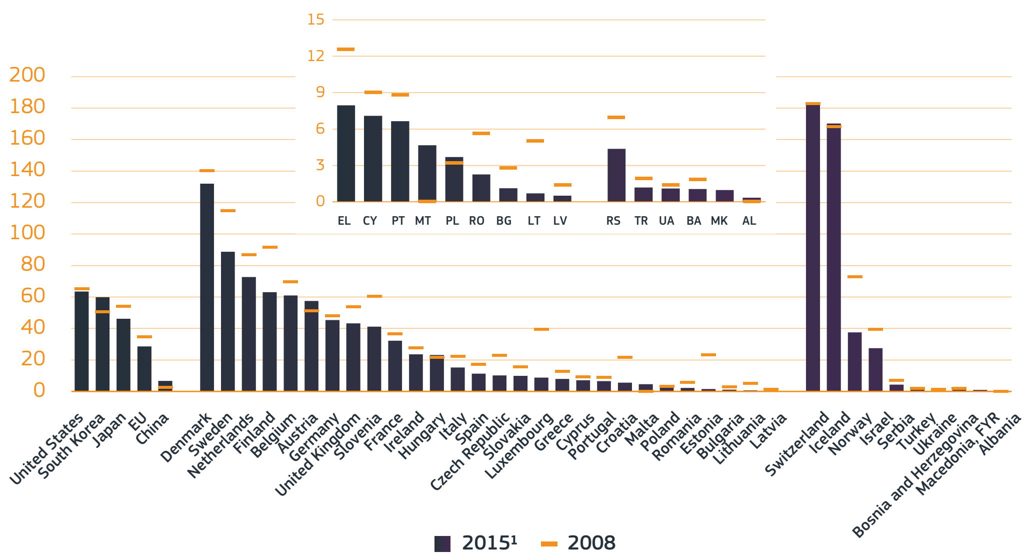
Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research and Innovation Policies
Data: Eurostat (CIS 2014)
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/parti/i_4-b_figures/f_i_4-b_5.xlsx

The number of public-private co-publications has fallen slightly in the EU and continues to lag behind the United States, Japan and South Korea, although this aggregate value masks large differences across Member States, especially between countries in the EU's core and periphery.

Figure I.4-B.6 depicts the number of public-private co-publications per million of population for the EU, its main competitors and associated countries. While for the EU as a whole the indicator fell between 2008 and 2015 (34.7 and 28.7 respectively), more variation can be observed when looking at the Member-State level. Overall, it can be seen that the EU is a long way behind the United States (63.4 in 2015), South Korea (59.9) and Japan (46.2). There is also a clear divide between Central and Northern, and Eastern and Southern European countries, with the former performing considerably better. The gap is striking when looking at the best-and worst-performing countries, with Denmark (132) and Sweden (88.7) at the top, and Latvia (0.5), Lithuania (0.7) and Bulgaria (1.1) at the bottom. As regards the Southern European countries, Italy is the best performing with 15.2 co-publications per million population, while Malta is the worst with 4.7[16].

The drivers of these striking differences can be found in 'push' factors relating to the quality of the scientific research performed by universities and public research organisations as well as to the institutional environment of government and public scientific institutions. This includes governance arrangements and the incentive mechanisms in place to engage in this type of cooperation. However, 'pull' factors related to firms' scientific ability to interact with these institutions, and the existence of adequate framework conditions and public support to underpin stronger science-business cooperation can also play their part.

Figure I.4-B.6 Public-private co-authored scientific publications per million population, 2008 and 2015



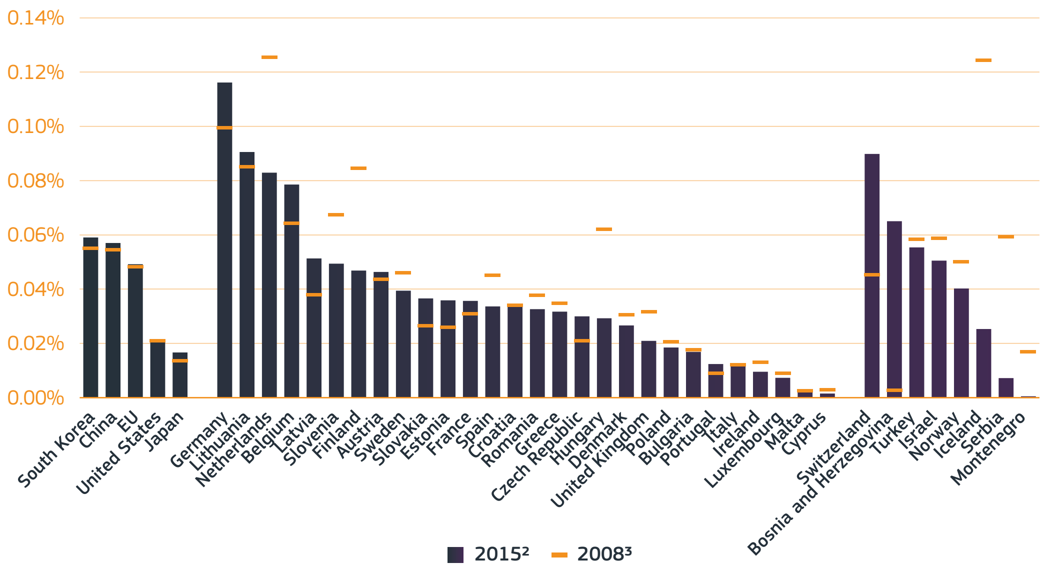
Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research and Innovation Policies
Data: EIS 2016, CWTS based on Web of Science database (March 2017 data), Eurostat, OECD
Note: [1]LV, AL: 2013; US, JP, CN, KR, IL, BA: 2014.
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/parti/i_4-b_figures/f_i_4-b_6.xlsx

16 It must be noted that the analysis does not control for factors such as geography or the R&I system's critical mass.

Public expenditure on R&D financed by business enterprises has risen slightly in the EU since 2008, but there is large heterogeneity among the Member States.

Figure I.4-B.7 shows that while public expenditure on R&D financed by business enterprises as a percentage of GDP has slightly increased overall in the EU since 2008, several Member States report a significant fall in the value. Indeed, the Netherlands, Finland, Hungary and Slovenia report the most significant drops, while a lower but still significant reduction can also be seen in Spain, the United Kingdom, Sweden, Romania, Denmark, Ireland, Greece, Poland, Luxembourg, Cyprus and Bulgaria. Conversely, Germany reports the most significant increase, followed by Belgium, Latvia, Slovakia, Estonia, the Czech Republic, Lithuania, France, Portugal and Austria. Overall, Northern, Central and Eastern European countries have the highest share of public expenditure on R&D financed by business enterprises, although differences between Member States are significant and no clear geographic divide can be observed. Three country clusters can be identified, with the highest values in: (i) Germany, Lithuania, the Netherlands and Belgium ranging between a share of 0.12% and 0.08%, (ii) the middle range reporting shares between 0.05% for Latvia to 0.03% for Denmark, and finally the bottom cluster (iii) ranging between 0.02% for the United Kingdom and 0.002% for Cyprus. On an international scale, the EU outperforms the United States and Japan by far, while performing below the values reported by South Korea and China. For the associated countries, Switzerland and Bosnia and Herzegovina reported the highest values, although still below the values reported for Germany. Overall, while Figure I.4-B.7 shows that the EU is performing well on an international scale for public-private cooperation, the large differences between Member States reveal that there remains a lot of room for improvement to foster linkages between the public and private sectors in most Member States.

Figure I.4-B.7 Public expenditure on R&D financed by business enterprise[1] as % of GDP, 2008 and 2015



Science, Research and Innovation performance of the EU 2018

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research and Innovation Policies

Data: Eurostat, OECD

Notes: [1]Public expenditure on R&D financed by business enterprise does not include financing from abroad. [2]IL: 2013; FR, BA: 2014; EL, IS, RS: 2016. [3]DK, LU, NL, AT, SE, NO, RS: 2009; EL, ME: 2011, BA: 2012.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/parti/i_4-b_figures/f_i_4-b_7.xlsx

Open to the world

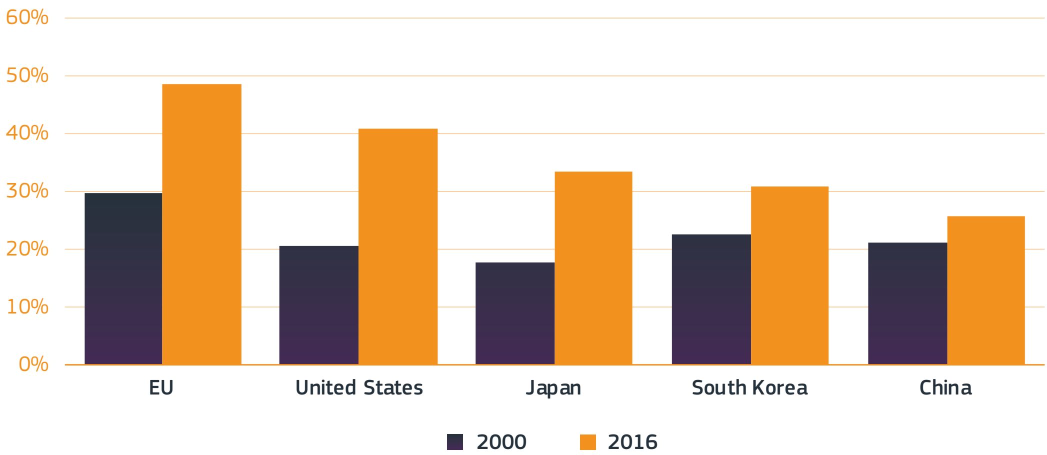
Much of the knowledge created in a country does not stem from within its borders. Greater openness to the world remains crucial to support stronger knowledge flows. It is no longer enough to cooperate with the closest neighbours. New forms of communication and transportation and the global networks being built around the world are creating opportunities for international exposure and more knowledge flows, having a positive effect on the development of a country's science base, its productivity and growth. This encompasses closer cooperation within the ERA and the rest of the world.

Europe continues to be a leading pole in international scientific collaboration which has increased sharply worldwide.

As reported in Figure I.4-B.8, the importance of international collaboration is visible for all countries, having risen significantly from 2000 to 2016. The EU experienced an extraordinary increase in its share of international scientific collaborations (including intra-EU publications) relative to its total publications, from 29.6% to 48.4%, while the rise was even higher in the United States and Japan, from 20.6 % to 40.9% and 17.5% to 33.4%, respectively. Interestingly, unlike all the other countries observed which report a considerable increase in the overall number of scientific publications, Japan is the only country where a fall can be seen, despite the significant increase in the number of international co-publications. a significant rise in international scientific co-publications can also observed in South Korea and China, from 22.5% to 30.8% and 21.1% to 25.6%, respectively, paired with considerable increases in the overall number of scientific publications. While the trend in greater international collaboration is a natural consequence of globalisation, the EU, which actively supports international cooperation in research and science via various initiatives and funding schemes, remains a scientific pole for international cooperation[17].

17 European Commission (2016a).

Figure I.4-B.8 International scientific co-publications as % of total scientific publications, 2000 and 2016



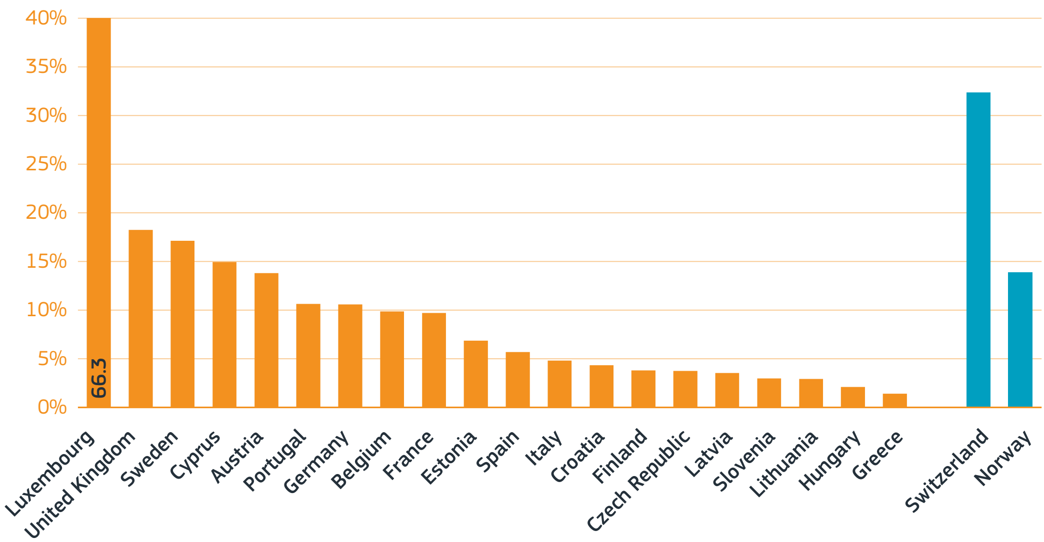
	2000					2016				
	EU[1]	United States	Japan	South Korea	China	EU[1]	United States	Japan	South Korea	China
International scientific co-publications	91,186	54,624	12,918	3,072	5,761	227,471	147,412	23,295	16,156	70,369
Total scientific publications	308,406	265,723	73,686	13,680	27,255	469,826	360,283	69,723	52,509	274,886
% share of interna-tional co-publications	29.6	20.6	17.5	22.5	21.1	48.4	40.9	33.4	30.8	25.6
International co-publication growth[2] (%)						*60*	*63*	*45*	*81*	*92*
Total scientific publi-cations growth[2] (%)						*34*	*26*	*-6*	*74*	*90*

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research and Innovation Policies
Data: CWTS based on Web of Science database
Note: [1]EU average includes intra-EU collaborations. [2]The growth formula used is (y#2016-y#2000)/Y#2000*100.
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/parti/i_4-b_figures/f_i_4-b_8.xlsx

Foreign-born human resources working in science and technology are crucial for European research as they allow international knowledge to flow across countries.

The number of incoming researchers and scientists countries can attract is another relevant source of knowledge. Openness and an attractive scientific environment built on quality public research, competitive wages and solid career prospects for researchers are essential to attract top scientists from abroad. Figure I.4-B.9 reveals disparities across the Member States, with countries such as Luxembourg, the UK, Sweden, Cyprus and Austria, as well as Switzerland and Norway, where foreign-born HRST form an important part of the workforce, and others such as Hungary, Greece, Slovenia, Lithuania and Latvia which report a very low share of researchers from abroad[18].

Figure I.4-B.9 Foreign-born human resources in science and technology core (HRSTC)[1] as % of total HRSTC, 2014



Science, Research and Innovation performance of the EU 2018

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research and Innovation Policies

Data: Eurostat (LFS survey, Migration and labour market module, 2014)

Note: [1]HRSTC: Persons with tertiary education (ISCED) and employed in science and technology.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/parti/i_4-b_figures/f_i_4-b_9.xlsx

18 HRSTC are HRST who fulfil the HRST criteria as well as the criteria of being employed in science and technology occupations.

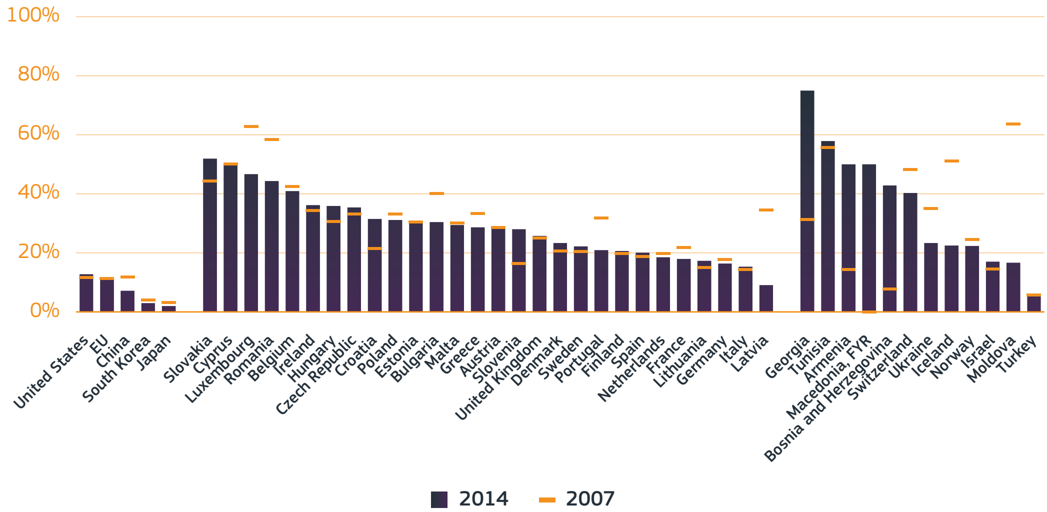
Europe and the United States lead in international technological cooperation, proxied by the share of patents with foreign co-inventors in the total number of patents[19], although large differences can be observed across the Member States.

While for the EU aggregate, the share of patents filed with foreign co-inventors remained roughly stable from 2007 to 2014, large variations can be observed for most Member States. Eastern European countries have the highest share of patents filed with foreign co-inventors, with Slovakia, Cyprus, Luxembourg and Romania reporting the highest values. Unsurprisingly, large countries such as Germany, Italy, France and the Netherlands are at the bottom of the distribution, given that the necessity to cooperate is lower than in small countries. It is therefore more interesting to compare countries of similar size (in population). For example, while Romania has a share of 44.3 % of patents with foreign co-inventors, the Netherlands has 18.5 %, although the countries are of a similar size. Belgium, Hungary and the Czech Republic significantly outperform Sweden and Greece whilst lagging behind values found, for example, in Tunisia. The most striking values can be found for Latvia and Lithuania with particularly low shares of patents filed with foreign co-inventors, especially when compared to associated countries of similar size, such as Georgia. Last but not least, cooperation within the EU is of particular importance for Member States, given that the shares of patents with foreign co-inventors are significantly higher for each Member State, with the exception of Latvia, than those reported for the EU as a whole[20]. Overall, no clear geographic pattern emerges, while the EU as a whole is almost on a par with the United States and performs significantly better than China, Japan and South Korea (Figure I.4-B.10).

19 It should be noted that while this indicator can provide valuable information on international technological cooperation, the numbers should be handled with care, taking into account the small amounts in some cases, notably for small countries, which make values volatile.

20 The EU value is excluding intra-EU cooperation.

Figure I.4-B.10 Share (%) of WIPO-PCT[1] patents with foreign co-inventor(s) in total number of patents[2], 2007 and 2014



Science, Research and Innovation performance of the EU 2018

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research and Innovation Policies
Data: OECD
Notes: [1]Patent Cooperation Treaty (PCT) patents, at international phase designating the European Patent Office. [2]Full counting method used.
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/parti/i_4-b_figures/f_i_4-b_10.xlsx

Foreign direct investment and foreign business research investment

In addition to scientific and technological international cooperation, knowledge also flows via FDIs.

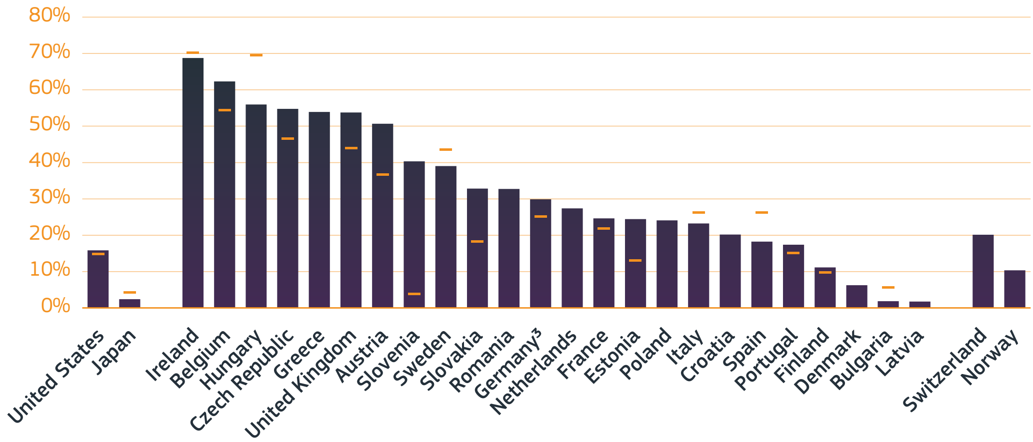
If a company decides to invest into or transfer part of its R&D production to a new location, part of its knowledge will be transferred with it. While knowledge transfer is linked to most forms of foreign investment, the most tangible is via inward BERD (business enterprise research and development expenditure) flows.

Inward BERD[21] (into the EU) shows large variations between Member States, accompanied by a positive general outlook for the EU as a whole.

Figure I.4-B.11 shows that from 2003 to 2013, while the inward flow of BERD (as a percentage of total BERD) has increased for most countries, Ireland, Hungary, Sweden, Italy, Bulgaria and Spain, as well as Japan show a contraction of the share of such investments. Overall, large disparities can be noticed, with Ireland, Belgium, Hungary, the Czech Republic Greece and the UK attracting proportionately the highest shares of BERD from outside and the lowest shares being attracted by Bulgaria, Latvia, Denmark and Finland. Slovenia, Slovakia, Estonia and Austria show a remarkably high increase in the share of BERD inward flows. For a large set of Eastern and Southern European countries BERD inflows as a percentage of GDP, however, continue to be low.

21 R&D expenditure by foreign-owned firms.

Figure I.4-B.11 Inward BERD (R&D expenditure of foreign-owned firms) as % of business expenditure on R&D, 2003 and 2013



2013 Inward BERD	US	JP	IE	BE	HU	CZ	EL	UK	AT	SI	SE	SK	RO	DE
% of BERD	15.9	2.4	68.8	62.3	56.0	54.7	53.9	53.8	50.6	40.4	39.0	32.9	32.7	29.9
% of GDP	0.31	0.06	1.41	1.07	0.54	0.57	0.13	0.57	1.06	0.53	0.89	0.13	0.04	0.58

2013 Inward BERD	NL	FR	EE	PL	IT	HR	ES	PT	FI	DK	BG	LV	CH	NO
% of BERD	27.4	24.6	24.4	24.1	23.2	20.2	18.3	17.4	11.1	6.3	1.9	1.8	20.1	10.3
% of GDP	0.31	0.41	0.14	0.09	0.17	0.08	0.12	0.10	0.29	0.11	0.01	0.01	0.41	0.09

Science, Research and Innovation performance of the EU 2018

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research and Innovation Policies

Data: DG Research and Innovation (BERD flows study)

Notes: [1]LV, HU, RO: 2004; NO: 2005; PL: 2007; NL, CH: 2008; EL: 2009. [2]LV: 2006; IE, DK, PT: 2007; EL, FI: 2011; CH, JP: 2012; CZ: 2014. [3]DE (2013): R&D expenditure on services is not included.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/parti/i_4-b_figures/f_i_4-b_11.xlsx

Trade

Finally, knowledge can be transferred via trade, especially in the form of exports of high-tech and medium-high-tech goods (MHT) and services. However, to adequately assess how much of a country's knowledge has been transferred, it is important to compute the amount of knowledge (proxied here by the value added) that was added by the country itself versus how much knowledge stemmed from foreign contributions. a high share of foreign value added would indicate how much knowledge has flown into the country, while a high share of domestic value added paired with high shares of exports would indicate an outflow of knowledge, which means both can be evaluated positively. Figure I.4-B.12 shows the evolution of foreign value added in high-tech and MHT exports between 2000 and 2011 as a percentage of total exports, as well as now-cast values for 2014.

The importance of foreign created value added in high-tech and MHT exports is crucial in Europe, notably for several Central, Eastern and Southern European countries, for which it is a particularly important source of technological inflows.

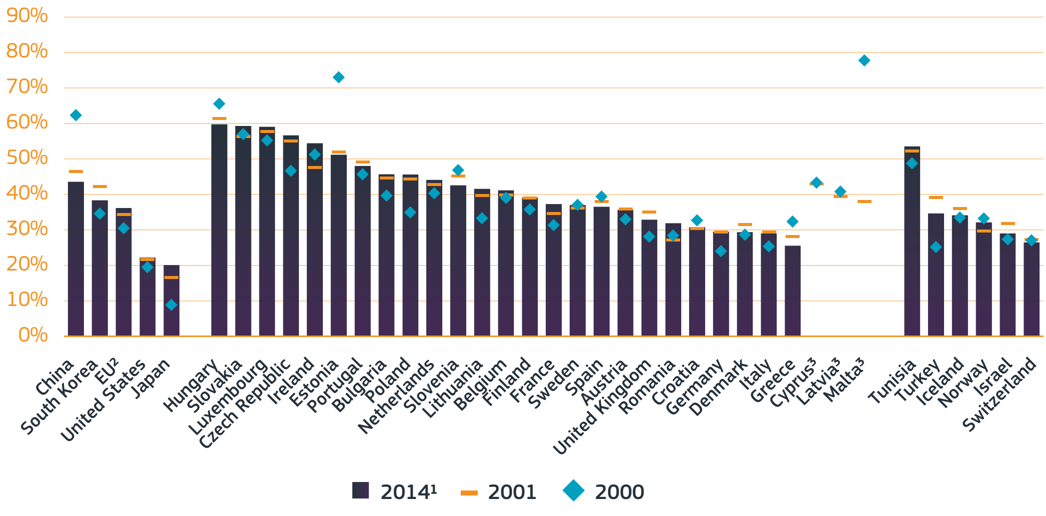
The foreign value added of gross exports in high-tech and MHT sectors, presented in Figure I.4-B.12, shows that China (with 43.6% in 2014) and South Korea (38.4%), as well as the Eastern European countries (59.7% for Hungary and 59.3% for Slovakia), report high shares of foreign value added, while also enjoying both high shares of high-tech and medium high-tech exports (see figure I.4-C.4 for Hungary and Slovakia). In general, an increase in foreign value added in high-tech and MHT goods can be observed for most countries, with the exception of e.g. China, several the Eastern European countries, Greece and to a lesser extent Spain. For highly exporting countries such as China and South Korea, as well as Eastern European countries, around half of the value was added to the goods before entering the country, indicating a large inflow of knowledge. This contrasts with the considerably lower, share of foreign value added in Germany, Denmark, France, the UK, Austria and Sweden, which are thereby exporting their knowledge. China has decreased its foreign value added considerably, which might suggests that it increased its in-house expertise over the past decade and also its production.

This chapter has aimed at analysing the evolution of knowledge flows in and out of the EU. The objective has been to provide nuances to the discussion on why productivity is slowing down and to see whether trends in knowledge flows contribute to the slowdown of innovation diffusion. In general, the flow of knowledge is less smooth in the EU than its international counterparts, and notably the United States.

A lack of *open innovation* can be observed in the EU, as measured by the knowledge transferred between the public and the private sector in the form of public-private co-publications and the share of public R&D expenditure funded by the private sector. The EU lags considerably behind the United States, South Korea and Japan, with no significant evolution in recent years. More positive patterns emerge when the focus is on the *openness of the EU to the world*. As a consequence of globalisation, international scientific collaboration has increased worldwide. The EU continues to act as scientific pole and has been increasing its shares since the 2000s, although during that period the United States experienced a significantly higher rise in international collaborations. This might indicate that the EU is not taking enough advantage of international dynamics. Similarly, it can be observed that, when looking at output as proxied by patents with foreign co-inventors, the EU is not yet taking sufficient advantage of international advances, and still lags behind the United States in spite of a positive trend to close the gap. Overall, while the EU has strong research links with international peers, it is not fully reaping the potential benefits of these links for innovation.

Furthermore, a mixed picture emerges when examining individual Member States. A divide between the core and the periphery can be traced across the Open Science, Open Innovation and Open to the World dimensions, with Eastern European countries standing out and showing important progress. In recent years, discussions about an innovation divide within the EU have emerged[22], with Central and Northern European countries traditionally displaying the best innovation performance (Sweden, Denmark, the Netherlands, the UK and Germany), and the more modest innovators (such as Latvia, Poland, Croatia, Bulgaria and Romania[23]) following. These trends are mirrored when knowledge flows are analysed, although it is also evident that considerable efforts have been made.

Figure I.4-B.12 Foreign value-added share (%) of gross exports in high-tech and medium-high-tech sectors, 2000, 2011 and 2014



Science, Research and Innovation performance of the EU 2018

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research and Innovation Policies

Data: OECD (Trade in Value Added (TiVA)

Notes: [1]The nowcast approach was used for 2014. [2]EU for 2014 was estimated from the available data for Member States and does not include CY, LV and MT. [3]CT, LV, MT: Data are not available for 2014.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/parti/i_4-b_figures/f_i_4-b_12.xlsx

22 Veugelers, R. (2016). The European Union's growing innovation divide. Bruegel, Bruegel policy contribution.

23 European Commission (2017). European Innovation Scoreboard 2017.

CHAPTER I.4-C: INNOVATION OUTPUTS

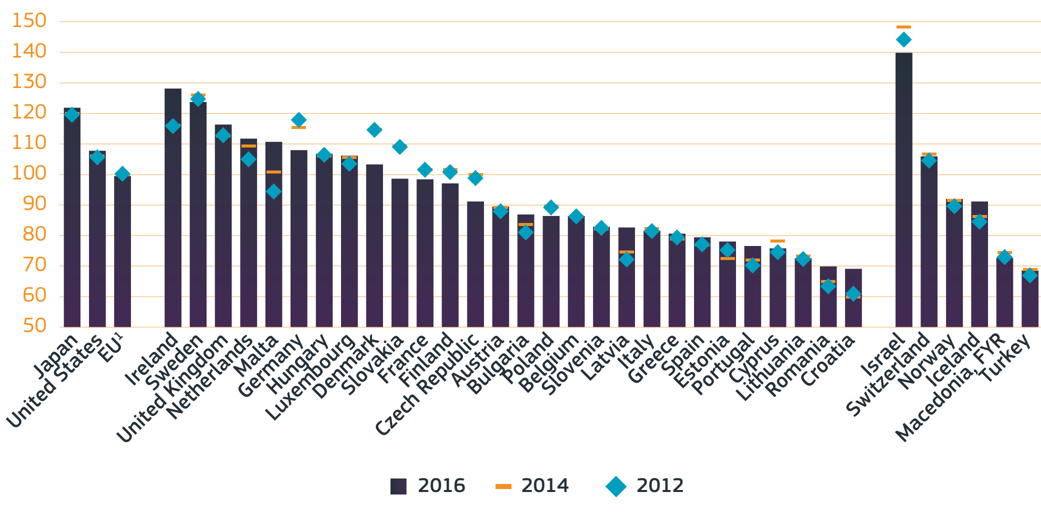
Innovation outputs

As regards key innovation outputs, progress in the EU has been slow in recent years. According to the Innovation Output Indicator, the EU now performs slightly below the United States and is clearly outperformed by Japan. There is a general North-South and West-East gap in innovation output performance, with some notable exceptions, such as Malta and Hungary. The gap between top and middle-group performers has widened in recent years.

According to the Commission's Innovation Output indicator (IOI)[24], which is based on four components (patents, employment in knowledge-intensive activities, trade in knowledge-based goods and services, innovativeness of high-growth enterprises) and five sub-indicators, the EU has been outperformed by the US and Japan, both of which have slightly improved their performance since 2012, while the EU's performance stagnated from 2012 to 2016.

In terms of differences across Member States, Ireland is the best EU performer, followed by Sweden, the UK and the Netherlands. a low level of innovation outputs is found in Romania and Croatia. However, the two countries have progressed well in recent years in their upwards convergence, together with Malta, the Netherlands and Ireland while, since 2012, innovation outputs have declined in Germany, Denmark, Slovakia, Finland and the Czech Republic. The decline in performance of some of these Member States is mainly caused by a lower share of employment in fast-growing enterprises in innovative sectors, while performance in other indicators has been more stable.

Figure I.4-C.1 Innovation output indicator (EU2011 = 100), 2012, 2014 and 2016



Science, Research and Innovation performance of the EU 2018

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research and Innovation Policies

Data: Eurostat, OECD, DG JRC

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 2014 is 99.6.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/parti/i_4-c_figures/f_i_4-c_1.xlsx

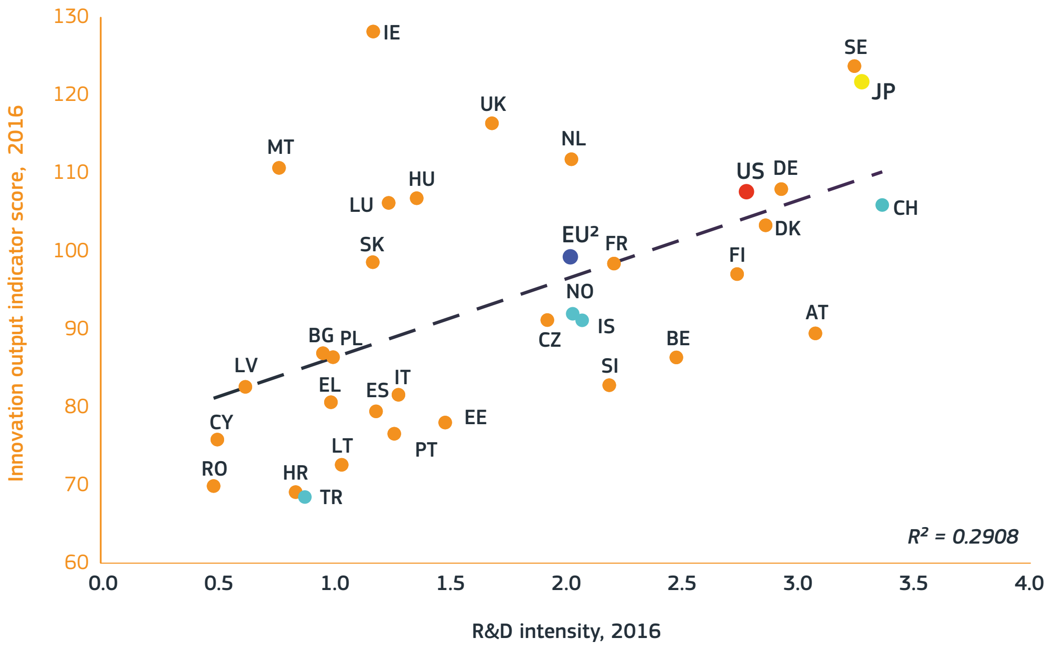
24 For further details on data sources and how the indicator was calculated, see Vertesy (2017).

Innovation outputs are broadly linked to investment in R&D and correlated with GDP per capita (productivity) and economic outcomes.

Figure I.4-C.2 below shows the correlation between the IOI and R&D investment. In general, there is a good correlation and countries with a high level of R&D investment also perform well on innovation outputs. Countries performing well on innovation outputs compared to their effective level of R&D spending include Ireland, Luxembourg and Cyprus. Countries where innovation outputs do not match spending levels include Denmark, Slovenia, Croatia, Lithuania and Greece. It should be noted that this direct correlation does not account for time lags or spillover effects and economic structures. Strong performance differences between Member States (see Figure I.4-C.2) imply there is room for improvement, including through adequate framework conditions.

As regards the different components of the IOI, Sweden, Finland and Germany perform best in PCT patents, as shown in the section on patents below. Many Central and Eastern European countries perform poorly in this field, partly as a result of a lack of global players in patent-intensive manufacturing sectors. The EU performs at a similar level as the United States, but is clearly outperformed by Japan.

Figure I.4-C.2 Innovation output indicator score, 2016 and R&D intensity, 2016[1]



Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research and Innovation Policies

Data: Eurostat, OECD, DG JRC

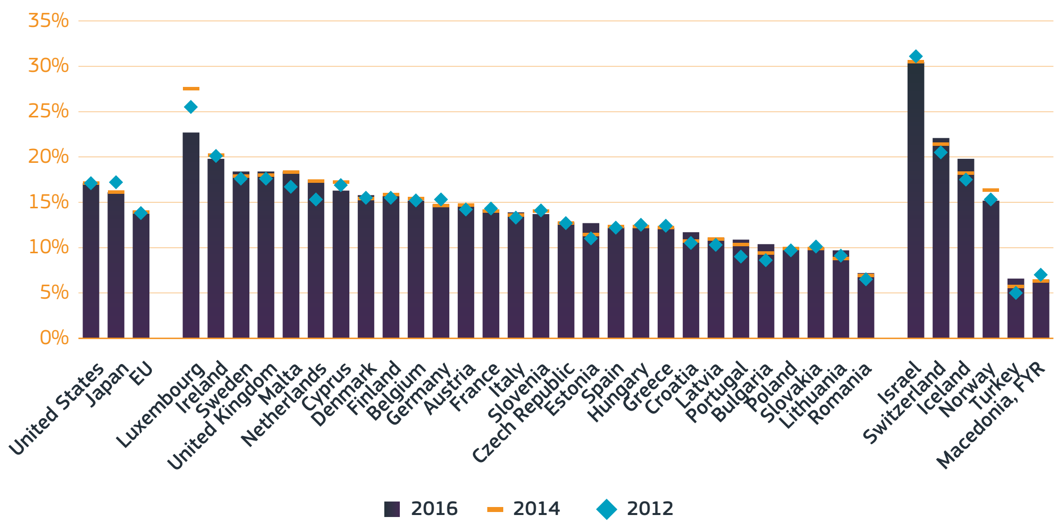
Notes: [1]BG, CZ, EE, FR, HR, LV, LT, HU, MT, PL, RO, SI, SK, CH, TR, US, JP: 2015. [2]EU: for the innovation output Indicator two sets of values are available: values for worldwide comparison and values for European comparison. The values for worldwide comparison are shown on the graph. The value for European comparison for 2016 is 99.6.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/parti/i_4-c_figures/f_i_4-c_2.xlsx

As concerns employment in knowledge-intensive activities, the United States and Japan outperform the EU. Economies with strong financial services and software sectors, such as Luxembourg and Ireland, show the best results in the EU.

When it comes to employment in knowledge-intensive activities, the second component of the indicator and an important economic outcome of innovation, Luxembourg (financial services) and Ireland (financial services, software) perform best, while Eastern European countries such as Romania and Lithuania are among the worst performers. Both the United States and Japan outperform the EU. Performance reflects a North-South and West-East innovation divide in Europe, although in smaller southern Member States, such as Malta and Cyprus, their efforts to focus on high-value-added services are making a difference to overcome this pattern.

Figure I.4-C.3 Employment in knowledge-intensive activities in business industries as % of total employment, 2012, 2014 and 2016

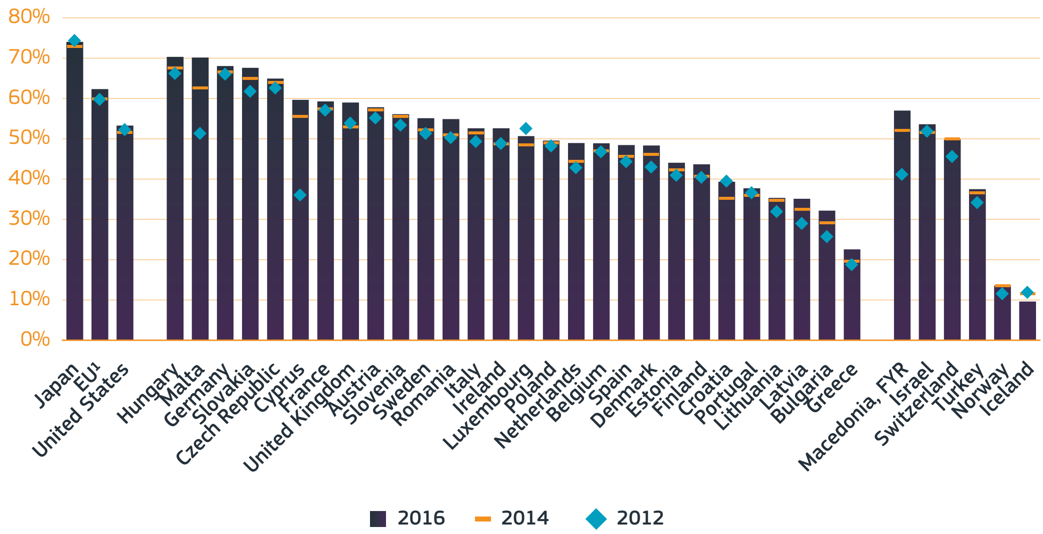


Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research and Innovation Policies
Data: Eurostat, OECD, DG JRC
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/parti/i_4-c_figures/f_i_4-c_3.xlsx

Apart from Germany and Malta, Central and Eastern European countries show the best performance in medium- and high-tech exports, mainly thanks to strong car exports.

As regards the export share of medium- and high-tech (MHT) products, Germany and some Eastern European countries (notably Hungary, Slovakia and the Czech Republic) perform well as a result of high exports of cars and machinery. In addition, Malta is a strong performer (although from a small export base and hence with fluctuating results), thanks to semiconductor exports. The EU has a higher share of MHT exports than the United States, but clearly lags behind Japan.

Figure I.4-C.4 Exports of medium- and high-technology products as % of total product exports, 2012, 2014 and 2016

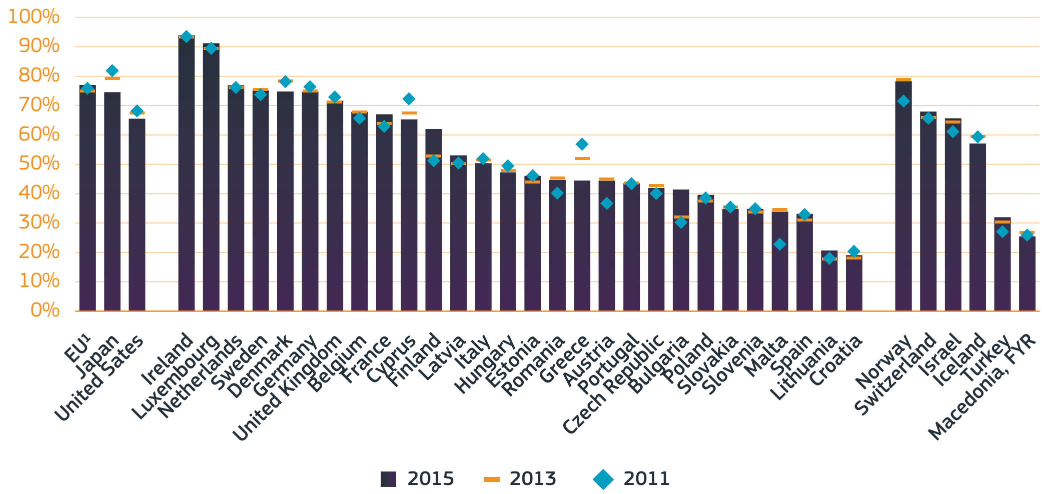


Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research and Innovation Policies
Data: DG JRC (based on Eurostat and UN data)
Note: [1]Two sets of values are available: values for worldwide comparison and values for European comparison. The values for worldwide comparison are shown on the graph. The value for European comparison for 2016 is 57.0.
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/parti/i_4-c_figures/f_i_4-c_4.xlsx

The EU has a higher share of knowledge-intensive service exports than the United States and a similar share to Japan. Countries with a high share of financial services and ICT services in their economy show the best results in the EU.

When it comes to knowledge-intensive service exports, Ireland and Luxembourg take the lead in the EU, as a result of high shares of financial and ICT services exports in these countries. Countries with a large tourism industry (tourism-related services are not classified as knowledge intensive), such as Spain and Croatia, tend to perform poorly in this indicator.

Figure I.4-C.5 Knowledge-intensive services exports as % of total services exports, 2011, 2013 and 2015



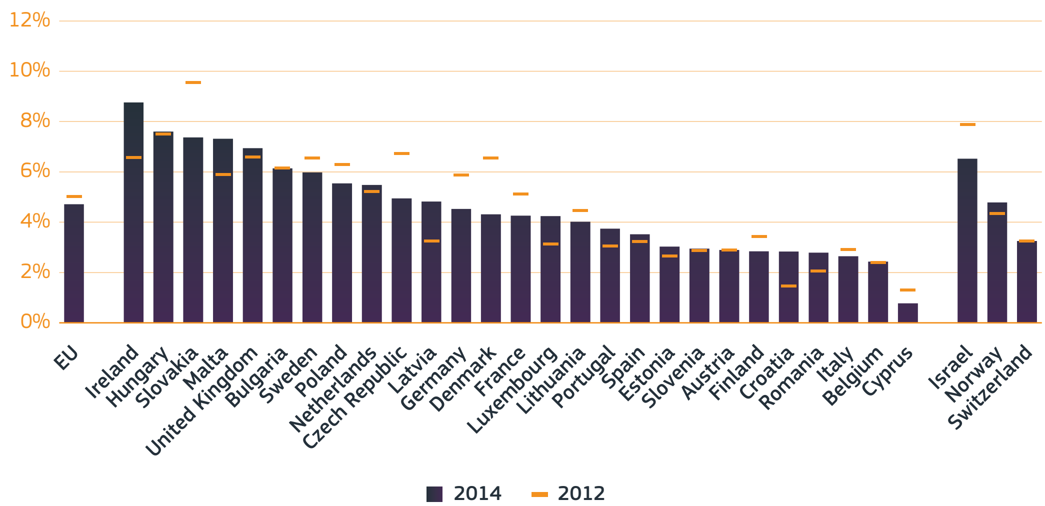
Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research and Innovation Policies
Data: DG JRC (based on Eurostat and UN data)
Note: [1]Two sets of values are available: values for worldwide comparison and values for European comparison. The values for worldwide comparison are shown on the graph. The value for European comparison for 2015 is 69.3.
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/parti/i_4-c_figures/f_i_4-c_5.xlsx

There is a more mixed pattern regarding the share of employment in fast-growing enterprises in innovative sectors, with a good performance registered in both Eastern and Western Europe.

The final component of the IOI relates to the share of employment in fast-growing enterprises in innovative sectors. Here, Ireland is in the lead, followed by Hungary. In recent years, these two countries have experienced fast employment growth in innovative sectors of the economy. However, Slovakia, the leader in 2012, has fallen back since then. Cyprus, which is still affected by a recession in the reference period, is the worst performer in this indicator, followed by Belgium and Italy. Economic growth, and related employment growth, have been slow in recent years in these countries – reflected in a low share of fast-growing companies measured by employment.

The European Innovation Scoreboard (EIS) presents another, yet larger, composite index on innovation, based on 27 indicators. All five components of the Innovation Output Indicator are also indicators of the EIS. The 2017 edition of the IUS shows Sweden, Denmark, Finland, the Netherlands, the UK and Germany as innovation leaders in Europe, while Romania and Bulgaria are in the lowest category of modest innovators.

Figure I.4-C.6 Employment in fast-growing enterprises in the top 50% most innovative sectors as % of total employment, 2012 and 2014



Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research and Innovation Policies
Data: Eurostat, OECD, DG JRC
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/parti/i_4-c_figures/f_i_4-c_6.xlsx

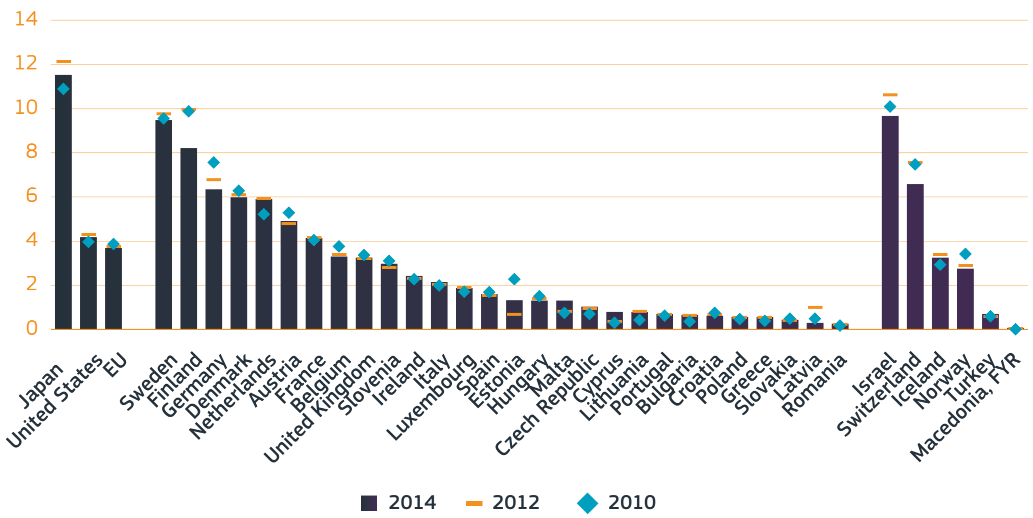
Technological and non-technological outputs

In relative terms, the EU performs on a similar level in international patent applications as the United States, but is outperformed by Japan and South Korea. Technological performance varies widely across EU Member States, reflecting a persistent innovation divide.

As concerns international (PCT) patent applications, the EU performs at a similar level as the United States when patents are related to GDP. However, on a per-capita basis, the United States outperforms the EU. Both Japan and South Korea clearly outperform the EU on both measures. Patents are a standard component of composite indicators on innovation, mainly used to proxy technological output. Structural differences in economies are an important determinant of performance as regards patent applications. Patent propensity is linked, amongst others, to the share of manufacturing in value added (manufacturing companies tend to patent more than service-sector companies), to the high-tech orientation of the manufacturing sector (higher patent activity in the high-tech sector), to the share of ICT services (the software industry is patent intensive), and to the enterprise size distribution in a country (larger enterprises tend to have a higher patent propensity). Patenting is also linked to the location of a company's headquarters as patenting tends to be carried out in the headquarter country.

Innovation leaders, such as Finland, Germany and Sweden, perform strongly in patent applications, while moderate and modest innovators, such as Lithuania, Malta and Romania show low levels of patenting, especially as regards international (PCT) patents. In order to catch up with the patenting level of competitors it will be important to reduce the innovation divide in Europe by increasing patent propensity in low-performing Member States.

Figure I.4-C.7 PCT patent applications[1] per billion GDP (in PPS€), 2010, 2012 and 2014

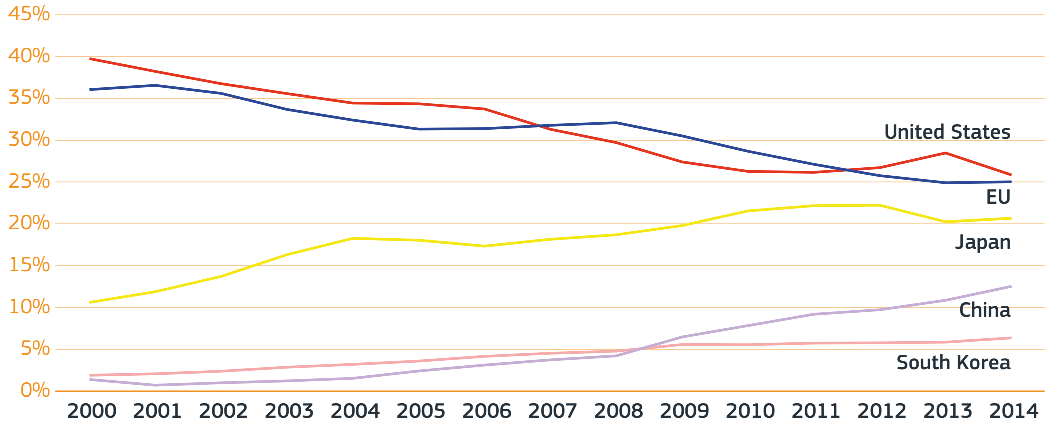


Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research and Innovation Policies
Data: Eurostat, OECD, DG JRC
Note: [1]Patent applications filed under the PCT, at international phase, designating the European Patent Office (EPO). Patent counts are based on the priority date, the inventor's country of residence and fractional counts.
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/parti/i_4-c_figures/f_i_4-c_7.xlsx

While Europe's share in international patent applications is declining, Asian countries, notably China, are catching up.

In many European countries, the number of international and national patent applications has declined recently, while patenting has been expanding quickly in East Asian countries. As a result, these countries, especially China, are catching up in world patent shares, while Europe's share is falling. The United States' share, which has long been in decline, stabilised in recent years before falling again in 2014.

Figure I.4-C.8 World share (%) of PCT patent applications[1], 2000-2014



Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research and Innovation Policies
Data: OECD
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.
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/parti/i_4-c_figures/f_i_4-c_8.xlsx

Europe is fairly efficient in translating its relatively low business R&D expenditure into technological outputs, especially compared to the United States, although it is outperformed by Japan.

As a whole, the EU and most of its innovation leaders perform relatively well as regards transforming business R&D expenditure into technological outputs, such as patent applications. The Netherlands stands out in this context with a particularly good performance, while Sweden and Finland also perform well. On the other hand, the EU is outperformed by Japan, which shows a high patent intensity, even when compared to its high level of business expenditure on R&D.

Figure I.4-C.9 Patent applications per billion GDP (PPS€), 2014 and business R&D intensity, 2013

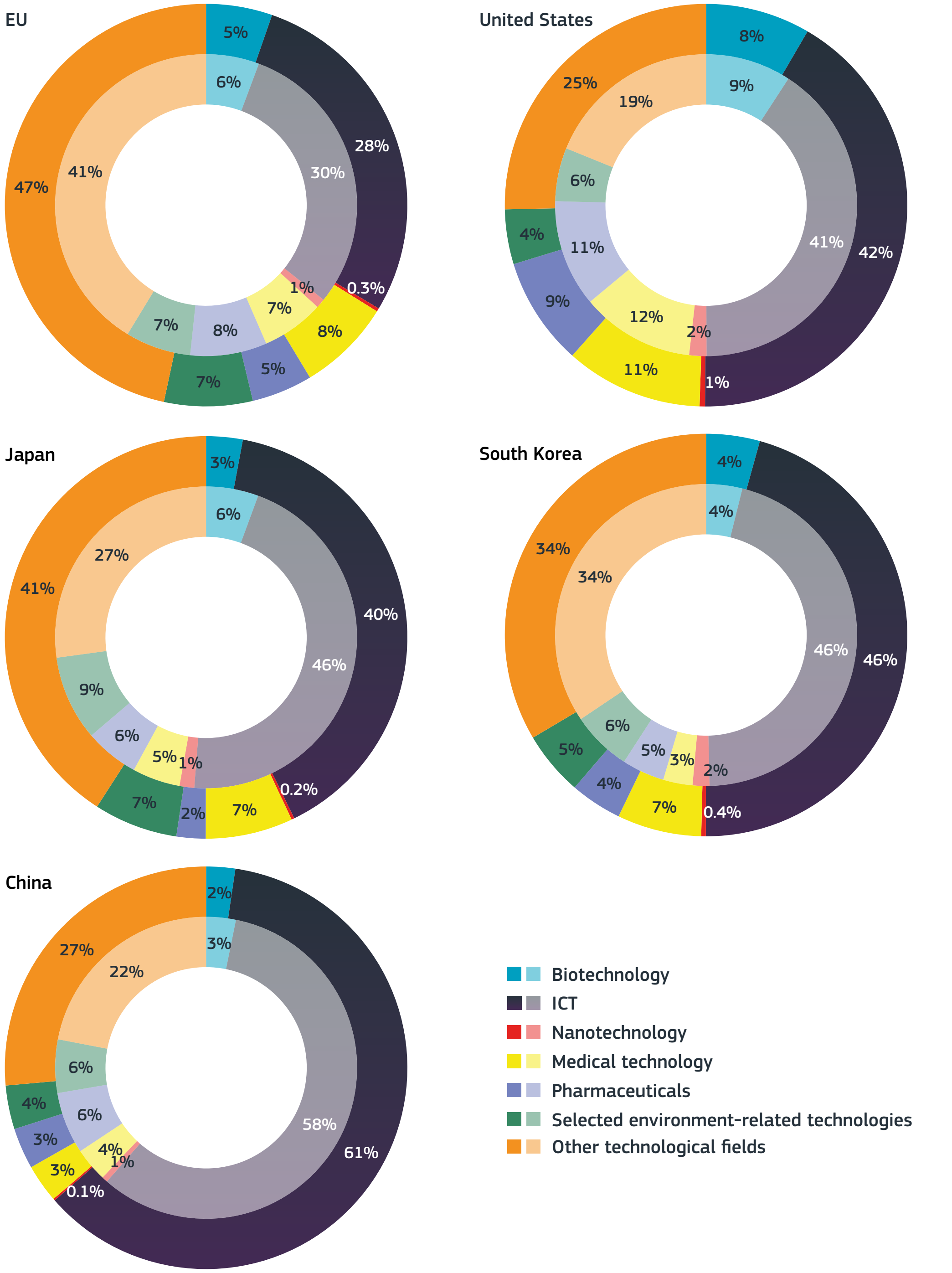
Science, Research and Innovation performance of the EU 2018

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of Nationa Research and Innovation Policies
Data: Eurostat, OECD, UNESCO (UIS database)
Note: [1]CH: 2012; TN: 2014.
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/parti/i_4-c_figures/f_i_4-c_9.xlsx

The EU is technologically less specialised than the United States, Japan, South Korea and China. While Japan, South Korea and especially China have strengths in ICT, in addition the United States is strong in bio- and medical technology and in pharmaceuticals.

Patent specialisation patterns differ between countries and change over time. The comparison between 2005 and 2013 (see Figure I.4-C.10) shows a lower share of EU patents in the field of ICT compared to competitors, and that the gap with some countries has increased since 2005. The data also show the growing importance of other technological fields and of environmental technologies, where Europe has relative strengths. The United States performs particularly well in pharmaceuticals, medical technology and ICT. Japan and South Korea have relative strengths in ICT and environmental technologies. China has a strong and growing specialisation in ICT. In general, the EU is less specialised than key competitors in fields that have a high patent propensity, notably ICT.

Figure I.4-C.10 Share of patent applications (WIPO-PCT) by technology fields, 2014 (exterior) versus 2005 (interior)

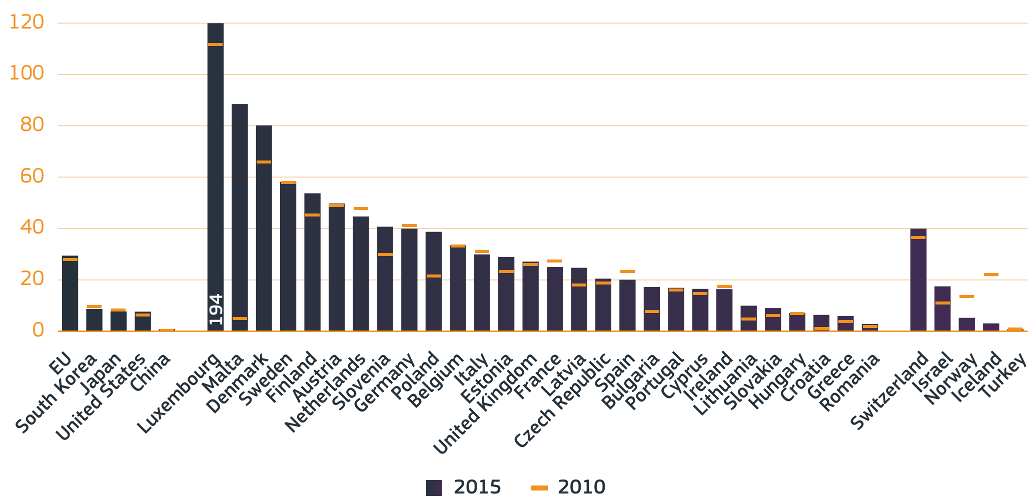


Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research and Innovation Policies
Data: OECD
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/parti/i_4-c_figures/f_i_4-c_10.xlsx

With reference to community design applications, performance patterns reflect factors outside R&I. It appears easier for Europe to advance in non-technological outputs than in more traditional innovation outputs, such as patents, as evidenced by the good performance of smaller Member States and Central and Eastern European countries.

Performance in IP areas such as community designs (see figure below) and community trademarks is influenced less by the quality of the innovation system, than that related to patents, as designs relate more to products' aesthetic features, while trademarks are linked to marketing. This is connected with the fact that designs are less technology-oriented, costs are lower and time lags shorter. Differences in taxation and regulation also seem to play a role, as evidenced by the strong performance of very small Member States (such as Luxembourg and Malta), reflecting the attractive framework conditions in these countries[25]. Countries performing traditionally well in innovation, like Sweden, Denmark and Finland, also perform well in IP outputs such as community designs. Some Eastern European countries, such as Slovenia, Poland and Estonia, rank much better in this area than in patents, with high growth rates in recent years, partially reflecting initial reforms in incentive systems and framework conditions. However, other EU countries performing poorly, in general, on innovation, tend to be less active and innovative in community designs. Performance patterns in community trademarks are similar to those shown for community designs and are also affected by factors outside the direct innovation policy umbrella, such as differences in taxation and regulation, as evidenced by the strong performance of very small Member States.

Figure I.4-C.11 Community design[1] applications to the EU Intellectual Property Office (EUIPO) per million population, 2010 and 2015



Science, Research and Innovation performance of the EU 2018

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research and Innovation Policies

Data: Eurostat

Note: [1]A registered community design is an exclusive right that covers the external appearance of a product or part of it.

Stat. link: https://ec.europa.eu/info/sites/info/files/srip/parti/i_4-c_figures/f_i_4-c_11.xlsx

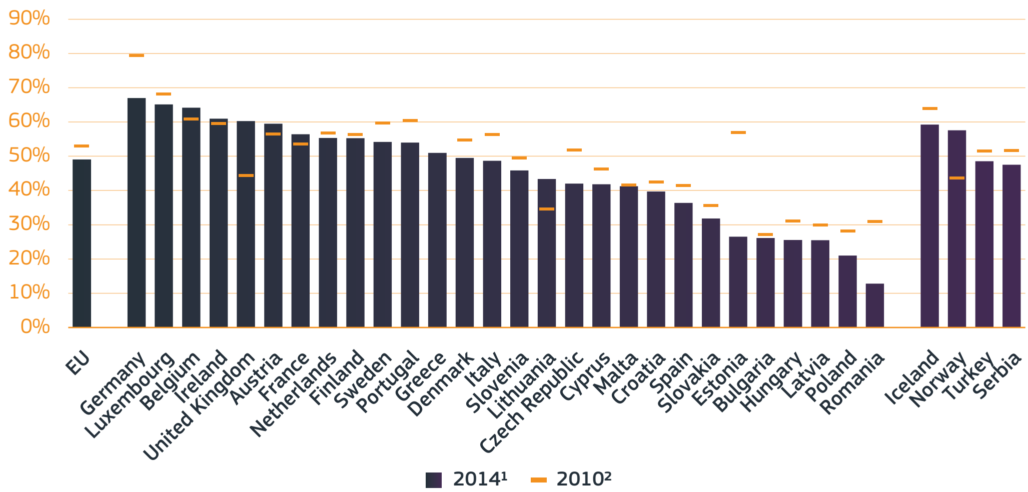
25 However, these tax incentives can be used in aggressive tax planning schemes, very often to the detriment of other Member States.

Innovative enterprises

The share of innovative enterprises is highly correlated with productivity and hence GDP per capita levels. Of concern is the decline in the share of innovative enterprises in most EU countries since 2010.

Germany, Luxembourg, Belgium and Ireland – all countries with GDP and productivity levels above the EU average and with a developed science base – show the highest shares of innovative enterprises (see figure below). Latvia, Poland and Romania, countries with a below-EU-average GDP per capita and building their science and innovation capacity, show the lowest shares. The latter countries might still profit from low-wage-related cost-competitiveness, while high-wage countries are in greater need of innovation to remain competitive and compensate for high production costs. The share of innovative companies is also linked to countries' economic structure. Those with a higher share of medium-high and high-tech manufacturing companies usually face stronger competitive pressures, shorter product cycles or higher shares of knowledge-intensive services (ICT, finances), and naturally show a higher share of innovative enterprises. Somewhat worrying is the fact that the share of innovative enterprises has declined in many EU countries since 2008-2010, as evidenced by the CIS results.

Figure I.4-C.12 Innovative enterprises as % of total number of enterprises, 2010 and 2014



Science, Research and Innovation performance of the EU 2018

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research and Innovation Policies
Data: Eurostat (CIS 2014, CIS 2010)
Note: [1]TR, RS: 2012.
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/parti/i_4-c_figures/f_i_4-c_12.xlsx

As regards the different types of innovation activities, leading innovation countries perform above the EU average both in product and process innovations, as well as in marketing and organisational innovations.

With reference to the different types of innovation activities (see Figure 1.4-C.13), there is a clear innovation divide in Europe, with leading innovation countries performing well in both product and process innovations as well as in marketing and organisational innovations within their enterprises. Countries with overall low innovation levels perform poorly in all innovation activities, but particularly in product innovations, which typically require more resources to generate than other types of innovations.

Figure I.4-C.13 Innovative enterprises by type of innovation activity as % of total enterprises, 2014

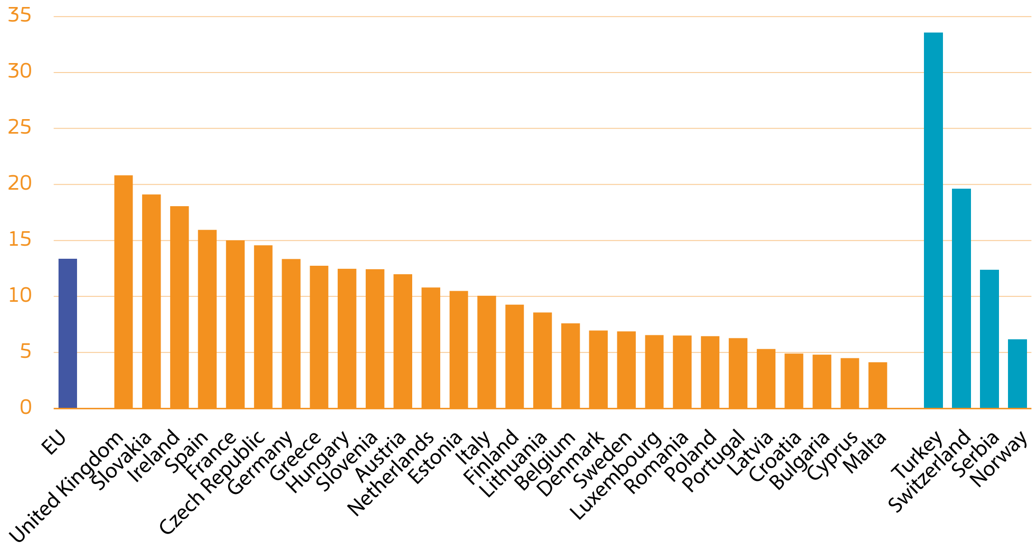
	Product and/or process innovative enterprises	of which:		Organisation and/or marketing innovative enterprises	of which:	
		Product innovative enterprises	Process innovative enterprises		Organisation innovative enterprises	Marketing innovative enterprises
EU	36.8	23.9	21.6	35.9	27.3	22.8
Belgium	52.9	31.9	38.8	46.2	35.9	28.4
Bulgaria	17.1	10.9	9.2	16.3	10.8	11.7
Czech Republic	35.7	25.1	22.4	27.3	17.1	20.5
Denmark	38.0	24.4	23.7	38.4	30.1	29.0
Germany	52.6	34.4	24.1	50.7	37.8	35.9
Estonia	20.8	11.0	13.0	15.9	10.4	12.1
Ireland	48.8	35.7	37.8	53.5	44.4	39.6
Greece	38.7	23.4	29.6	40.7	25.5	32.5
Spain	23.5	11.2	14.8	26.4	21.8	15.8
France	40.9	27.7	27.1	42.7	35.0	25.3
Croatia	26.9	18.7	21.6	32.1	23.2	23.6
Italy	37.0	24.7	24.5	35.3	24.5	23.5
Cyprus	33.6	22.9	27.6	32.2	25.0	25.5
Latvia	13.8	8.5	9.7	20.0	14.9	13.6
Lithuania	36.8	20.9	31.4	25.2	16.7	18.7
Luxembourg	42.0	28.8	25.7	55.3	47.0	34.1
Hungary	18.2	12.0	9.6	16.3	9.6	11.3
Malta	30.7	19.6	20.8	31.8	26.4	20.0
Netherlands	47.3	32.5	28.1	33.3	25.2	20.0
Austria	44.4	30.8	32.8	47.7	37.3	29.8
Poland	15.8	9.5	10.9	12.5	9.0	7.8
Portugal	44.8	28.4	35.4	38.4	25.9	29.0
Romania	6.5	3.6	4.3	9.4	6.7	6.6
Slovenia	33.0	25.2	22.6	34.9	24.4	25.1
Slovakia	20.3	12.6	12.9	23.1	14.7	16.8
Finland	48.3	34.5	32.0	38.4	29.7	25.9
Sweden	44.3	31.4	25.8	36.1	22.7	28.1
United Kingdom	40.9	26.8	17.9	45.5	40.1	18.5
Iceland	50.1	36.2	34.0	45.0	33.4	32.0
Norway	46.2	32.9	26.9	44.0	30.0	31.4
Switzerland	52.7	41.7	26.0	62.6	45.9	50.5
Turkey	38.0	22.7	26.8	41.0	28.5	33.6

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research and Innovation Policies
Data: Eurostat (CIS 2014)
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/parti/i_4-c_figures/f_i_4-c_13.xlsx

However, at country level, the share of innovation turnover does not seem directly correlated to the share of innovative enterprises.

As concerns the share of innovation turnover in total turnover (see Figure I.4-C.14 below), there would appear to be almost no correlation with the share of innovative enterprises. However, when analysing the results, it should be noted that data on the share of companies are dominated by the high number of SMEs whilst, as regards turnover, larger companies play a bigger role, including foreign affiliates, which tend to import innovations from the headquarter country. According to the latest CIS data, the share of innovation turnover in the EU is the highest in the UK with Slovakia and Ireland ranking second and third, respectively. This might be explained by foreign affiliate companies producing goods characterised by shorter product cycles and higher turnover related to innovation (automobiles, ICT hardware and pharmaceuticals). Low performers, such as Latvia, Bulgaria and Romania, also perform poorly in the share of innovative enterprises.

Figure I.4-C.14 Innovation turnover as % of total turnover, 2014[1]



Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research and Innovation Policies
Data: Eurostat (CIS 2014, CIS 2012)
Note: [1]TR, RS: 2012.
Stat. link: https://ec.europa.eu/info/sites/info/files/srip/parti/i_4-c_figures/f_i_4-c_14.xlsx

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