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Science, Research and Innovation performance of the EU

A contribution to the Open Innovation Open Science Open to the World agenda

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Public research and innovation policies and investment and their evolutions since the crisis	Claire Nauwelaers
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The role of well-designed framework conditions for business investment in R&I	Daria Ciriaci
International knowledge flows	Cristina Chaminade, Monica Plechero
Do research and other sources of innovation drive productivity gains in top European R&D investors	Fernando Hervas, Sara Amoroso
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Foreword

Research and innovation are key to building a prosperous future for the EU. They therefore figure prominently in the Europe 2020 strategy and the European Semester process and underpin progress towards the 10 priorities of the Juncker Commission, from providing a new boost to jobs, growth and investment, to developing the digital single market and developing the Energy Union.

The EU has fantastic strengths. It is open, diverse, and hosts excellent institutions. With Horizon 2020, the Union funds research and innovation on an unprecedented scale. But we face three major challenges. First, we need to strongly improve our track record in getting research results to market and technologies developed in Europe are often commercialised elsewhere. Second, although Europe generates more scientific output than any other region in the world, we often fall behind on the very best science. Third, Europe punches below its weight in international science cooperation and science diplomacy.

This Report presents an in-depth indicator based analysis of the EU's science, research and innovation performance and provides insight into the underpinning factors and drivers. It provides extensive evidence of the EU's performance in relation to each of these three challenges.

The Report shows, first and foremost, that the EU's productivity gap with the US has widened following the economic and financial crisis and that this is linked to a relative underinvestment in R&D and an inability to re-orient the economy towards activities with a higher knowledge content. While the Report shows that the EU continues to be one of the world's major players in science and technology, it also shows that the EU's economy needs to become more dynamic and innovation-intensive.

Open Innovation is about getting more actors involved in the innovation process and creating an ecosystem in which innovation flourishes. Yet the evidence shows that the EU continues to be locked into a specialisation pattern in which high-tech activities such as ICT, pharma or biotech are underrepresented. This is intimately linked to the fact that we do not yet have the correct conditions in place to attract enough private sector investment in innovation and for innovation-intensive businesses to grow and become major global players. Further progress needs to be made in relation to the availability of venture capital, the reduction of heavy product market regulations and in removing barriers to entrepreneurship and the ease of doing business.

Open Science is about greater collaboration, access and reuse of results and is the foundation of excellence in science and future prosperity. Here the Report shows how continued policy efforts are paying off. The EU is now not only the largest producer of scientific publications in the world, but has also become the largest producer of high quality publications and is reducing the gap with the US in other metrics of scientific quality. On the other hand, the intensity of knowledge circulation and therefore the openness of the EU's science system still lags behind that of its main competitors. More needs to be done to equip the EU with a high quality science base and to strengthen the EU's position as a global leader in open science.

Europe is a world leader in science, and this should translate into a leading voice in global debates. Europe should also be leading the way in developing global research partnerships to address challenges in areas like energy, health, food and water. The Report shows how the growing openness of the global research and innovation system has enhanced the importance of international collaboration, and has become a crucial factor in accessing new sources of knowledge and improving competitiveness. The EU is the world leader in terms of international co-publications, but the major part of that is intra-European and in terms of technological collaboration, the EU is not taking sufficient advantage of the emergence of China as a technological powerhouse.

Innovation is at the basis of transforming the EU into a knowledge based economy. By providing a comprehensive and indicators based analysis of the EU's research and innovation performance and its drivers, I am sure that this Report will provide policy makers across Europe with clear insights into the challenges that lie before them.

Carlos Moedas
European Commissioner for Research, Science and Innovation

Table of contents

Executive Summary

A continuing productivity challenge is hindering the European Union (EU) from re-taking the path towards sustainable economic growth and the creation of high quality jobs.

The recession has emphasised the EU's long-term growth gap against the United States (US), while at the same time other economies such as South Korea or China are rapidly catching up.

The *gap in per capita GDP and GDP growth between the EU and the US is largely driven by a gap in labour productivity*, which is about 15% lower in the EU, with the gap having increased over the past few years. The catching-up process of the Member States with the largest labour productivity gap vis-à-vis the US (all in Central and Eastern Europe) continued over the 2007-2014 period. For those Member States (except Ireland) with a productivity level close to the US, however, the gap vis-à-vis the US expanded over 2007-2014.

Data presented in the Report shows that high labour productivity and high employment rates can coexist, although some adjustment period with higher rates of unemployment may be necessary when moving from a middle to a high-income economy.

Addressing the GDP gap between the EU and the US and thereby restoring the EU's long term competitiveness will therefore ultimately require raising labour productivity. This depends in turn on *increasing multifactor productivity (MFP), which relates to innovation* and investments such as R&D, ICT and skills development. In this respect, it is worth noting that since the beginning of the recession, a number of advanced EU countries that had caught up with the US in the period 1995-2007 have started falling behind.

The EU underinvests in the basic drivers of innovation: R&D, education, ICT

Investing in the basic driving forces of innovation, such as in R&D, skills development or Information and Communication Technologies (ICT) is at the heart of transforming the EU into a knowledge based economy.

As regards investment in R&D, some progress has been made since the onset of the crisis, with the EU's R&D intensity increasing to a level of over 2% of GDP after years of stagnation. However, *the EU's R&D intensity remains far from the 3% target* and R&D intensity growth in countries such as China and South Korea has been much more dynamic over the past few years.

The EU's public R&D *sector has emerged stronger from the crisis*, as a result of continued public investment in R&D, driven also in part by significantly increased funding at the EU level. The *EU's business R&D intensity has also been on a slow upward trend since 2005*, but its level remains far from that of major competitors such as the US or Japan and, since 2013, the gap appears to be growing again.

The Report also shows that the level of *public investment in R&D is a key determinant of the quality of public research*. In the EU, countries that have invested above average amounts in public research tend to also be those having a well performing system in terms of scientific excellence. An adequate level of public funding is an important precondition for a high quality science base. In this respect, it is worrying that some Member States with a low quality science base have reduced their public investment levels over the past few years.

Skilled human capital is an important precondition for moving towards a knowledge-intensive society and economy. The EU is faced with demographic challenges in this respect as its population ages and fewer young people enter the labour market. As regards public investment in education, the EU is at a similar level as the US and outperforms South Korea and Japan. *Taking public and private investment together, however, the EU is outperformed by both the US and South Korea, with a particularly large gap as regards tertiary education*. Nevertheless, it should be noted that EU performs well in terms of the tertiary attainmet rate of 30-34 year olds, in the production of science and technology graduates and of new doctoral students.

The EU's ICT sector is not only smaller than that of the US and Japan, its knowledge intensity is also much lower, pointing to the fact that the EU is a consumer, rather than a producer, of ICT goods and services. The EU faces the risk of a lock-in in less R&D-intensive activities and it is not fully capturing the benefits ICT can bring to other parts of the economy.

The EU needs to put in place better incentives and conditions for businesses to innovate: **Open Innovation**

Open innovation is about involving far more actors in the innovation process, from researchers, to entrepreneurs, to users, to governments and civil society. To capitalise on the results of European research and innovation Europe needs to create the right ecosystems, increase investments, and bring more companies and regions into the knowledge economy.

The EU is still not dynamic enough in transforming itself into a knowledge economy based on high-tech activities and continues to be locked into a specialisation pattern largely concentrated on medium-high-tech sectors.

Boosting the EU's multifactor productivity requires a *profound shift of the economic structure* towards activities with a higher knowledge content. This, in turn, relies on putting in place a business environment, which facilitates private sector investments in research and innovation as well as the creation and growth of R&D and innovation intensive businesses which operate at the cutting edges of science and technology.

This report highlights that the share of knowledge-intensive activities in the EU economy (high-tech, medium-high-tech and knowledge-intensive services) is below that of the US and South Korea. In addition, it is worrying to note that, although the share is growing in the EU, it does so in a less dynamic way than in some of its main competitors.

The EU exhibits a specialisation in medium-high-tech sectors (e.g. automobiles and parts), with the share of high-tech manufacturing (e.g. ICT, pharmaceuticals, and biotech) being lower than in the US and much lower than in South Korea. Furthermore, the knowledge intensity of the high-tech manufacturing sector is higher in the US and South Korea than in the EU, which suggests that the EU also lags behind in capturing the most knowledge-intensive activities within this sector.

As gearing the European economy towards more knowledge-intensive activities will ultimately depend on a renewal of the economic fabric, it is important to put in place framework conditions allowing a swift reallocation of resources towards more innovative activities and enabling new players to enter the market.

The Report shows that *the EU is lagging behind the US and South Korea in important framework conditions such as product market regulation, barriers to entrepreneurship, ease of doing business or intellectual property right protection*. Europe needs to do more to create a regulatory environment for innovation to flourish and tune the legislative processes to the increasingly shorter cycles of technologies.

The EU as a whole, and all individual Member States, also *continue to lag behind the US in the amount of available venture capital*. Not only is there far less venture capital in Europe, but venture capital funds do not have the scale or scope to grow companies from early stage to mid-cap and from mid-cap to global players. While the persistent lack of financing for innovation in the EU may be a result of a combination of both supply (i.e. a lack of available funding) and demand (i.e. a lack of fundable projects), it seems that the crisis has also deteriorated the overall situation.

A shift in the European economy towards knowledge-intensive activities with higher added value will require *the European research and innovation system to become more strategic in terms of its focus areas*. The Report shows that the EU is still less specialised than the US in key strategic areas such as nanosciences and nanotechnology, ICT, materials or biotechnology. In addition, both China and South Korea have been increasing their number of highly cited publications in strategic fields at a higher speed than the EU and the US. A similar pattern applies for technological outputs.

A picture that emerges throughout the Report is *the persistence of an innovation divide across the EU*, with the Member States having joined the EU since 2004 performing, on average, at lower levels. It should be noted, however, that the characteristics of this innovation divide appear to be gradually changing, with some of the newer Member States increasing their performance substantially. In terms of R&D intensity, for instance, Slovenia is now ranked 6th across the 28 Member States, and has surpassed Belgium and France, while both the Czech Republic and Estonia are approaching the EU average. The Report also shows the importance of the European Structural and Investment Funds in financing the research and innovation systems of the newer Member States, which will contribute to further close the innovation divide.

The EU needs to continue improving the quality of its science base and the intensity of knowledge circulation: **Open Science**

Excellent science is the foundation of future prosperity and openness is key to excellence. Despite a growing number of impressive developments at the frontier of science in Europe and an improving position of the EU worldwide, indicators of most excellent science show that the Europe is not top of the rankings in certain areas.

With more than 27% of the world total, *the EU continues to be the largest producer of scientific publications in the world*, ahead of China, which has overtaken the US. A significant evolution since 2000 is that the EU has overtaken the US as regards the total number of highly cited publications.

There is evidence throughout the Report that continued policy attention to research and innovation and structural reforms ultimately pay off. The continued policy attention to reform the public research base and stimulate excellence has led *the EU to diminish the gap with the US in terms of scientific quality* whilst staying clearly ahead of countries such as South Korea, Japan and China.

A shift towards more knowledge-intensive activities also benefits employment. The Report shows that *employment in science and technology has been particularly resilient during the crisis*. Whilst total employment in the EU decreased by 0.7% on average per year between 2008 and 2013, human resources in science and technology increased by 2.1% per year over the same period and the number of researchers by 2.5%.

For the public science base to be fully effective in terms of increasing innovation performance and delivering impact, it needs to be well connected to the business sector and knowledge has to circulate freely. Public-private collaboration is a key aspect in this, in particular in an environment in which open innovation is becoming increasingly important and more actors are involved in the innovation process. In this respect, the EU has made some progress over the past few years, *but its intensity of public-private collaboration still lags behind that of Japan, South Korea and, in particular, the US.* Further efforts are needed to stimulate such cooperation, and the nature of the economic fabric should be taken into account when determining the optimal policy mix.

Moreover, the mobility of human resources is also an important mechanism to foster knowledge circulation between the public and the private sector. Yet here as well, *the EU is still not fully benefiting from the embedded knowledge of researchers trained by universities* as the number of researchers employed by the business sector is significantly lower than in the US, Japan and South Korea.

The EU needs to capitalise on its strengths in an increasingly global context: **Open to the World**

Europe is a global leader in science, and this should translate into a leading voice in global debates. To remain relevant and competitive, Europe needs more engagement in science diplomacy and global scientific collaboration to enable partnerships between regions and countries.

Challenges in areas like energy, health, food and water are global. And Europe should be leading the way in developing global research partnerships to address these challenges.

While the role of the EU in the global research and innovation system is diminishing, on most of the indicators of research and innovation performance, it is still second only to the US and the global research and innovation system is becoming more open and connected.

The world is becoming more knowledge-intensive, more open and more interconnected, an evolution which the crisis has only temporarily checked. All major world regions are increasing their knowledge investments and this has led to a *fundamentally changed global R&D landscape*. The EU and the US in 2000 still accounted for nearly two thirds of global R&D expenditure. Their combined share has now dropped below 50%. China, on the other hand, has more than quadrupled its share in world R&D expenditure over this period, increasing from below 5% in 2000 to about 20% in 2013.

The same evolution is apparent when looking at other dimensions of the knowledge-based economy. The number of tertiary graduates in China has quintupled since 2001, making it now by far the world's largest producer of tertiary graduates. Its share of total scientific publications increased from 6% in 2000 to nearly 20% in 2013 and it is also continues to bridge the gap in terms of scientific excellence and patent applications.

Due to this changing landscape, *the role of international collaboration has further increased and has become an important factor* in addressing sources of new knowledge and improving competitiveness. The Report illustrates that such collaboration also pays off: the scientific impact of internationally co-published papers is higher than that of papers published by single-country authors.

The EU is the world leader in international co-publications. However, intra-European collaboration still represents the major part of this. On the international scene, the US continues to be the EU's main partner, while the importance of China as a strategic partner is rising.

The *growing openness of the global research and innovation system* also leads to increasing mobility of researchers. The Report shows how this is an important mechanism for boosting the quality of research and innovation systems, as the scientific impact of mobile researchers is higher than that of researchers who never move.

International technological collaborations are also gaining increasing importance in firms' innovation strategies, as they allow access to a broader set of competences, knowledge and skills. Such international technological collaboration has intensified over the past decade in both the EU and the US, yet in the US it has done so at a higher rate and has now overtaken the EU in terms of the share of patents resulting from international collaboration. Also, in terms of technological collaboration, China is becoming a key partner for the EU, but it appears that the US is taking greater advantage than the EU of the opportunities that come from collaborating with this emerging economy.

Introduction

After several years of economic turmoil with a double-dip recession and one of the worst financial and economic crises in generations, the European Union (EU) seems to have regained economic growth, even if the recovery remains weak and needs to solidify. The economic recession emphasised Europe's long-term growth gap with the United States, and unveiled structural weaknesses in the economy. At the same time, some Asian competitors, e.g. South Korea, and notably China, have increased their growth and continue to catch up. Thus, setting the foundations for strengthening the economic recovery and creating sustainable high quality growth and job creation is a priority for Europe.

The gross domestic product (GDP) gap and GDP growth gap between the EU and the United States is largely driven by a gap in labour productivity that is expanding, most notably among the most advanced European economies. Boosting labour productivity requires national economies to boost the amount of capital available per worker, i.e. capital deepening, and to increase the efficiency in which production factors are combined, i.e. multifactor productivity.

Since the crisis, investment in capital has been low in most EU countries, and multifactor productivity growth has been flat or negative, except for Ireland. Multifactor productivity growth has been particularly poor in the most advanced European economies, while in Japan, the United States, and notably, South Korea, it has grown steadily in the past few years. While there are many factors driving multifactor productivity, for most advanced economies, innovation and innovation-related investments, such as R&D, ICT, or skills development, are leading factors.

Against this backdrop, the Science, Research and Innovation performance of the EU 2016, a publication of the Directorate-General for Research and Innovation of the European Commission, assesses the European Research and Innovation (R&I) landscape within the global context. It identifies strengths and persistent challenges both for the EU as a whole and for its Member States. The report focuses on those aspects which underpin the creation of effective and efficient R&I systems that are able to sustain economic and productivity growth and that generate gainful job opportunities.

The objective of this analysis is to provide sound analytical foundations for evidence-based policy-making and to help policy-makers, but also researchers, businesses, and other stakeholders, identify policy priorities both at the EU and Member State level.

As such, the Report caters to a wide audience and this is reflected in its structure. Part I analyses the European R&I landscape based on a core set of indicators and is intended to provide policy-makers with a general overview of the key strengths and weaknesses of the different elements of the EU R&I system. More precisely, it analyses the role that R&I plays in the current economic context for the EU, the levels of investment in knowledge creation, the knowledge flows, the scientific and technological outputs and their specialisation in particular fields, the soundness of the framework conditions for effective development and uptake of innovation, and the socioeconomic impacts in terms of structural change of the European economy towards more knowledge- and technology-intensive activities.

Part II focuses in depth on a core set of areas that are particularly important for European R&I by providing further data and analysis and by using different quantitative and qualitative methodologies. More precisely, Part II analyses the role of research, and public research in particular, for economic development in Member States at different levels of technological development; the quantitative and qualitative impacts of the crisis for public R&D and innovation across the EU; research excellence in Europe; the level of research specialisation in Europe; international knowledge flows, framework conditions for research and innovation in the EU, high-growth innovative firms in Europe, the impact of R&D on productivity at the firm level, and the impacts of innovation on employment and skills development and strategies.

Part II of the Report has benefited from the work of academics and researchers as well as other services of the European Commission, such as the Joint Research Centre, Institute for Prospective Technological Studies (IPTS), the Directorate-General Economic and Financial Affairs, and the European Research Council Executive Agency.

Given the scope and level of analysis, the Report represents the most comprehensive analysis of research and innovation in the EU and complements other reports such as the annual Innovation Union Scoreboard (2), the annual EU R&D Industrial Investment Scoreboard (3), and the annual Innovation Union Progress at Country Level (4).

(2) http://ec.europa.eu/growth/industry/innovation/facts-figures/scoreboards/index_en.htm

(3) http://iri.jrc.ec.europa.eu/scoreboard.html

(4) http://ec.europa.eu/research/innovation-union/pdf/state-of-the-union/2014/iuc_progress_report_2014.pdf

Part I

The research and innovation landscape in Europe

TABLE OF CONTENTS

1. General economic outlook

After several years of economic turmoil with a double-dip recession and one of the worst financial and economic crises in generations, the European Union (EU) seems to have retaken the path towards economic growth, even if the recovery remains weak and needs to solidify. Setting the foundations for strengthening the economic recovery and creating high quality jobs is a priority for Europe.

The European economic forecast report [5] of October 2015 showed that the economic recovery in the EU was in its third year and should continue in 2016. For the EU as a whole, real GDP is forecast to grow by 2.0% in 2016 and 2.1% in 2017. To a large extent, this more positive outlook is driven by factors related to the overall decrease in energy prices, following the drop in oil prices, the monetary stimulus by the European Central Bank and other EU central banks, and the euro's exchange rate depreciation, notably against the US dollar.

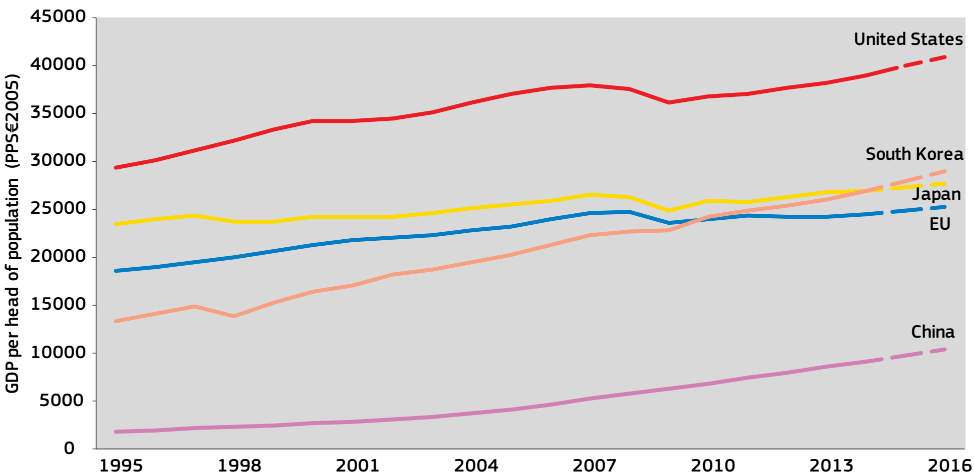
Despite these positive developments, doubts still persist about the robustness of the recovery in the EU, should the above mentioned tailwinds start to fade. At the same time, new challenges are appearing, such as the slowdown in emerging market economies and global trade, and persisting geopolitical tensions.

The economic recession has emphasised Europe's long-term growth gap against the United States and unveiled structural weaknesses in the EU economy.

The economic crisis has emphasised the persistent output gap between the EU and the United States, and the rapid catch-up of other economies, such as South Korea or China.

The legacy of the crisis will continue to be felt for years to come. The levels of private and public debt in many countries remain very high and the shortfall of investment of the past few years, with a drop of around EUR 430 billion since its peak in 2007 [6], has reduced economic growth, in a context of an ageing population that will hamper the expansion of the available labour force. In addition, continued structural weaknesses hindering the ability of countries to raise their levels of productivity, as will be presented, persist and cast doubts on the ability of Europe to grow in the long run.

Figure I-1-1 **Evolution of GDP per head of population in real terms[(1)], 1995-2016**



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Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat, DG Economic and Financial Affairs
Note: [(1)]PPS€ at 2005 prices and exchange rates.

[5] http://ec.europa.eu/economy_finance/publications/eeip/pdf/ip011_en.pdf

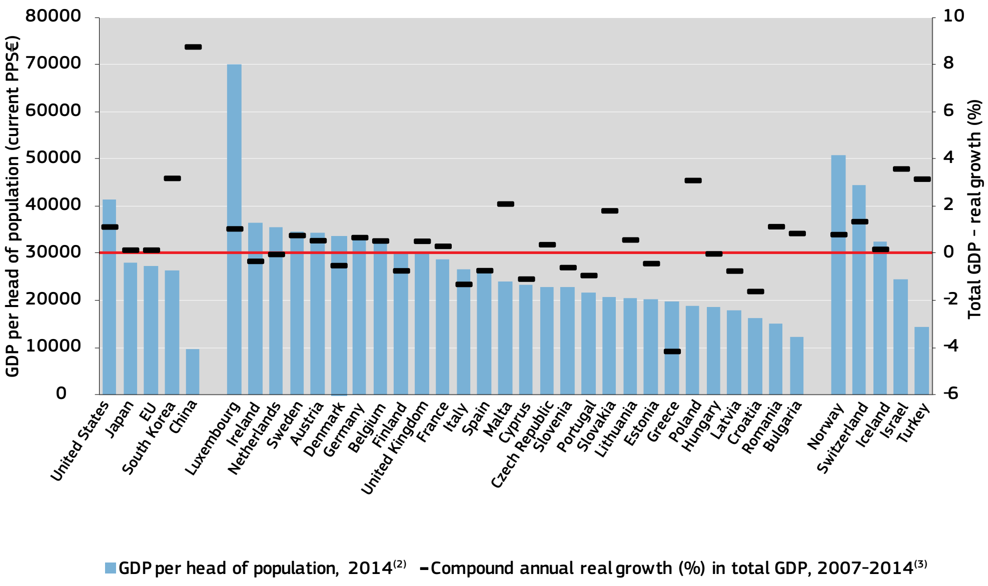
[6] http://ec.europa.eu/priorities/sites/beta-political/files/factsheet1-why_en.pdf

Within the EU, while overall slow economic growth has characterised the 2008-2013 recession period, large differences across Member States emerged, creating not only an income-level divide, but most importantly, a divide between Member States that grew, stagnated, or followed an economic adjustment process.

Income disparities across Member States in Europe are well known and documented. The divide between high-income Nordic and Western European countries and catching-up countries in Southern, Central, and Eastern Europe persists. However, the economic recession also evidenced the different ability of Member States to grow during this period, with stark differences within Western economies and Central and Eastern countries. More precisely, countries such as Germany, Sweden or Austria continued to grow during this period, while countries such as Greece, Spain, Portugal, Italy or Cyprus contracted, evidencing structural weaknesses and their inability to maintain the high levels of prosperity achieved in previous years. In Central and Eastern Europe, Poland and Slovakia achieved robust growth rates, while countries such as Hungary stagnated.

In order to improve this situation, several Member States have engaged in a series of structural reforms to improve the functioning of their markets and regain fiscal stability [7], which in some cases have appeared to start paying off, with above average growth rates forecast in countries such as Spain.

Figure I-1-2 **GDP per head of population, 2014 and real growth in total GDP[1], 2007-2014**



Science, Research and Innovation performance of the EU 2016

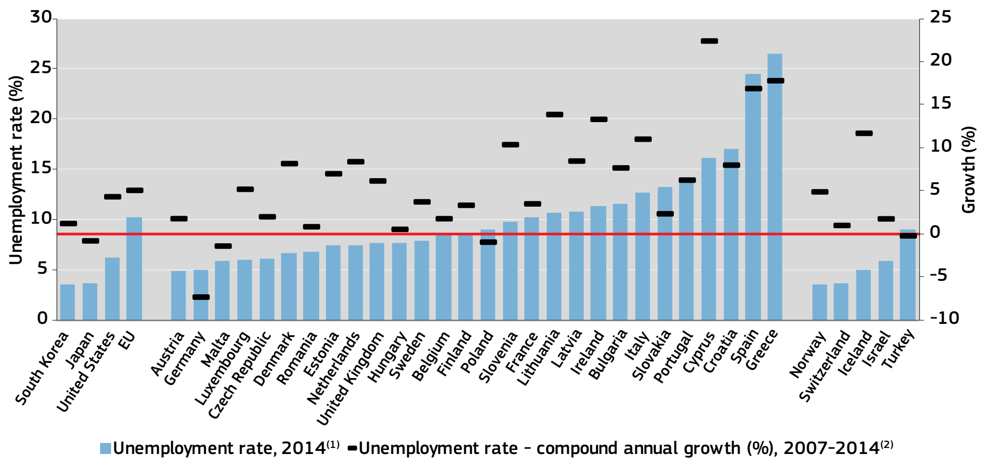
Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat, DG Economic and Financial Affairs
Notes: [1]Compound annual growth calculated from GDP in PPS€ at 2005 prices and exchange rates. [2]IL: 2013. [3]IL: 2017-2013.

[7] http://ec.europa.eu/economy_finance/publications/economic_briefs/2014/pdf/eb34_en.pdf

Low rates of economic growth have severe implications on the ability of many European economies to create new employment opportunities, notably in those countries that have been more severely hit by the crisis and where current unemployment rates are unsustainable.

As a consequence of the economic downturn, unemployment rates have increased sharply in Europe. Only a few Member States, notably Germany and Poland, managed to decrease their unemployment rates, while countries such as Greece, Spain or Cyprus saw their rates rocket to intolerably high levels. While labour market conditions are improving in general, and rosier economic growth forecasts for countries such as Spain will help ease the situation, unemployment remains unacceptably high. Boosting gainful job opportunities remains an overall priority for Europe, and for that, more robust economic growth throughout the EU is needed.

Figure I-1-3 **Unemployment rates, 2014 and compound annual growth, 2007-2014**



Science, Research and Innovation performance of the EU 2016

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat, DG Economic and Financial Affairs, OECD
Notes: (1)AT, UK, TR: 2013. (2)AT, UK, TR: 2007-2013; IL: 2011-2014.

The GDP gap and GDP growth gap between the EU and the United States is largely driven by a gap in labour productivity that continues to increase, most notably against the most advanced European economies.

The importance of productivity as a key driver of sustained economic growth and solidification of the recovery in Europe has been identified by several studies, such as 'The Future of Productivity' by the OECD [8]. Against this backdrop, labour productivity in the EU is around 15 percent lower than in the United States and this gap has increased in the past few years. Labour productivity in the EU grew at an average annual rate of 0.6% from 2007 to 2014, a lower rate than the 1.4% average of the long-term trend from 1995 to 2014. In the United States, it grew at 1.9%. Japan's labour productivity also grew faster during this period than in the EU, albeit below the United States rates, at 0.9%, and South Korea's increased briskly at 3.8%, outperforming all countries and accelerating their convergence towards the United States.

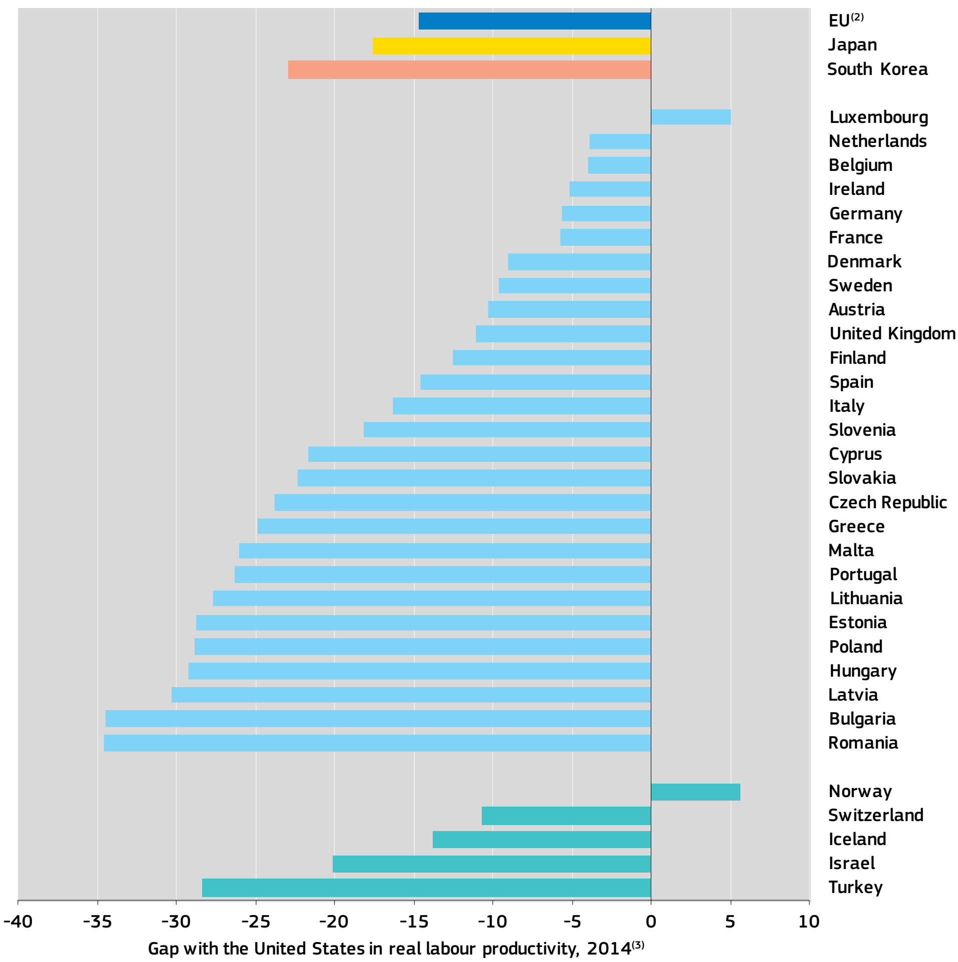
The aggregate figures mask significant differences across Member States. Some countries score above the United States, such as Luxembourg, or are close to it, such as the Netherlands, Belgium or Ireland. Yet for many countries the gap remains particularly wide. However, the dynamics of the past few years have shown an increasing

(8) http://www.oecd.org/economy/the-future-of-productivity.htm

divergence of the European leading economies and a convergence of some of the countries in Central and Eastern Europe that are catching-up to the level of the US. More precisely, since the beginning of the crisis, among the advanced economies only Ireland managed to close part of the gap, while for countries such as Finland, the United Kingdom, or the Netherlands the gap widened. This emphasises the productivity challenge that many EU countries face, a trend that started around the mid-1990s.

At the other end of the spectrum, several Central and Eastern European countries such as Romania, Poland, Bulgaria or Slovakia have managed to outperform the United States in terms of labour productivity growth and decreased their labour productivity gaps with other European economies.

Figure I-1-4 **The gap in real labour productivity (GDP per hour worked[(1)]) between each country and the United States, 2014**



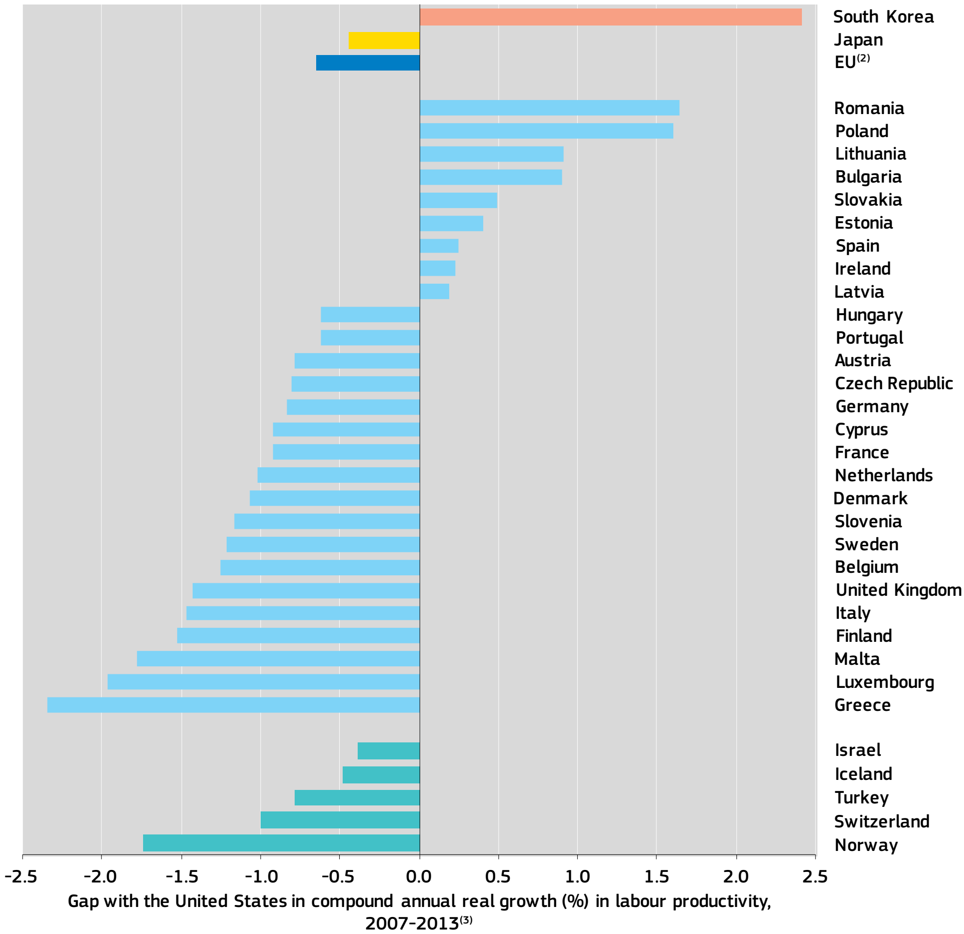
Science, Research and Innovation performance of the EU 2016

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

Data: Eurostat, DG Economic and Financial Affairs, OECD

Notes: [(1)]GDP per hour worked in PPS€ at 2005 prices and exchange rates. [(2)]EU: Croatia is not included. [(3)]IS, NO, CH, TR, IL, JP, KR: 2013.

Figure I-1-5 **The gap in compound annual real growth in labour productivity (GDP per hour worked[(1)]) between each country and the United States, 2014**



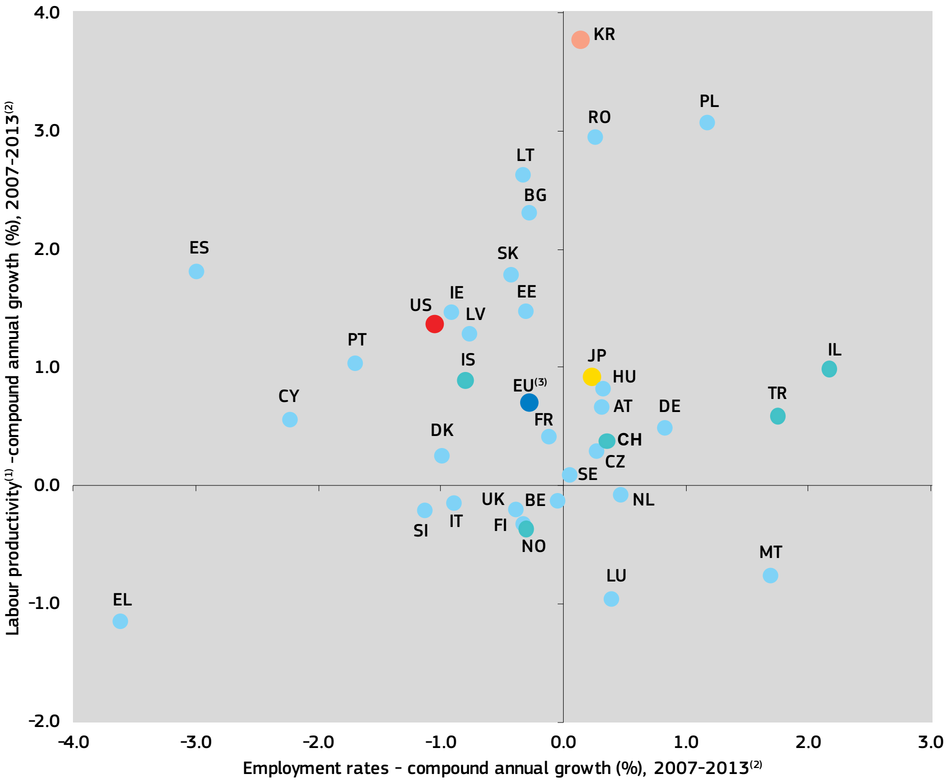
Science, Research and Innovation performance of the EU 2016

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat, DG Economic and Financial Affairs, OECD
Notes: [(1)]GDP per hour worked in PPS€ at 2005 prices and exchange rates. [(2)]EU: Croatia is not included. [(3)]IS, NO, CH, TR, IL, JP, KR: 2013.

Some European countries have managed to raise their labour productivity during the recession, but at the expense of employment loss, which does not provide a long-term solution to the need to raise productivity and employment levels.

During the economic downturn, some Western European economies such as Spain or Portugal managed to increase their labour productivity rates, but this was at the expense of millions of jobs, which evidenced an inability to raise labour productivity and boost job creation at the same time. Among the most advanced economies, countries such as Germany or Austria managed to slightly raise both labour productivity and employment at the same time, while Poland and Romania are examples of countries that also managed to do this among Central and Eastern European countries.

Figure I-1-6 **Real labour productivity[1] versus employment rates – compound annual growth, 2007-2013**



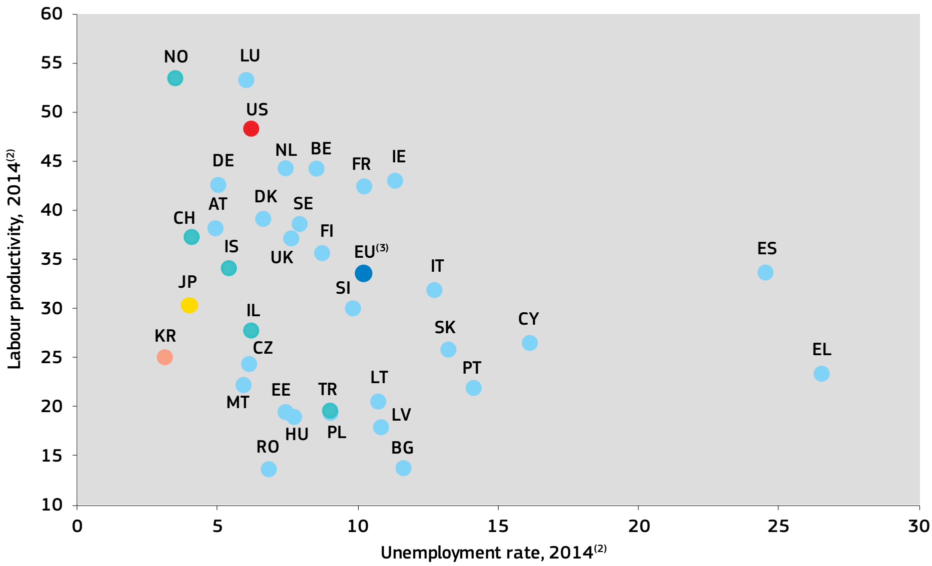
Science, Research and Innovation performance of the EU 2016

Source: DG Research and Innovation – Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat, DG Economic and Financial Affairs, OECD
Notes: [1]GDP per hour worked in PPS€ at 2005 prices and exchange rates. [2] FR, NL, AT, UK: 2007-2012. [3]EU: Croatia is not included.

There are no inherent trade-offs between high labour productivity and high employment, even if some adjustment periods may be necessary to move from a middle to a high-income economy, provided the right mix of investment and market conditions are put in place.

The recent dynamics in the relationship between labour productivity and unemployment rates has cast questions about the nature of the relationship and the existence of potential trade-offs. In other words, do countries need to sacrifice high levels of employment in order to raise the productivity of the employed labour force, or vice-versa, do countries need to suffer low productivity rates in order to provide employment to large segments of the population? The evidence suggests that there is no inherent trade-off, and there are several countries where high levels of productivity coexist with low levels of unemployment. At the same time, the cases of Spain and Greece, that suffer from high levels of unemployment and medium-low levels of productivity, seem to suggest that in some cases, the transition from low productivity to higher productivity may take a temporary toll on employment, unless the right set of conditions are put in place that allow both to be achieved.

Figure I-1-7 **Labour productivity[1] versus unemployment rates, 2014**



Science, Research and Innovation performance of the EU 2016

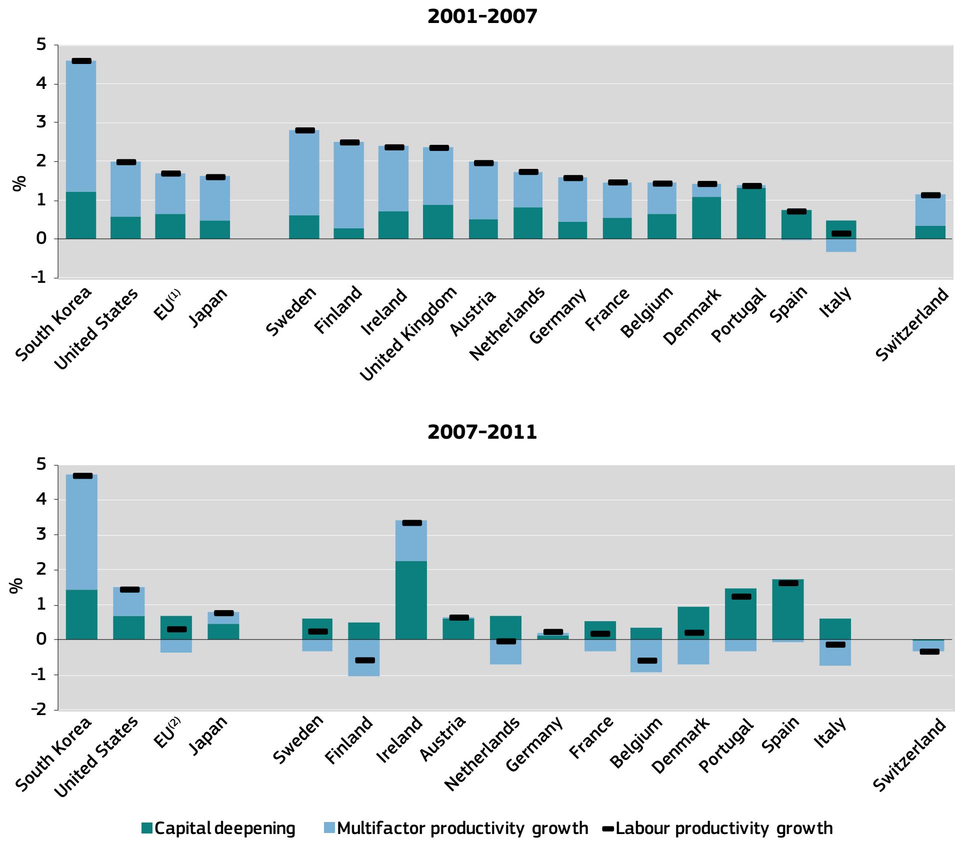
Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat, DG Economic and Financial Affairs, OECD
Notes: [1]GDP per hour worked in PPS€ at 2005 prices and exchange rates. [2]AT, UK, IS, NO, CH, TR, IL, JP, KR: 2013. [3]EU: Croatia is not included.

Boosting labour productivity depends on the ability of national economies to increase the amount of capital available per worker, i.e. capital deepening, and the efficiency in the combination of the production factors, i.e. multifactor productivity. Since the crisis, investment in capital has been low in most EU countries, and multifactor productivity growth flat or negative, except for Ireland.

While capital investments and multifactor productivity in the EU advanced at a similar pace to the United States and Japan around the turn of the millennium, resulting in rather comparable results in terms of labour productivity gains, the recession of the past few years has taken a particular high toll not only on the levels of capital investment, as previously stated, but also on the factors that drive multifactor productivity growth.

Countries such as Sweden, Finland, or the United Kingdom that led and outperformed the United States in terms of labour productivity gains thanks to multifactor productivity increases in the early 2000s, drastically changed patterns during the recession with some remarkable falls since then. Labour productivity gains have been meagre in most Western European countries for which data exist for this decomposition analysis. Although some progress was achieved, such as in Spain or Portugal, this was driven by higher amounts of available capital per employed worker, due to the high loss of jobs. The only exception to this rule was Ireland, despite being one of the first countries that was severely hit by the downturn.

Figure I-1-8 **Capital deepening, multifactor productivity and labour productivity - average annual real growth**



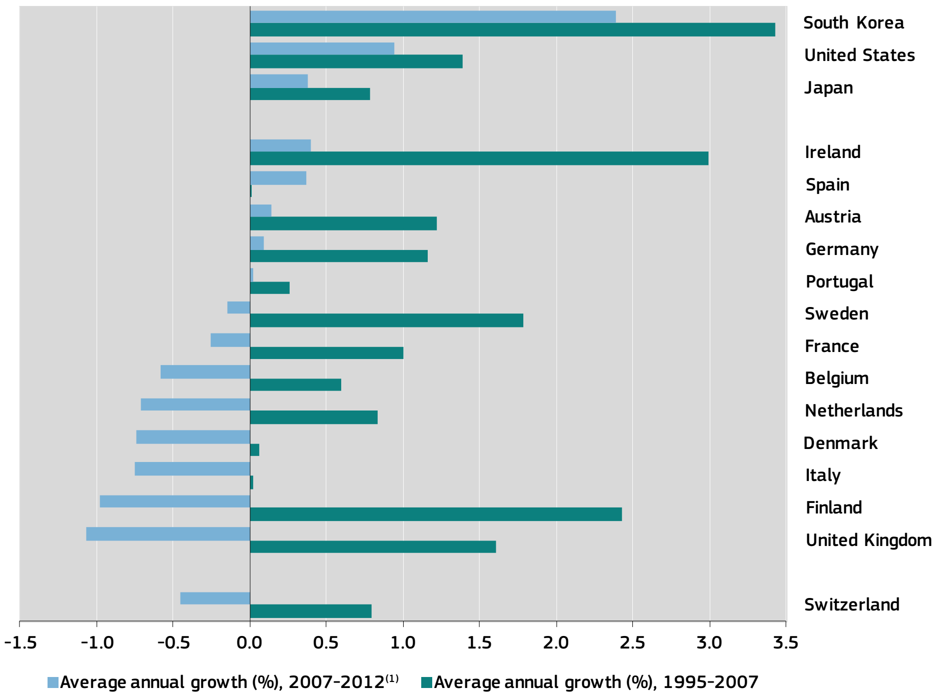
Science, Research and Innovation performance of the EU 2016

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: OECD, DG Research and Innovation
Notes: (1)EU 2001-2007 was estimated by DG Research and Innovation and includes: BE, DK, DE, IE, ES, FR, IT, NL, AT, PT, FI, SE, UK.
(2)EU 2007-2011 was estimated by DG Research and Innovation and includes: BE, DK, DE, IE, ES, FR, IT, NL, AT, PT, FI, SE.

During the recession, multifactor productivity growth has been particularly poor in the most advanced European economies, while in Japan, the United States, and notably, South Korea, it has grown steadily.

Long-term multifactor productivity trends show a persistent growth gap between the United States and Japan and the most advanced European economies for which data exist. In particular, it is worth noting that since the beginning of the economic recession, countries such as Finland or the United Kingdom that performed relatively strongly during the 1995-2007 period, largely thanks to development of the ICT sectors, began to trend negatively, as was also the case for Italy and Denmark, both countries already suffering from low multifactor productivity growth rates since the mid-1990s, and for the Netherlands, Belgium, France and Sweden. Only a handful of countries managed to slightly improve their performance, although at much slower pace than the United States or South Korea, countries that showed relentless improvement in the past two decades.

Figure I-1-9 **Multifactor productivity - average annual growth, 1995-2007 and 2007-2012**



Science, Research and Innovation performance of the EU 2016
Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: OECD
Note: (1)DK, NL, PT, UK, CH: 2007-2011.

While there are many factors driving multifactor productivity, for most advanced economies, innovation and innovation-related investments, such as R&D, ICT, or skills development, are crucial.

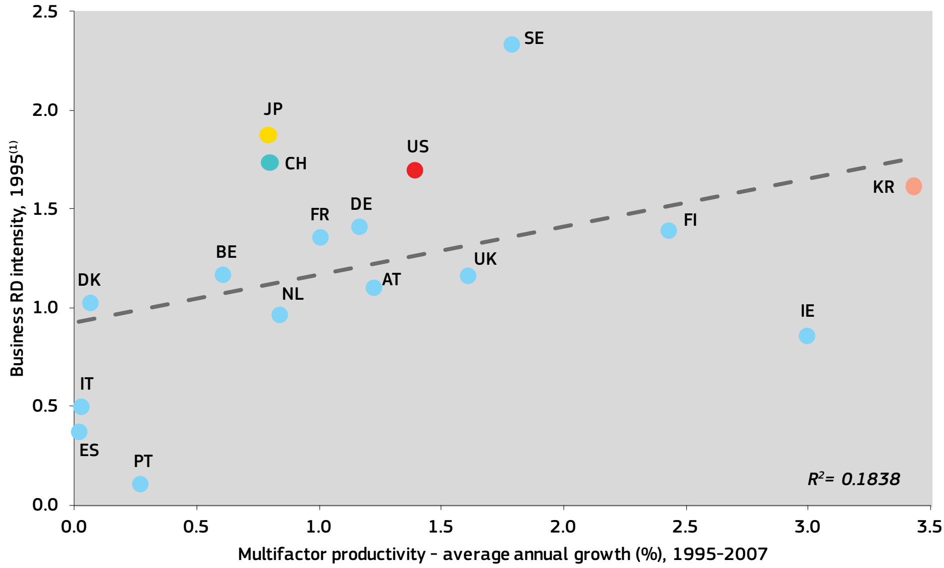
Multifactor productivity growth can be driven by many different factors that can range from the functioning of the institutional set-up, the abundance and quality of the infrastructure network or the functioning of the markets that allow for an efficient allocation of resources towards more productive activities.

Therefore, structural reforms and better regulatory and institutional frameworks are crucial to raise the combined efficiency in the use of labour and capital in a country. In addition, and notably for countries that benefit from high levels of prosperity and fairly good framework conditions, as argued in the Global Competitiveness Report series of The World Economic Forum [9], research, innovation, skills and technological development are of paramount importance for multifactor productivity growth.

While it is always difficult to properly measure complex phenomena such as multifactor productivity growth or innovation, the relationship between private R&D investment, as a crude proxy of innovation capacity, and multifactor productivity growth shows a positive relationship between the concepts.

[9] www.weforum.org/gcr

Figure I-1-10 **Business R&D intensity, 1995 versus average annual growth in multifactor productivity, 1995-2007**



Science, Research and Innovation performance of the EU 2016
Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat, OECD
Note: [(1)]CH: 1996; AT: 1998.

Against this backdrop, the next sections of Part I of this Report will assess the European R&I landscape within a global context and identifies the strengths and persistent challenges in terms of knowledge investments, knowledge flows, and framework conditions for the EU and its Member States to create effective innovation systems able to sustain productivity, economic growth, and gainful job opportunities.

2. Investment in knowledge and knowledge flows

Investing in knowledge-generation activities, such as R&D, skills development, or Information and Communication Technologies (ICTs) is crucial to support the development of inventions and enable the development and commercialisation of new products and services. In addition, as important as investing in knowledge creation, is creating a system that facilitates the effective circulation, diffusion, and use of this knowledge. Intensive collaboration facilitates knowledge flows across firms and with universities and public research organisations, which is associated with higher rates of knowledge diffusion. Moreover, in an increasingly multipolar world of knowledge creation, openness and strong collaboration with foreign partners is the key to tapping into new sources of knowledge.

Against this backdrop, this section will assess the levels of investment in R&D in the EU, both in the private and public sectors, its ability to foster talent and skills, and how it fares in developing and using ICTs to harness the benefits of the digital economy. Finally, it will also provide an overview of the knowledge flows, either local or international.

Investment in R&D

EU R&D investment in the global context

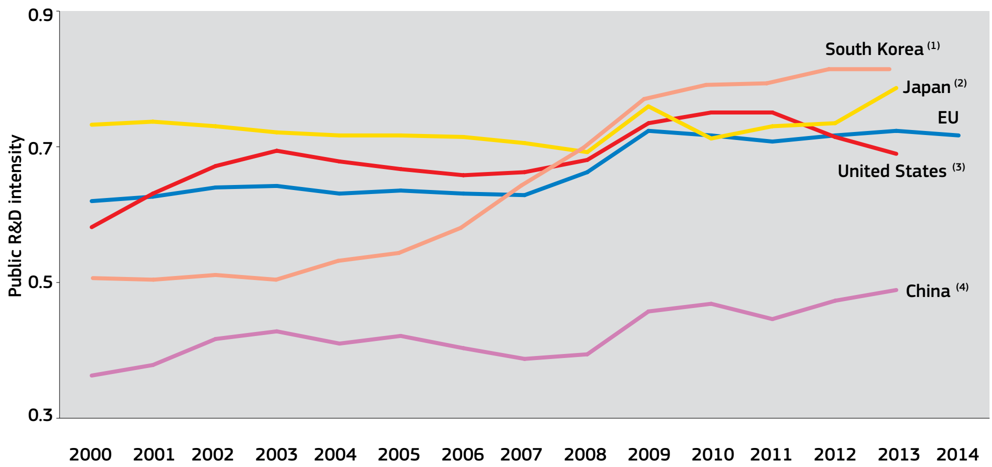
By setting the goal of reaching a R&D intensity (i.e. R&D expenditure as a percentage of GDP) of 3% GDP by 2020, as one of the five headline targets of its Europe 2020 strategy, the EU has put research and innovation at the heart of its economic strategy.

The 3% target acknowledges the essential role that R&D investments play in triggering smart and sustainable growth and in addressing societal challenges, as well as the fact that the EU lags significantly behind other leading regions on this indicator. Both public R&D and business R&D have a role to play in this context. The public R&D system (composed of higher education institutions and other public organisations performing R&D) plays a key role in generating the knowledge and talents needed by innovative firms. But it is only through business investment in R&D that the expected impact of R&D can fully materialise: by generating new, innovative and greener products, processes and services, business R&D enables higher labour and total factor productivity, industrial competitiveness and efficiency in the use of resources, as well as reduced environmental impacts. It is thus essential that public policies, on top of aiming to strengthen the public R&D system, also address the broader innovation eco-system and put in place the right framework conditions to enable business R&D and innovation to flourish.

Against this backdrop, the first part of this chapter will aim to assess to what extent the EU as a whole is on track (or not) towards its R&D intensity target. It will look successively at the expenditure trends in the public R&D and in the business sectors and will compare those with the trends in other major economic powers, before synthesising the situation of the EU vis-à-vis its target and its place in the changing global R&D landscape. In the second part of this chapter, progress will be assessed and compared at the Member State level, again in three steps: public R&D expenditure, business R&D expenditure, and the situation vis-à-vis the national 2020 R&D intensity targets that most Member States have set taking into account the specificities of their situations.

With a EU public R&D intensity reaching 0.72% GDP in 2014 vs 0.63% in 2007, the EU public R&D system emerges slightly stronger from the crisis period. The major Asian economic powers also continued to strengthen their public R&D systems.

Figure I-2-1 **Evolution of Public R&D intensity, 2000-2014**



Science, Research and Innovation performance of the EU 2016

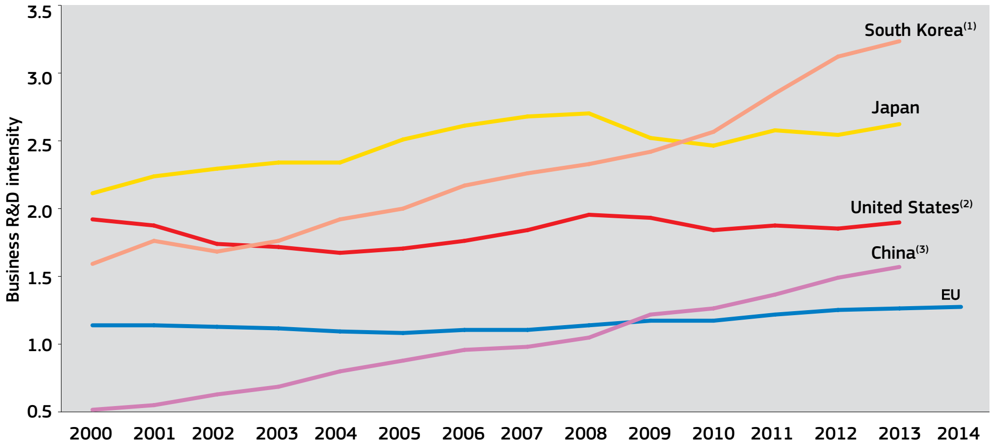
Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat, OECD
Notes: (1)KR: There is a break in series between 2007 and the previous years. (2)JP: There is a break in series between 2008 and the previous years. (3)US: (i) Government intramural expenditure on R&D (GOVERD) refers to federal or central government only; (ii) Higher education expenditure on R&D (HERD) does not include most or all capital expenditure; (iii) There is a break in series between 2003 and the previous years. (4)CN: There is a break in series between 2009 and the previous years.

In 2008-2009, the continued increase of public R&D expenditure in the EU within the context of a depressed GDP allowed a significant increase in public R&D intensity, as visible in Figure I-2-1. In the following years, public R&D expenditure evolved in line with GDP, resulting in a stable public R&D intensity. In total, with EU public R&D intensity reaching 0.72% in 2014 vs 0.63% in 2007, the public R&D system emerges stronger from the crisis period (for the EU as whole, while diverging evolutions occurred at the Member State level, as analysed below). This represents an increase in the level of expenditure of 15% in real terms from 2007 to 2014 (with more than two-thirds of this increase made during the 2007-2009 period). 69% of the increase in public R&D expenditure over 2007-2012 is the result of increased national public funding, while 20% came from increased 'funding from abroad' (the bulk of this from the EU budget: Framework programme and Structural Funds).

While increases in public R&D intensity in the 2008-2009 period have been a generalised phenomenon across the major economic powers (with South Korea overtaking the US and Japan in that period), trends have been more divergent since 2011, with a decline in the US contrasting with the significant increases in South Korea, Japan, and China.

EU business R&D intensity has been on a quasi-continuous and very slow positive trend since 2005. Despite a more positive trend than in the US and Japan over the crisis period, it remains far below the business R&D intensity of these two countries and the 2013 figures point to a re-increasing gap. The most striking evolutions are, however, outside this trio with the continued and very rapid growth of business R&D intensity in China, which overtook the EU in 2009, and in South Korea, which overtook Japan in 2010.

Figure I-2-2 **Evolution of business R&D intensity, 2000-2014**



Science, Research and Innovation performance of the EU 2016
Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat, OECD
Notes: (1)KR: There is a break in series between 2007 and the previous years. (2)US: Business enterprise expenditure on R&D (BERD) does not include most or all capital expenditure. (3)CN: There is a break in series between 2009 and the previous years.

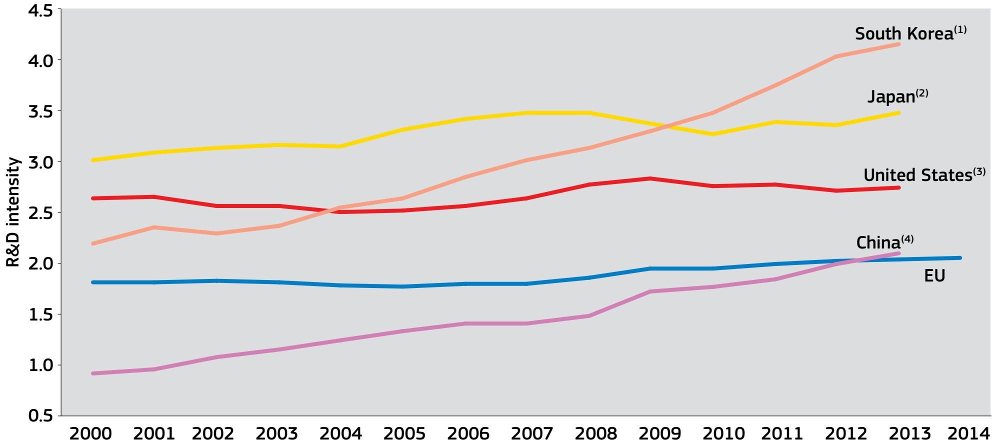
With only a limited halt after the initial shock of the crisis, EU business R&D intensity has been on a quasi-continuous and very slow positive trend since 2005 (when it bottomed out at 1.11% GDP), reaching 1.30% GDP in 2014. This represents an increase in the level of expenditure of 28% in real terms between 2005 and 2014. A large range of manufacturing and service sectors contributed to this increase, with 'Motor vehicles' and 'Other transport equipment' being the most important contributors to the increase in business R&D expenditure over the period from 2008-2012 on the manufacturing side, and 'Professional, scientific and technical activities' and 'Computer programming, consultancy and information service activities' on the services side. As analysed in Chapter 5, two phenomena played a role; on one hand, many sectors became more R&D-intensive (for instance 'Other transport equipment', but also several low-tech sectors) and, on the other hand, some R&D-intensive sectors (such as 'Motor vehicles' and 'Pharmaceuticals') were more resilient throughout the crisis and increased their shares (in value-added) in the EU economy.

The impact of the crisis on business R&D investment has been much more important in the US and Japan than in the EU, leading to a drop in the business R&D intensities of these countries in 2009-2010 as shown in Figure I-2-2 (and thus a reduction in the business R&D intensity gap of the EU vis-à-vis the US and Japan). In real terms, while business R&D expenditures grew by 12% in the EU from 2007 to 2012, they grew by only 4% in the US and declined by 6% in Japan. However, the 2013 figures point to a significant renewed dynamics of business R&D expenditures in the US and Japan (+ in 5% real terms in both cases) while in the EU we do not see any similar acceleration (+1% in real terms in 2013, +2% in 2014).

It is, however, outside this trio that the most striking evolutions can be seen: South Korea, having doubled its business R&D intensity since 2000, overtook the US in 2003 and Japan in 2010. China, having trebled its business R&D intensity since 2000, overtook the EU in 2009. Profound structural changes in these economies through the rapid growth of several R&D-intensive manufacturing sectors explain these dramatic evolutions in business R&D intensities.

Despite the positive trends in both public and private R&D intensities over the 2007-2014 period, the EU is not on track to reach its 3% R&D intensity target by 2020. In 2013, China overtook the EU in terms of total R&D intensity.

Figure I-2-3 **Evolution of R&D intensity, 2000-2014**



Science, Research and Innovation performance of the EU 2016

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat, OECD
Notes: (1)KR: There is a break in series between 2007 and the previous years. (2)JP: There is a break in series between 2008 and the previous years. (3)US: (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)CN: There is a break in series between 2009 and the previous years.

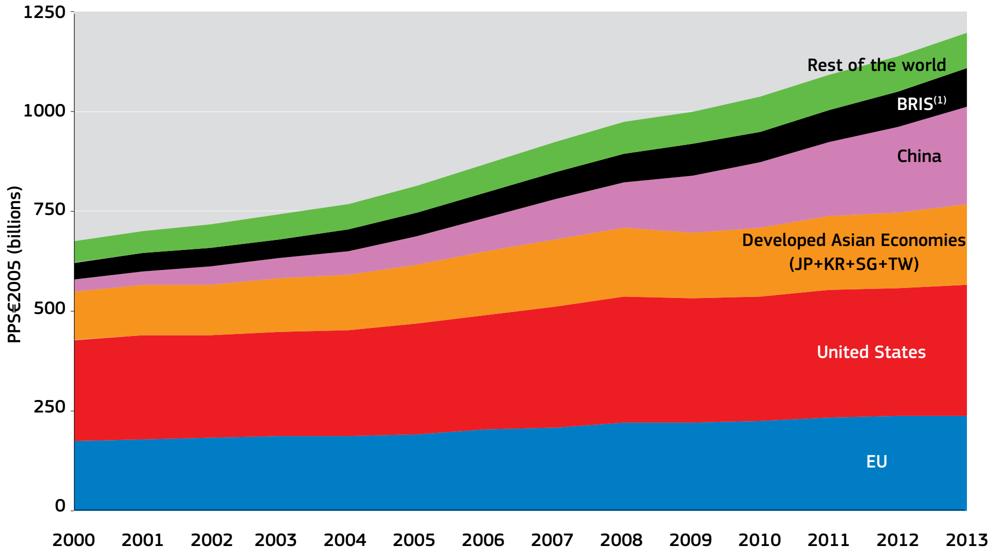
The positive trends in both public and private R&D intensities over the 2007-2014 period allowed total EU R&D intensity to increase from 1.78% in 2007 to 2.03% in 2014: this contrasts with the stagnation of EU R&D intensity over the period from 2000-2007 (EU R&D intensity was at 1.79% in 2000). However, the prolongation of the 2007-2014 trend would lead the EU to miss its 2020 3% R&D intensity target by far: it would result in a level of only 2.28% in 2020. In fact, in order to meet the 2020 target of 3%, the annual growth rate of EU R&D intensity would need to more than triple compared to the average growth rate over the 2007-2014 period (6.7% vs 1.9%)[10]. In addition, the most recent trend seems to point to a deceleration: in 2014, for the first time since 2007, EU R&D intensity did not increase, with a status quo at 2.03%.

The world is becoming more R&D-intensive and the relative weight of the EU in this new global R&D landscape is decreasing, mainly due to the rapid rise of China.

Figure I-2-4 shows the continuous increase in R&D expenditure through which the world is becoming more R&D-intensive: the crisis entailed only a very temporary and limited slowdown in this trend. While all major regions have increased their R&D investments, the most impressive increase is in China.

(10) While we need to bear in mind that the growth rate in R&D intensity over the 2007-2014 period was boosted by a depressed GDP.

Figure I-2-4 **Evolution of world GERD in real terms (PPS€ at 2005 prices and exchange rates), 2000-2013**

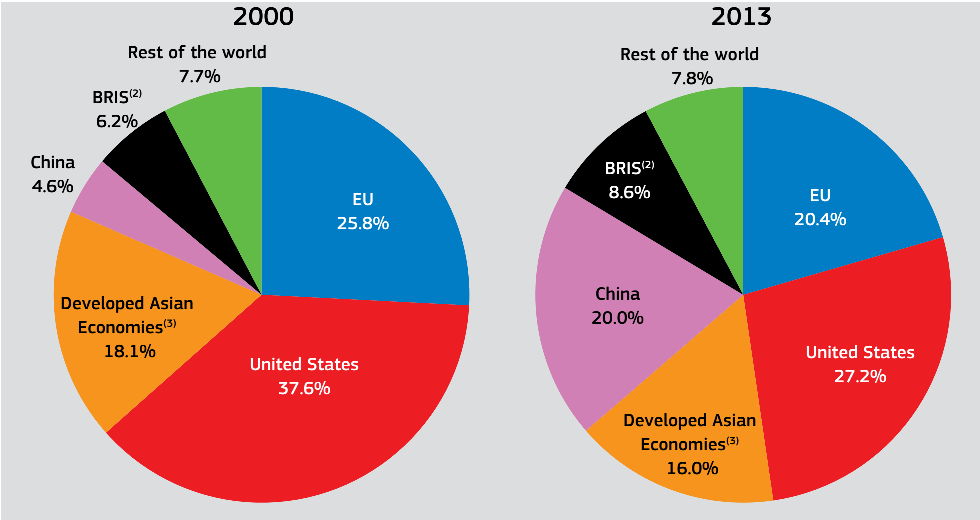


Science, Research and Innovation performance of the EU 2016

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat, OECD, UNESCO
Notes: (1)BR+RU+IN+ZA. (2)Elements of estimation were involded in the compilation of the data.

As is visible in Figure I-2-5, this leads to a changing global R&D landscape, where the relative weight of the EU is decreasing. While in 2000, the EU and US together still represented nearly two-thirds of global R&D expenditure, in 2013, more than half the global R&D expenditure was spent elsewhere. In 2013, the EU represented 20.4% of total R&D expenditure in the world, measured in PPS€ at 2005 prices and exchange rates, down from 25.8% in 2000. The continuously decreasing share of the EU in world R&D expenditure is mainly due to the rapid rise of China, which more than quadrupled its share, from 4.6% in 2000 to 20% in 2013. The decrease in the US share since 2000 has even been slightly more pronounced than that of the EU, from 37.6% to 27.2% in 2013, while the share of the developed Asian economies has eroded from 18.1% in 2000 to 16% in 2013 (in this group of economies, the decrease in Japan's share has been partly compensated for by the increase in South Korea's share).

Figure I-2-5 **% distribution of world GERD[1], 2000 and 2013**



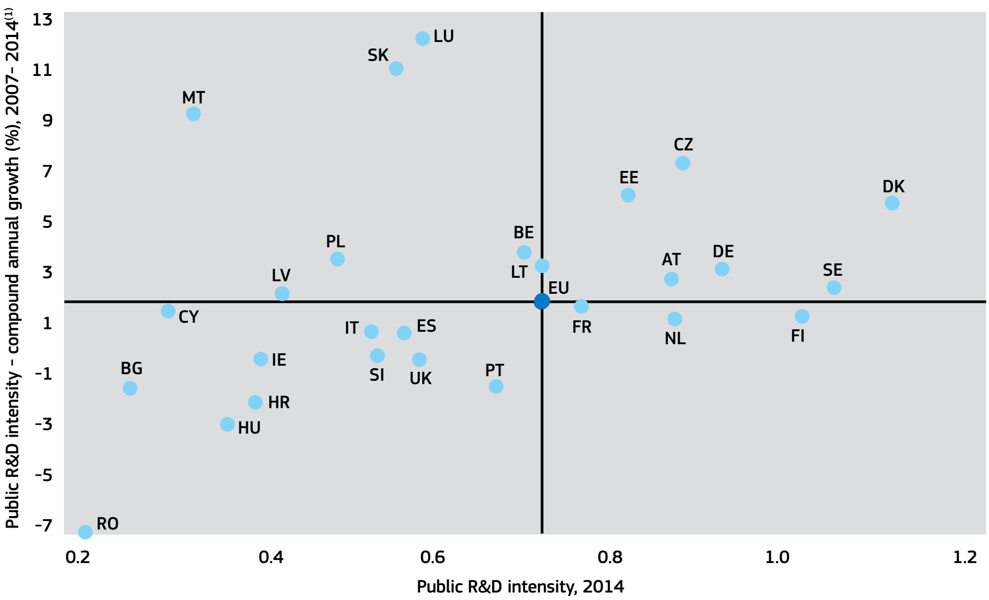
Science, Research and Innovation performance of the EU 2016

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat, OECD, UNESCO
Notes: [1]The % shares were calculated from estimated values in current PPS€. [2]BR+RU+IN+ZA. [3]JP+KR+SG+TW.

R&D investments in the Member States

Trends in public R&D intensity over the crisis period have been very divergent between Member States. Remarkable growths in public R&D intensity have been observed in some advanced economies such as those of Denmark and Germany and in some economies that are catching-up, such as Estonia and the Czech Republic. However, in Romania, Bulgaria, Croatia and Hungary, reduced funding for public R&D risks delaying considerably the transformation of these countries into knowledge-based economies.

Figure I-2-6 **Public R&D intensity, 2014 and compound annual growth, 2007-2014**



Science, Research and Innovation performance of the EU 2016

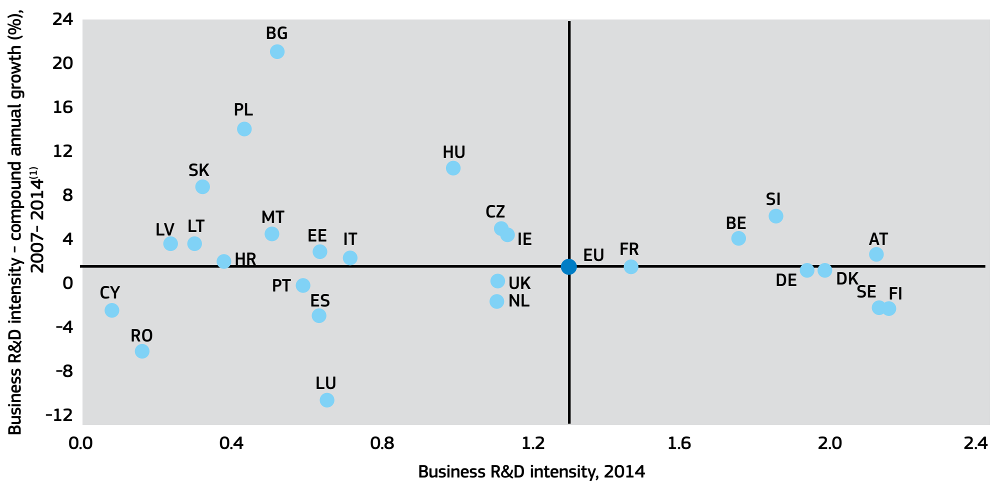
Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat
Notes: [1]PT: 2008-2013. [2]EL: Greece is not included on the graph because valid data are available only for 2011-2014.

Many Member States which already had a relatively strong public R&D system before the crisis continued to increase their investments throughout the crisis period, with notably remarkable evolutions in Denmark and Germany, as is visible in Figure I-2-6. Several Central and Eastern European countries (in particular Slovakia, Estonia, and the Czech Republic) as well as Malta also display strong growth rates in public R&D intensity since 2007, thanks in particular to the significant mobilisation of European Structural Funds, as analysed in Part II. As a result, the Estonian and Czech public R&D intensities are now higher than the EU average.

However, the most striking -and worrying- trend is that some Member States which already had a public R&D intensity well below the EU average, such as Bulgaria, Romania, Croatia and Hungary, have experienced budget cuts in their public R&D in recent years instead of building R&I capacities through more investments. Furthermore, the negative trends in some Member States with a strong public R&I system, such as the United Kingdom, are worrying as they risk undermining their strengths. Finally, the below-average trends for Ireland, Slovenia and Spain are to be noted as they are even more negative than would appear at first glance due to two phenomena. First, as these are all countries that were strongly hit by the crisis and which experienced very significant drops in GDP, the trend in public expenditures is more negative in real terms than in percentage of GDP. Second, in line with what was observed at the EU level, public R&D expenditure increased significantly in these countries between 2007 and 2009, and thus comparing 2014 with 2007 does not allow for one to distinguish the more important drop compared to 2009. Comparing 2014 to 2009, public R&D expenditure decreased in Slovenia in real terms by 15%, in Spain by 14% and in Ireland by 14%.

Trends in business R&D intensity over the crisis period are also divergent between Member States. While the strongest growth rates of business R&D intensities can be found among the economies that are catching-up in Central and Eastern Europe, there is also a group of advanced economies which continue to progress from already relatively high pre-crisis levels of business R&D intensities (Belgium, Denmark, Austria, Germany, and France). Negative trends are found in various types of situations: in Member States with very high levels of business R&D intensities (Finland and Sweden), moderate levels (notably Luxembourg and Spain) and very low levels (Romania and Cyprus).

Figure I-2-7 **Business R&D intensity, 2014 and compound annual growth, 2007-2014**



Science, Research and Innovation performance of the EU 2016

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

Data: Eurostat

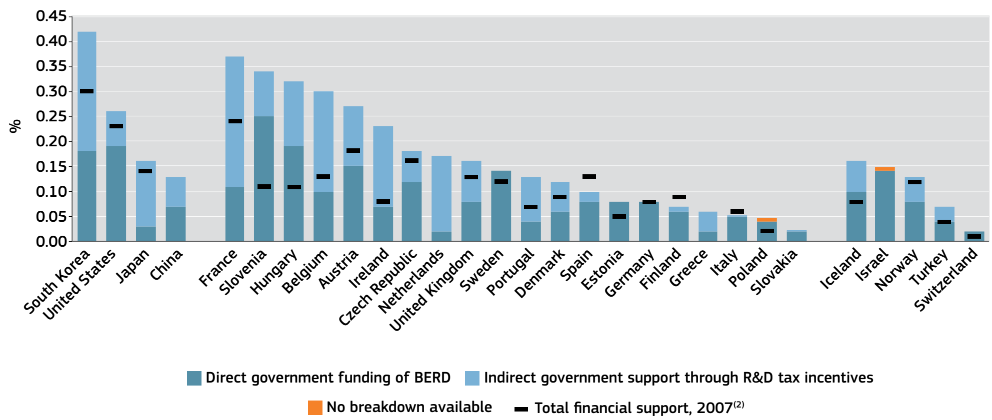
Notes: (1)ES, SI: 2008-2014. (2)EL: Greece is not included on the graph because valid data are available only for 2011-2014.

As shown in Figure I-2-7, the strongest growth rates of business R&D intensity over the 2007-2014 period can be observed in the economies that are catching-up in Central and Eastern Europe (Bulgaria, Poland, Slovakia, Hungary and Slovenia). The situations and developments in business R&D in this group of countries are, however, of a diverse nature. For instance, while foreign direct investments in R&D play an increasing role in Poland, as reflected in the rise of the share of foreign-affiliated R&D in business R&D expenditure from 31% in 2007 to 45% in 2011, in Slovenia this share remained stable (29% in 2011 vs 28% in 2007). In general, strong growth rates from very low starting points have to be interpreted with caution; the limited amounts involved may be linked to a very limited number of investments and/or may be linked to particular sectorial phenomena instead of truly representing the overall attractiveness of the country in terms of R&D investments. This is the case in Bulgaria, where the increase has been concentrated in one sector (R&D services) and may be linked to clinical trials carried out for foreign pharmaceutical companies.

Positive growth rates starting from an average or high level of business R&D investments, as seen in several advanced EU economies (Belgium, France, Denmark, Austria and Germany), can be more safely interpreted as reflecting the impact of the policies put in place to stimulate business R&D investment, such as R&D tax incentives and 'Competitiveness poles' in Belgium and France, combined with the opportunities linked to their industrial specialisations (e.g. 'Pharmaceuticals' in Belgium and Denmark, 'Motors vehicles' in Germany). In contrast, negative trends in several Member States on the Western side of the EU (such as Luxembourg and Spain) put into question the effectiveness of their policy mixes to leverage business R&D. The two Member States with the highest business R&D intensities, Finland and Sweden, also experienced negative trends, linked to the difficulties in their ICT sectors.

Through notably increased use of R&D fiscal incentives, the level of public support for business R&D has increased throughout the crisis period in many Member States.

Figure I-2-8 Public support for business R&D, 2007 and 2013[1]



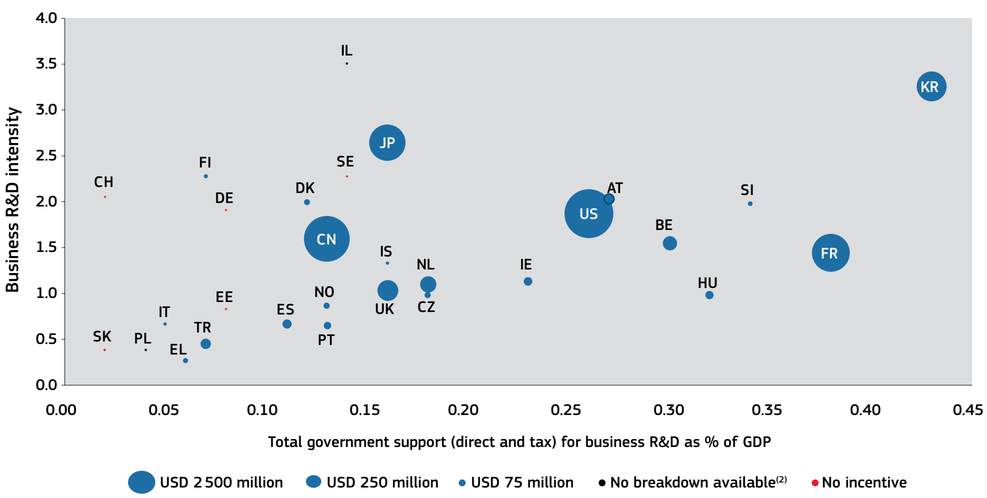
Science, Research and Innovation performance of the EU 2016

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: OECD (STI Scoreboard, 2015)
Notes: [1]For ES, FR, PT, UK and NO, preliminary R&D tax incentive estimates are reported for 2013 (or closest year). For BE, IE, ES, CH, IL and US values refer to 2012. For IS values refer to 2011. Estimates of direct funding for BE, FR, IT and PT are based on imputing the share of direct government-funded BERD in the previous year to the current ratio of BERD to GDP. For AT, the 2011 share is used for 2013. In AT, R&D tax incentive support is included in official estimates of direct government funding of business R&D. It is removed from direct funding estimates to avoid double counting. DE, EE, SE and CH did not provide information on expenditure-based R&D tax incentives for 2013. For IL, the R&D component of incentives cannot be identified separately at present. No data on the cost of expenditure-based R&D tax incentive support are available for PL. Estimates refer to the cost of incentives for business expenditures on R&D, both intramural and extramural, unless otherwise specified. Direct support values refer only to intramural R&D expenditures. [2]CZ, IE, ES, FR, HU, PT, UK, NO, CH, US, JP: 2006; IT, TR: 2008; EL, NL, SK, IL, CN: Not available.

Figure I-2-8 shows that total public support for business R&D, composed of direct funding (through grants, loans, procurement) and indirect funding (through R&D fiscal incentives), has increased in percentage points of GDP in many Member States between 2007 and 2013. Particularly strong increases are noticeable in Slovenia, Belgium, Ireland, Estonia, Hungary, France, Portugal and Austria. In all these countries except Estonia, R&D fiscal incentives play a key role. The amount of foregone tax revenues is even higher than direct funding in Belgium, Ireland, France, Portugal and the Netherlands.

While Figure I-2-9 makes visible the logical correlation between the volume of public support for business R&D (in percentage of GDP) and the business R&D intensity, the interesting elements are the outliers. For instance, in France, taking into account a level of business R&D intensity which is not very high, the intensity of public support for business R&D appears to be quite striking. On the contrary, several Member States combined a very level of business R&D intensity without a high level of public funding of business R&D. It is to be noted, however, that all these Member States display a very high level of public R&D expenditure (see Figure 6), possibly reflecting an approach where the support for public R&D is seen as having a more important role to play in fostering business R&D than (direct and indirect) public funding for business R&D. As shown in Figures 6, 7 and 8, Germany and Denmark combine increased public R&D intensity with stagnating public support for business R&D (at a rather low level) and increased business R&D intensity. In Germany, an important way for the public authorities to foster business R&I is to support public R&D organisations which are able to provide services to businesses through contractual research (as reflected in the volume of R&D expenditure performed in the public R&D system while being funded by business representing 0.11% of GDP, the highest level in the EU — the EU average is 0.05%).

Figure I-2-9 **Business R&D intensity versus public support for business R&D as % of GDP, 2013[1]**

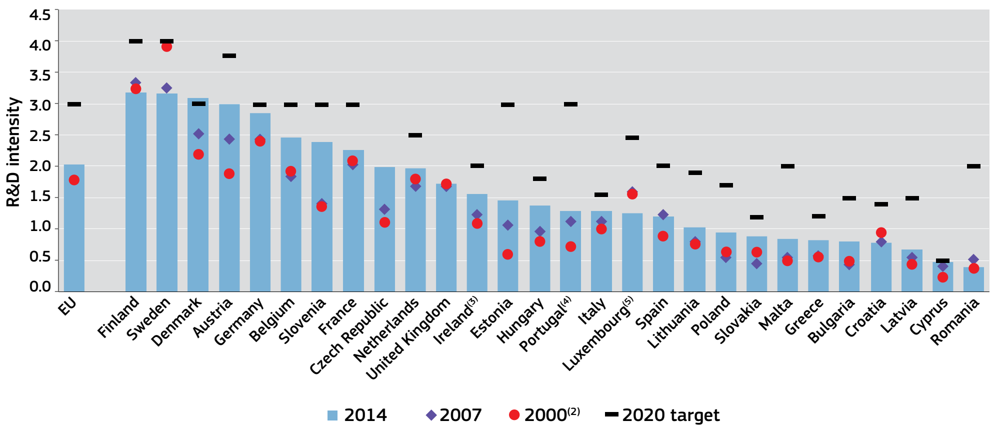


Science, Research and Innovation performance of the EU 2016

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: OECD (STI Scoreboard, 2015)
Notes: [1]The bubble size refers to volume of tax support for business R&D, Millions USD PPP, 2013 or latest available year. ES, FR, PT, UK, NO: Preliminary R&D tax incentive estimates reported for 2013 (or closest year). BE, FR, IT, PT: Estimates of direct funding based on imputing the share of direct government-funded BERD in the previous year to the current ratio of BERD to GDP. AT: 2011 share is used for 2013; R&D tax incentive support is included in official estimates of direct government funding of business R&D. It is removed from direct funding estimates to avoid double counting. [2]There is no breakdown available between Government direct funding and the volume of tax support for business R&D. [3]Elements of estimation were involved in the compilation of the data.

While the R&D intensity has increased over the 2007-2014 period in 21 Member States, for most Member States a very significant acceleration in R&D intensity growth is required to meet their national 2020 R&D intensity targets. The situation is even more challenging for Romania, Luxembourg, Portugal, Spain, Sweden, Croatia and Finland, which need to reverse a decreasing trend.

Figure I-2-10 **R&D intensity 2000, 2007, 2014 and 2020 target[1]**



Science, Research and Innovation performance of the EU 2016

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat
Notes: [1]CZ, UK: R&D intensity targets are not available. [2]EL, SE: 2001; HR: 2002; LT, MT: 2004. [3]IE: The R&D intensity target is 2.5% of GNP which is estimated to be equivalent to 2.0% of GDP. [4]PT: The R&D intensity target is between 2.70% and 3.30% (3.00% was assumed). [5]LU: The R&D intensity target is between 2.30% and 2.60% (2.45% was assumed). [6]DK, EL, FR, HU, NL, PT, RO, SI, SE: Breaks in series occur between 2000 and 2014.

While Figure I-2-10 presents the levels of total R&D intensity reached in each Member State in 2000, 2007 and 2014 and the national 2020 R&D intensity targets, Figure I-2-11 below allows for a detailed assessment of the situation for each Member State through a comparison between the annual average R&D intensity growth, which is required to meet its 2020 target, and the average growth over the period from 2007-2014.

While the R&D intensity in 21 Member States increased over the 2007-2014 period, the table shows that for most Member States a very significant acceleration of R&D intensity growth is required to meet their target. The situation is even more challenging for Romania, Luxembourg, Portugal, Spain, Sweden, Croatia and Finland, which need to reverse a decreasing trend. While Denmark, Cyprus and Germany achieved or can be expected to soon achieve their targets, the level of ambition of these targets can be questioned.

Slovenia, Slovakia, Hungary and Belgium seem on track to reach their target, but the sustainability of the recent trends needs to be carefully assessed in each case. For instance, in Hungary, the contrasting trends in public and private R&D intensity put into question the sustainability of the overall growth of the R&D intensity, as the diminishing public R&D intensity undermines the availability of highly skilled human resources in science and technology.

Figure I-2-11 Situation of each Member State with regard to its R&D intensity target

	R&D intensity 2014 (provisional)	R&D intensity target 2020	R&D intensity compound annual growth (%) 2000-2014(1)	R&D intensity compound annual growth (%) 2007-2014(2)	R&D intensity compound annual growth (%) required to meet the 2020 target 2014-2020
Belgium	*2.46*	*3.00*	*+1.7*	*+4.2*	*3.4*
Bulgaria	*0.80*	*1.50*	*+3.5*	*+9.0*	*11.1*
Czech Republic	*2.00*	*:(3)*	*+4.2*	*+6.3*	*:*
Denmark	*3.08*	*3.00*	*+2.3*	*+3.0*	Target reached
Germany	*2.84*	*3.00*	*+1.2*	*+2.2*	*0.9*
Estonia	*1.46*	*3.00*	*+6.6*	*+4.6*	*12.7*
Ireland	*1.55*	*2.00(4)*	*+2.5*	*+3.3*	*4.4*
Greece	*0.83*	*1.21*	*+2.8*	*+3.8*	*6.5*
Spain	*1.20*	*2.00*	*+2.2*	*-0.4*	*8.9*
France	*2.26*	*3.00*	*+0.9*	*+2.1*	*4.9*
Croatia	0.79	*1.40*	-1.5	-0.1	*10.0*
Italy	*1.29*	*1.53*	*+1.8*	*+1.8*	*3.0*
Cyprus	*0.47*	*0.50*	*+5.3*	*+2.2*	*1.0*
Latvia	*0.68*	*1.50*	*+3.1*	*+2.9*	*14.2*
Lithuania	*1.02*	*1.90*	*+3.1*	*+3.5*	*11.0*
Luxembourg	*1.24*	*2.30 - 2.60(5)*	*-1.6*	*-3.6*	*12.0*
Hungary	1.38	*1.80*	+4.9	+5.3	*4.5*
Malta	*0.85*	*2.00*	*+5.6*	*+6.4*	*15.4*
Netherlands	*1.97*	*2.50*	*-0.1*	*+1.0*	*4.0*
Austria	*2.99*	*3.76*	*+3.3*	*+3.0*	*3.9*
Poland	0.94	*1.70*	+2.7	+7.5	*10.5*
Portugal	*1.29*	*2.70 – 3.30(6)*	*+2.6*	*-1.9*	*15.1*
Romania	0.38	*2.00*	-0.3	-6.3	*31.7*
Slovenia	*2.39*	*3.00*	*+2.3*	*+4.5*	*3.9*
Slovakia	0.89	*1.20*	+2.4	+10.2	*5.1*
Finland	3.17	*4.00*	-0.2	-0.8	*3.9*
Sweden	*3.16*	*4.00*	*-1.3*	*-0.4*	*4.0*
United Kingdom	*1.72*	*:*	*-0.03*	*+0.3*	*:*
EU	*2.03*	*3.00*	*+0.9*	*+1.9*	*6.7*

Science, Research and Innovation performance of the EU 2016

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

Data: Eurostat, Member States

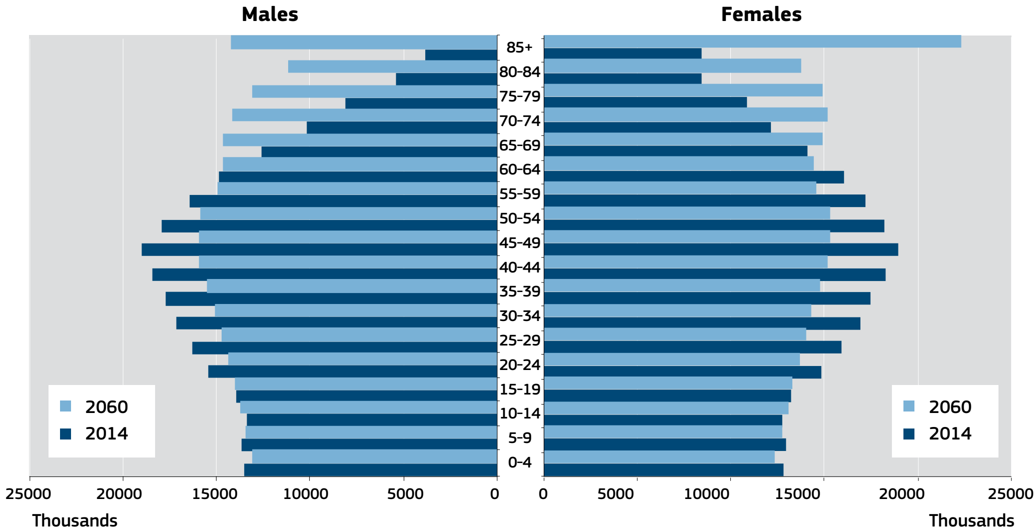
Notes: (1)HR: 2002-2014; EL, SE: 2003-2014; LT, MT: 2004-2014. (2)EL, PT, SI: 2008-2014. (3)CZ: A target (of 1%) is available only for the public sector. (4)IE: The national target of 2.5% of GNP has been estimated to equal 2.0% of GDP. (5)LU: A 2020 target of 2.45% was assumed. (6)PT: A 2020 target of 3.00 was assumed. (7)Values in italics are estimated or provisional.

Investment in education and skills and human resources in science and technology

Moving towards a knowledge-intensive society and economy increases the importance of skilled human capital for research, innovation and economic development. This section looks at key demographic trends, at levels of investment in education and training, at outcomes in terms of educational attainment and skills, and at the evolution of human resources in science and technology in the EU and in key competitors.

The growing knowledge orientation of the economy together with unfavourable demographic trends in Europe makes investment in skills and their lifelong upgrading increasingly important.

Figure I-2-12 EU population age structure 2014 and 2060



Science, Research and Innovation performance of the EU 2016
Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat

The EU is facing an increasing demand for skilled labour (as evidenced for instance by data on unemployment rates by level of education: in 2014 in the EU unemployment rates for those with tertiary attainment were one third of the rates for those with low levels of educational attainment), including researchers. The driving force behind this trend is the continuously growing knowledge orientation of the economy, with value chains becoming longer, more complex and knowledge-intensive.

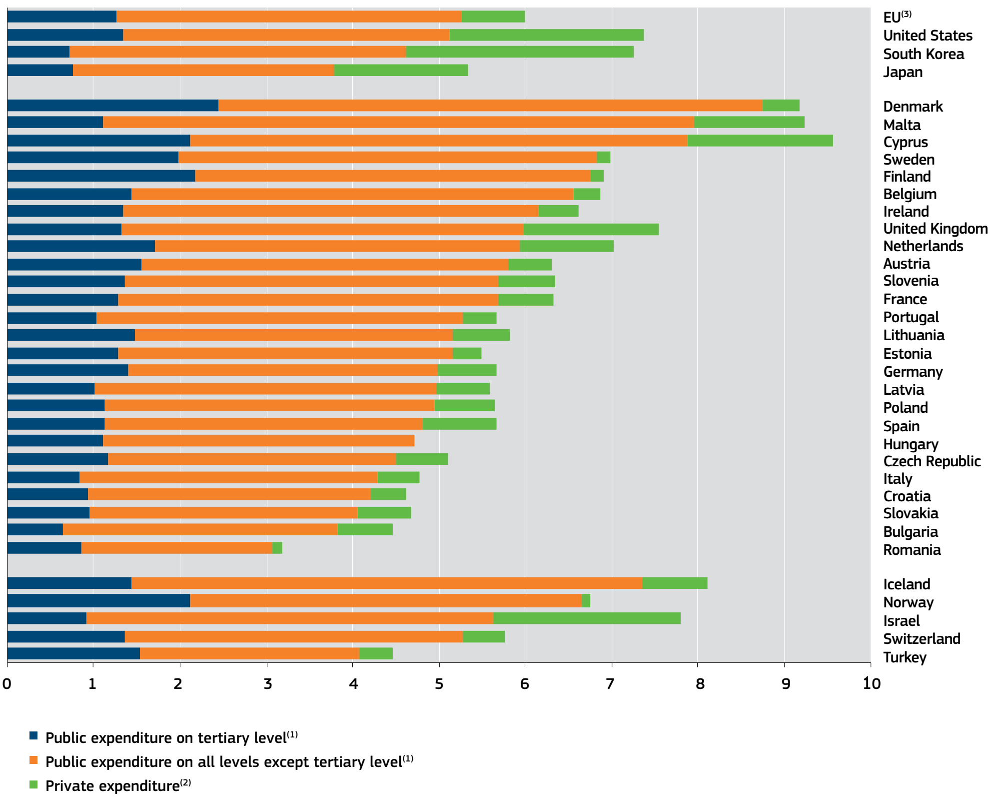
At the same time, current demographic developments (see Figure I-2-12) imply a decreasing number of young people entering the labour market in the coming years, while the baby boomer generation is set to retire in the next decade. The EU's working age population peaked in 2011, with southern, central and eastern European countries more affected by the shrinking labour force than northern and western countries. At the same time, life expectancy is continuously increasing and the old age dependency ratio is growing, directly (employment in health and care sector) and indirectly (longer working life) affecting the labour market.

The demographic shift towards fewer young people and more elderly people presents Europe with important challenges. Given strong investment in excellence (US) and in basic skills (East Asia) in other world regions, a global massification in tertiary education and a more favourable demography outside Europe, the EU faces growing competitive challenges as regards the quality and quantity of its human capital, which could endanger its traditional comparative advantage as regards skilled labour.

While investment levels in compulsory education are near the international average, the EU is still underinvesting in tertiary education compared to the US and South Korea. As regards tertiary education, there are wide disparities in spending levels between Member States, with Nordic countries and Cyprus in the lead.

Public investment in education in the EU is at a similar level as in the US and higher than in Japan and South Korea (see Figure I-2-13). However, when public and private spending are considered together, the EU is outperformed by the US and South Korea. There are also large differences in spending levels between EU Member States. The low level of spending on education in countries such as Bulgaria and Romania is somewhat reflected in educational outcomes, as evidenced by the PISA study, where both countries score low, although non-financial factors also play an important role. The big differences between Member States in the quality of education, also compared to spending levels, shows that there is potential for improving educational outcomes, for example, via mutual learning between Member States and the identification of good practice. Skills tests such as PISA also show that reforms bear fruit and that it is possible to improve outcomes considerably in the medium term. There is a general consensus that early investment in education has the highest returns, since the outcomes of earlier stages of education also determine results at later stages. High levels of numeracy at the lower secondary level are also important for the outcomes of learning at the upper secondary level, including vocational streams, and have an impact on enrolment in science and technology studies later in life.

Figure I-2-13 Expenditure on educational institutions from public and private sources as % of GDP, 2011



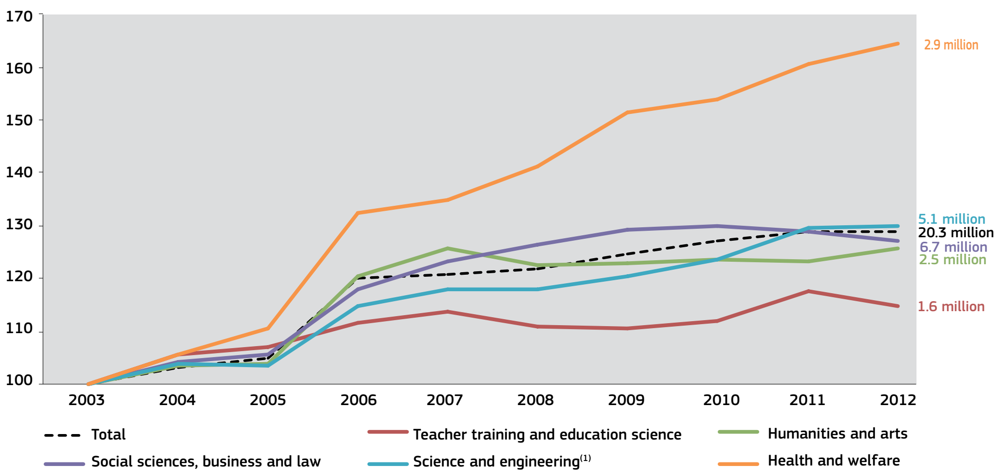
Science, Research and Innovation performance of the EU 2016

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat, OECD
Notes: [1]EL, LU: No data available. [2]EL, LU, HU: No data available. [3]EU: Croatia is not included.

While spending on primary and secondary education is comparable in the EU to the levels found in North America or East Asia, there is a marked gap in tertiary education, mainly caused by lower levels of private spending in Europe. Public and private spending on tertiary education as a percentage of GDP is about 1.4 percentage points higher in the US, compared to the EU. The spending gap per tertiary student currently amounts to over EUR 10 000 per year (or about EUR 200 billion for tertiary education as a whole). The Nordic countries and Cyprus (in this country a large share of tertiary students traditionally study abroad with corresponding financing requirements) show relatively high tertiary spending levels. Tertiary education spending levels show significant correlation to participation and attainment rates and also to scientific excellence, both important factors for research and innovation systems.

After a modest acceleration caused by the crisis, the number of tertiary students in the EU is currently stagnating and could, for demographic reasons, start to decline in the near future. This also anticipates a slower growth rate in the number of tertiary graduates in the medium term. The evolution of the number of science and engineering students, after lagging behind, has caught up since the crisis.

Figure I-2-14 Evolution of the number of tertiary students in the EU (index 2003 = 100)



Science, Research and Innovation performance of the EU 2016

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat
Note: (1)Includes the total number of students from both 'science, mathematics and computing' and 'engineering, manufacturing and construction'.

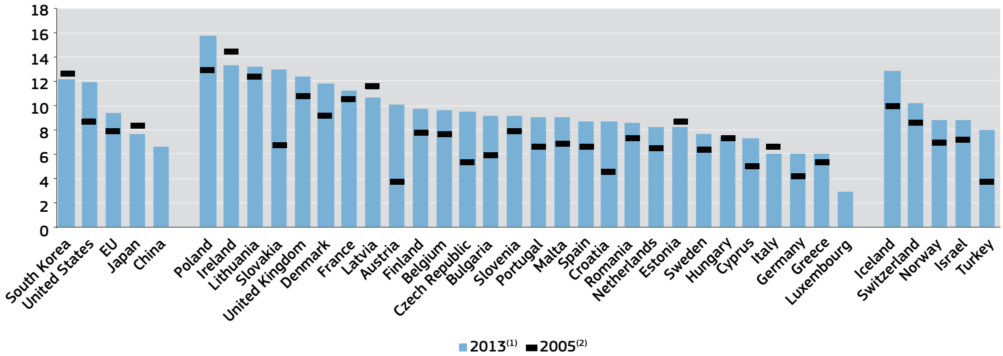
As tertiary participation rates approach saturation in many Member States, and because of shrinking cohort size, the number of tertiary students in the EU is now stagnating at about 20 million students (see Figure I-2-14 above) and might, for demographic reasons, start to decline in the near future. The evolution of the number of science and engineering students, after lagging behind, has in recent years caught up with overall trends. Linked to overall demographic trends, and in particular the shrinking size of youth cohorts, the number of students in teacher training and education science has fallen in the recent past, while the number of students in health and welfare is increasing significantly.

There is still scientific debate about the optimal number and share of university graduates in the population and their relevance for balanced R&I systems. However, available statistical data show that returns to tertiary education in terms of average earnings and employment rates are still high, suggesting that there is not yet an over-supply of tertiary graduates.

However manufacturing-oriented economies, such as Germany and Austria for example, also traditionally rely on a strong supply of graduates from vocational education and training.

Europe has progressed well in the past in terms of tertiary graduates per 1 000 population, but still lags behind the US and Japan and growth might decline in the future.

Figure I-2-15 **New graduates from tertiary education (per thousand population), 2005 and 2013**



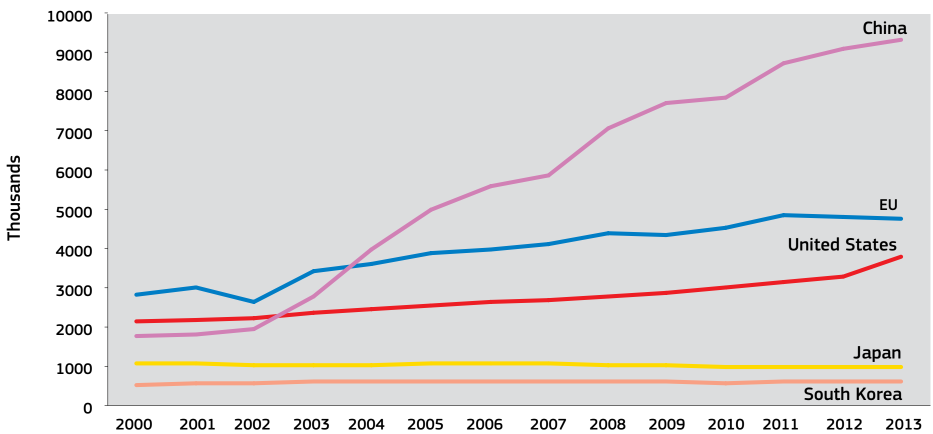
Science, Research and Innovation performance of the EU 2016

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat, OECD
Notes: (1)IL, CN: 2012. (2)LU, CN: No data available for 2005.

As regards new tertiary graduates per thousand population (see Figure I-2-15 above) the EU performs at a similar level as the US and Japan, but below South Korea. Differences between Member States are significant, with several eastern European countries (Poland, Lithuania and Slovakia) showing high numbers of new graduates and thus catching up on tertiary attainment. These countries also experienced high growth rates in the past.

In terms of the absolute number of tertiary graduates, and despite good progress, the EU has been overtaken by China, which is now the world's largest producer of tertiary graduates by far.

Figure I-2-16 **Total number of tertiary graduates, 2000-2013**



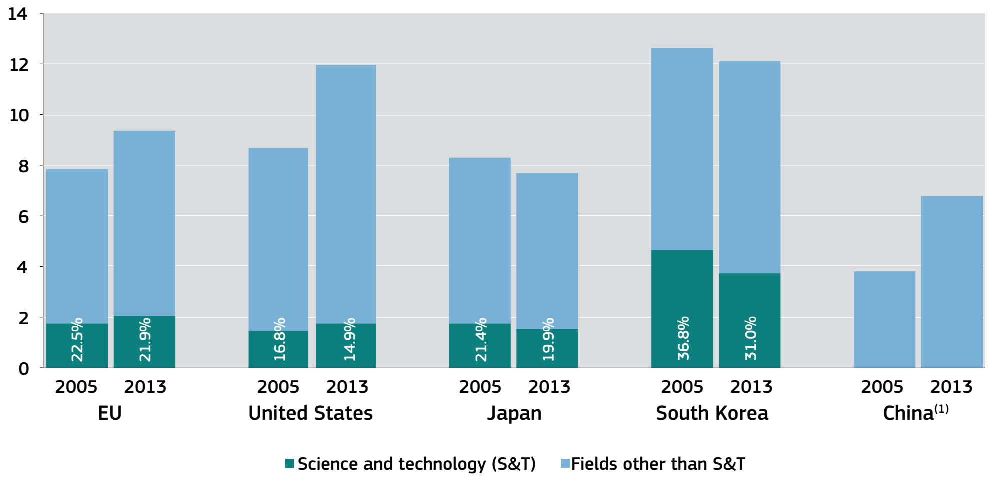
Science, Research and Innovation performance of the EU 2016

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat, OECD, UNESCO (UIS)
Note: (1)Elements of estimation were involved in the compilation of the data.

In 2004, China (with a population 2.7 times the EU total) overtook the EU in terms of the absolute number of tertiary graduates (see Figure I-2-16 above). The number of tertiary graduates has quintupled in China since 2001 to surpass 9 million in 2012, nearly twice the EU figure. There was, at the same time, stagnation in the number of tertiary graduates in Japan and South Korea, as tertiary participation rates in these countries are reaching saturation and demographic factors, such as declining cohort size, come into play.

The EU has progressed more than the US, Japan and South Korea in the share and relative number of science and technology graduates, but South Korea still has a higher share.

Figure I-2-17 Tertiary graduates per thousand population, 2005 and 2013 (% share of science and technology graduates in total graduates)



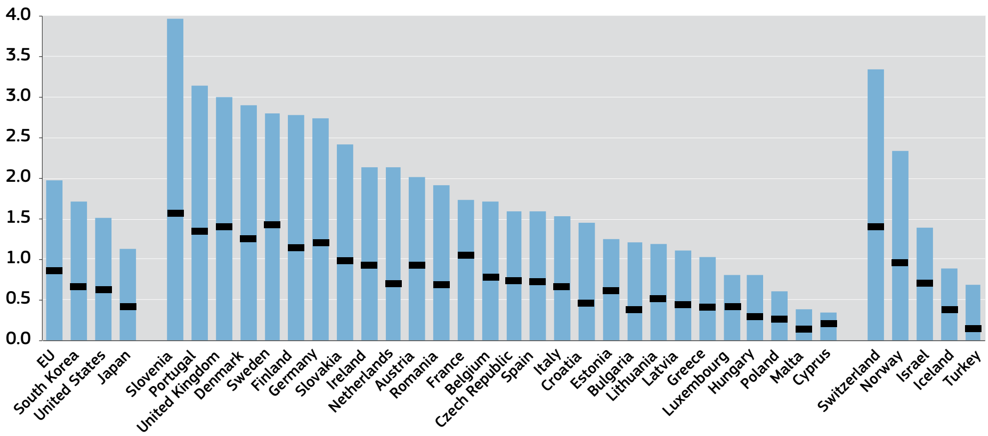
Science, Research and Innovation performance of the EU 2016

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat, OECD, UNESCO (UIS)
Note: (1)CN: Data refer to total tertiary graduates per thousand population. A breakdown of the total between S&T and fields other than S&T is not available.

As regards science and technology graduates (see Figure I-2-17 above) the EU countries have progressed more since 2005 in terms of graduates per 1 000 population than the US, Japan and South Korea (partially as a result of the Bologna effect of more degree levels and more double-counting), but South Korea still has a much higher share of S&E graduates in all tertiary graduates and more graduates relative to population.

The EU performs well in the production of new doctoral graduates, including in the field of science and technology. Some EU countries are among the best performers worldwide.

Figure I-2-18 **New doctoral graduates per thousand population aged 25-34, 2013**



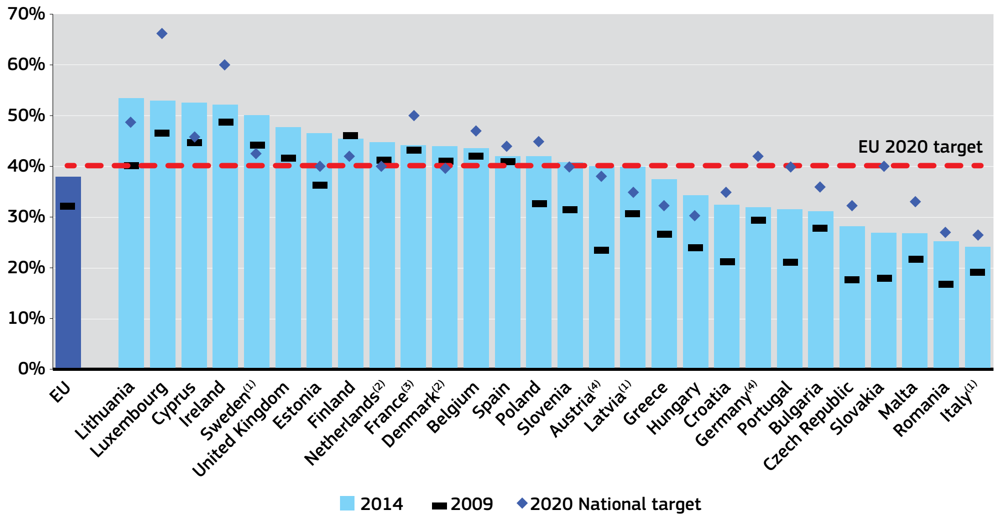
Science, Research and Innovation performance of the EU 2016

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat, OECD
Notes: (1)IS, IL: 2012. (2)PL: 2009; IS, IL: 2012.

When it comes to new graduates at the doctoral level (see Figure I-2-18 above), the EU performs at the same level as the US, but outperforms South Korea and Japan. Nordic countries and Germany perform very well; however, in smaller countries the data available understate performance since a high share of students receive their doctoral degrees abroad. Many eastern and southern European countries have a relatively low production of doctoral graduates, partially a result of a perceived lower attractiveness of academic careers.

The EU has made good progress as regards the headline target on tertiary attainment, but still lags behind the US, Japan and South Korea in attainment rates. Furthermore, differences between EU Member States are still significant.

Figure I-2-19 The EU headline target on the tertiary attainment of 30-34 year olds



Science, Research and Innovation performance of the EU 2016

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat
Notes: (1)LV, IT, SE: The 2020 national targets are set as averages between the values provided by the Member State (LV: 34-36%; IT: 26-27%; SE: 40-45%). (2)DK, NL: The 2020 national targets are set at over 40%. (3)FR: The 2020 national targets include persons aged between 17 and 33 years. (4)DE, AT: The 2020 national targets include ISCED97 level 4 attainment.

Progress in the number of tertiary graduates is (with some time lags) also reflected in the evolution of the EU headline target on tertiary attainment (of 30-34 year olds). With a tertiary attainment level of 38% in 2014 (see Figure I-2-19 above), the EU is on track to reach the headline target of 40% by 2020 and will probably even surpass it. Lithuania, Luxembourg, Cyprus and Ireland already have attainment rates of over 50%. Malta, Romania and Italy still show relatively low tertiary attainment rates. Italy has the lowest tertiary attainment rate among OECD countries. Despite the progress achieved, the EU still lags behind tertiary attainment levels of the US (46% in 2013), Japan (58%, 25-34 year olds, 2013) and Korea (68% in 2013).

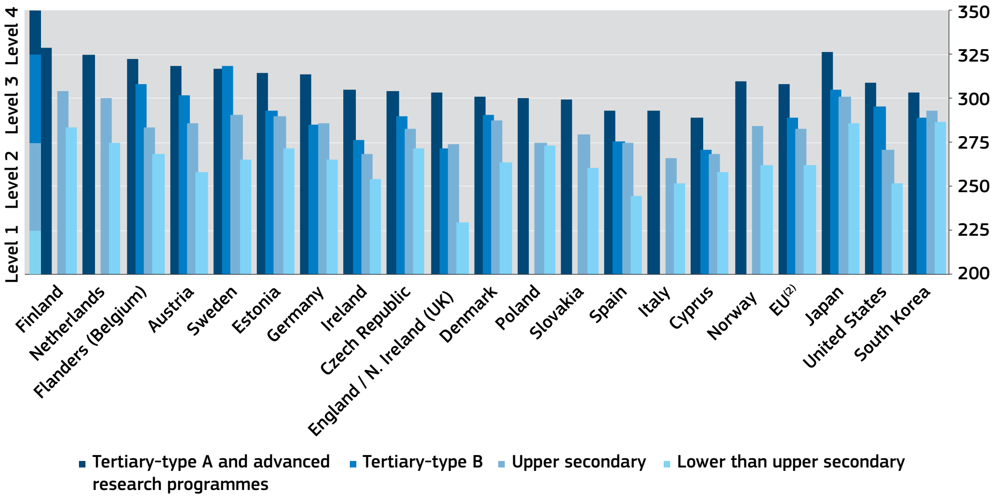
Tertiary attainment is only a proxy for the skill levels acquired. Studies show significant differences between the skill levels of tertiary graduates in EU countries and, therefore, a need to focus more on the quality of education in some countries.

As educational attainment rates in upper secondary and tertiary education reach saturation in many Member States, attention must shift to the quality of education and the acquisition of skills, especially skills relevant for the labour market . The demographic dividend, the declining cohort size in many countries, could help to provide the resources for that.

The results of the OECD PIAAC study on adult skills published in October 2013 (see Figure I-2-20 below) show strong differences between countries in average skill levels for people with the same level of educational attainment. According to this study, upper secondary graduates in Finland and the Netherlands score, on average, higher on key skills than tertiary graduates in countries such as Italy, Spain, the United Kingdom and Cyprus. This implies that there is still substantial room for improving the level of skills acquired in tertiary education in many Member States and that there are good practices to learn from within the EU.

Nevertheless, results should be analysed with care, since the skill levels of young adults might also be influenced by factors outside education, such as work experience, long unemployment spells, or non-formal learning. The skill level acquired at a tertiary level is also dependent on the skills acquired at earlier stages of education.

Figure I-2-20 **Mean literacy proficency scores of 16-29 year olds by highest educational attainment**[1]



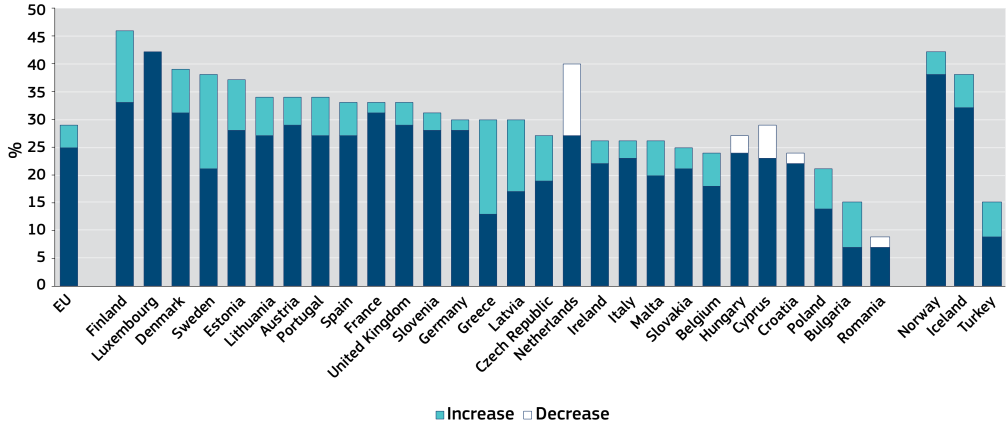
Science, Research and Innovation performance of the EU 2016

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: OECD - Survey of Adult Skills (PIAAC) (2012)
Notes: [1]Lower than upper secondary corresponds to the International Standard Classification of Education (ISCED97) categories 1, 2 and 3C short. Upper secondary education includes ISCED 3A, 3B, 3C long and 4. Tertiary type B corresponds to ISCED 5B. Tertiary type A corresponds to ISCED 5A and advanced research programmes correspond to ISCED 6. Where possible, foreign qualifications are included as per their closest correspondence to the respective national education systems. [2]EU is the unweighted average of the available scores for Member States.

As regards the increasingly important ICT skills, the Eurostat ICT household survey (see Figure I-2-21 below) shows for 2014 strong differences between Member States in the share of the population aged 15-74 with high computer skills (individuals who have carried out five or six out of six computer-related activities). The Nordic countries, Estonia and Luxembourg, perform best in this area. They also tend to have relatively high shares of ICT start-ups. The lowest performers in the EU as regards computer skills among the population are Romania and Bulgaria, countries with important software sectors, but where low per capita incomes lead to a relatively low household penetration of computers.

The share of individuals with high computer skills in the EU population is tending to increase, from 23% in 2007, to 25% in 2012, and 29% in 2014. Countries that progressed most in the last five years include Greece, Latvia and Sweden, while some countries even showed a decline in the share of population with high computer skills (the Netherlands, Hungary, Cyprus, Croatia and Romania).

Figure I-2-21 **The share of individuals with high computer skills in the EU population, 2014 and change compared to 2009**

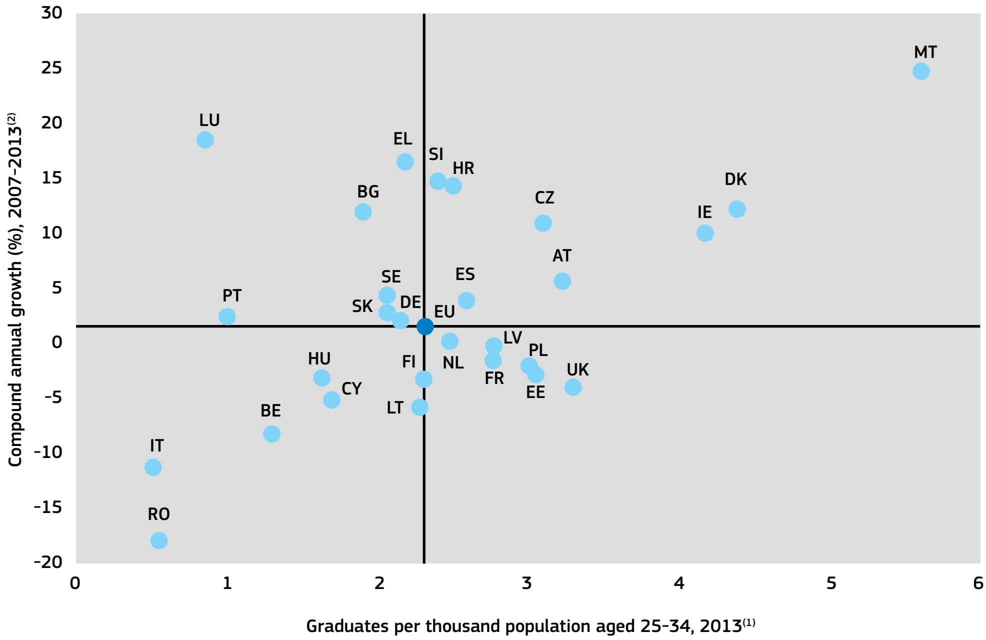


Science, Research and Innovation performance of the EU 2016
Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat

While the population's ICT skills are improving, there is still a growing need for ICT professionals. The number of ICT practitioners has, in the recent past, been growing by about 4% per year. Growth is fuelled by new developments such as Big Data, the Internet of things, the Cloud, and the growth of the app economy.

After 2005, the number of computing graduates declined, however, reflecting (with a time lag) the crisis of 2001, and have increased again since 2009. Nevertheless, the number of computing graduates in the EU increased in the period from 2007–2013 by less than 0.5% per year on average. In many Member States, however, it declined. As a result, there are not enough graduates to fill the vacancies available in this sector. According to recent Commission estimates there could be up to 825 000 vacancies for ICT professionals in the EU by the year 2020. Member States with a high number of computing graduates per 1000 population aged 25-34 include Malta (where an online gaming cluster is developing), Denmark, and Ireland (where many US ICT companies have their European headquarters), while figures are relatively low in Portugal, Luxembourg, Romania and Italy. However, in some countries, including Romania, the figures available tend to understate performance since computing is often integrated into subject areas such as mathematics. Nevertheless, a point of concern is that the number of computing studies graduates has decreased since 2013 by over 10% in countries such as Romania and Italy (see Figure I-2-22).

Figure I-2-22 **Graduates in the field of computing per thousand population aged 25-34, 2013 and compound annual growth, 2007-2013**



Science, Research and Innovation performance of the EU 2016

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat
Notes: [1]NL, PL, EU: 2012. [2]NL, PL: 2007-2012; RO: 2008-2013; IE: 2009-2013; IT: Break in series between 2011 and the previous years.

Employment in science and technology has been resilient during the crisis. While total employment declined, the number of researchers and R&D personnel has expanded considerably since 2008.

An adequate supply of skilled human resources is vital for the functioning of R&I systems and for the development of science and technology-intensive economic sectors. The EU hereby faces increasing demographic challenges in the coming decades with small young cohorts entering the labour market combined with a retiring baby boomer generation and a potential risk of sectoral and regional bottlenecks in the supply of skilled workers. However, rapid technological progress and changes in workplace requirements, growing inter-disciplinarity and a resulting low predictability of future skills needs make planning and foresight difficult. A certain surplus of skilled people can stimulate economic development and innovation, while growing internationalisation of labour markets make regional or national skills gaps less severe. On the other hand, there is growing international and inter-sectoral competition for highly skilled individuals.

The EU's active population in 2013 (referring to the total labour force, which includes both employed and unemployed persons) amounted to about 241 million, of which 215 million were employed and 26 million unemployed (see Figure I-2-23 below). Human resources in science and technology (HRST), that is people with tertiary attainment or working in an S&T field, accounted for 117.7 million people in the EU, or 54.6% of total employment, a share that has shown a constant increase in the past. Those who have successfully completed tertiary-level education (HRSTE) accounted for 42.0% of total employment, with Ireland, Cyprus and Luxembourg showing the highest shares, while those who have both completed tertiary-level education and are currently employed in an S&T occupation (HRSTC) accounted for 21.5% of total employment. This implies that about half of tertiary education graduates are employed in S&T occupations.

Figure I-2-23 **Key data on human resources in science and technology in the EU**

	Total (000s) 2014	as % of total employment 2014	Compound annual growth (%) 2008-2014[1]
Active population	242 511	111	0.2
Total employment (resident population concept - LFS)	217 709	100	-0.4
HRST - Human Resources in Science and Technology	120 062	55.1	2.2
HRSTE - Human Resources in Science and Technology - Education	92 639	42.6	3.4
HRSTO - Human Resources in Science and Technology - Occupation	74 754	34.3	0.9
HRSTC - Human Resources in Science and Technology - Core	47 331	21.7	2.3
SE - Scientists and Engineers	16 099	7.4	1.4
Total R&D personnel (FTE)	2 756	1.3	1.9
Researchers (FTE)	1 768	0.8	2.5

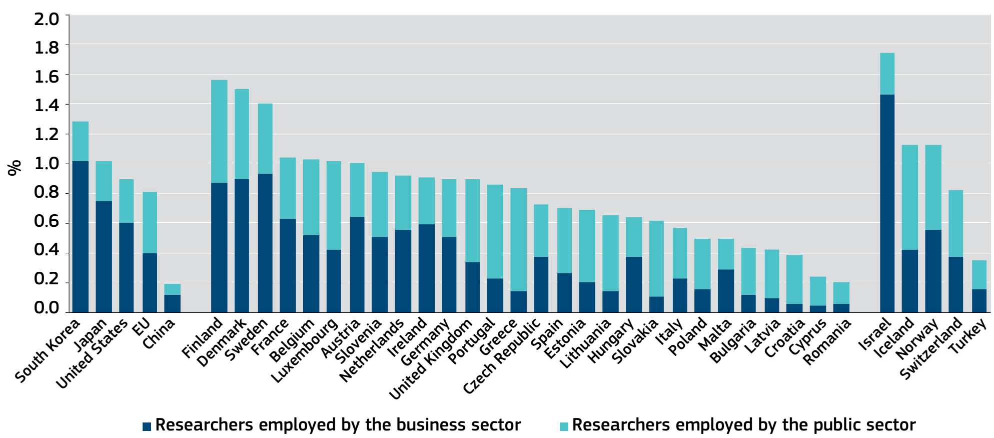
Science, Research and Innovation performance of the EU 2016
Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat
Note: [1]Break in series between 2011 and the previous years for Human Resources in Science and Technology data (except for the Education sub-group).

Human resources in Science and Technology have grown faster than total employment in the past and jobs in this area have been more resilient during the crisis. Whilst total employment decreased on average by 0.7% per year between 2008 and 2013, HRST increased by 2.1% per year, or 12 million, over the whole period, the number of scientists and engineers by 0.9%, research personnel by 2.0% and the number of researchers by 2.5%. This reflects the rising educational attainment of the labour force, as well as the shift to skill-intensive jobs and a knowledge-intensive economy.

Quantitatively, the stock of human resources in science and technology is still growing, partly because of increasing attainment rates. There is no evident overall skills gap yet, but 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 economic structures and development levels and is strongly correlated to the innovation outputs of countries. Countries with high shares of researchers in total employment tend to also be leaders in innovation.

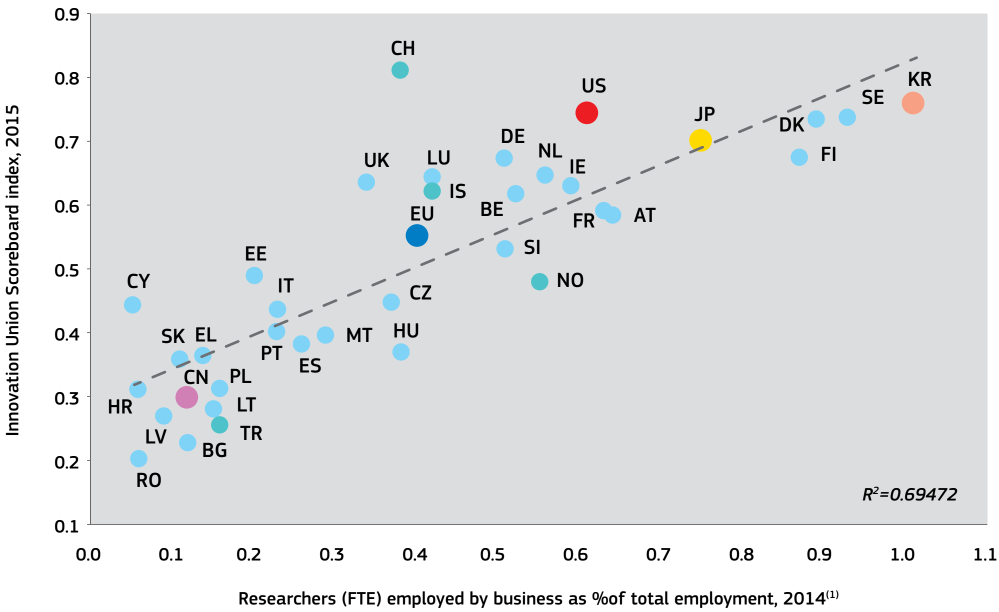
Figure I-2-24 **Total researchers (FTE) as % of total employment, 2014[1]**



Science, Research and Innovation performance of the EU 2016
Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat, OECD
Note: [1]IL, CH, US: 2012; IS, TR, JP, CN, KR: 2013.

In terms of researchers, as a percentage of total employment the EU lags behind the US, Japan and especially South Korea. This is particularly notable when it comes to researchers employed in the business sector (see Figure I-2-24 above). However, compared to the US and especially Japan, where the number of researchers is stagnating, the EU is catching up, while South Korea is pulling further ahead. China shows even stronger growth; it already has the largest number of business researchers in absolute terms and might also soon overtake the EU in terms of the total number of researchers. In the EU, the Nordic countries (Finland, Denmark and Sweden) show the highest share of researchers in total employment and also perform well as regards researchers employed by the business sector. The south-eastern European countries (Croatia, Bulgaria, Cyprus, Romania) and also Latvia show relatively low levels, particularly for researchers in the business sector. On the other hand, many central and eastern European countries (notably Bulgaria, Hungary, Poland) and Malta are catching up in terms of researchers and business enterprise researchers. There is a strong correlation between the share of researchers employed by the business sector and innovation outputs (see Figure I-2-25 below).

Figure I-2-25 **Innovation Union Scoreboard index, 2015 verrus researchers (FTE) employed by business as % of total employment, 2014**



Science, Research and Innovation performance of the EU 2016

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat, OECD
Note: (1)CH, US: 2012; IS, TR, JP, CN, KR: 2013.

The share of female researchers is still far from a gender balance with strong differences between European countries. The Baltic States and south-eastern European countries have the highest share, probably partly as a result of comparatively unattractive salaries and career prospects.

Figure I-2-26 **Researchers (FTE) - Total and business enterprise, 2014**

	Total researchers (FTE)				Business enterprise researchers (FTE)				
	2014[(1)] (thousands)	% of female researchers[(2)]	Compound annual growth (%) 2007-2014	as % of total employment[(3)]	2014[(1)] (thousands)	% of female researchers[(2)]	Compound annual growth (%) 2007-2014	as % of total employment[(3)]	as % of total researchers (FTE)
Belgium	46.9	:	3.7	1.0	23.8	:	4.0	0.5	50.8
Bulgaria	13.1	50.5	2.2	0.4	3.5	43.2	14.7	0.1	26.4
Czech Republic	36.0	24.5	3.7	0.7	18.3	14.7	5.9	0.4	50.7
Denmark	40.6	32.6	4.3	1.5	24.2	25.6	3.4	0.9	59.5
Germany	359.6	22.7	3.1	0.9	204.4	13.7	2.3	0.5	56.8
Estonia	4.3	42.5	2.2	0.7	1.3	29.4	3.8	0.2	29.0
Ireland	17.4	29.3	4.6	0.9	11.2	22.9	6.4	0.6	64.5
Greece	29.7	38.9	6.4	0.8	4.9	27.6	7.1	0.1	16.6
Spain	122.2	38.8	-0.1	0.7	44.6	31.1	0.8	0.3	36.5
France	269.4	26.1	2.6	1.0	162.7	20.5	3.9	0.6	60.4
Croatia	6.1	49.9	0.0	0.4	0.9	41.2	0.7	0.1	15.1
Italy	126.0	36.2	4.4	0.6	52.0	21.9	6.8	0.2	41.3
Cyprus	0.9	38.4	1.1	0.2	0.2	35.5	-0.2	0.1	20.8
Latvia	3.7	50.5	-1.5	0.4	0.8	45.8	10.0	0.1	20.7
Lithuania	8.6	48.4	0.3	0.7	2.0	34.0	6.3	0.2	23.1
Luxembourg	2.5	27.3	1.9	1.0	1.0	11.1	-5.5	0.4	40.9
Hungary	26.2	27.0	6.0	0.6	15.6	18.1	12.1	0.4	59.4
Malta	0.9	28.5	8.9	0.5	0.5	25.4	12.0	0.3	59.8
Netherlands	75.5	25.5	4.4	0.9	46.0	17.6	5.8	0.6	60.8
Austria	41.0	23.0	3.8	1.0	26.1	15.7	3.8	0.6	63.7
Poland	78.7	36.2	3.6	0.5	25.0	20.9	14.2	0.2	31.8
Portugal	38.5	44.7	1.4	0.9	10.5	29.5	6.7	0.2	27.4
Romania	18.1	45.2	2.9	0.2	5.2	38.8	2.0	0.1	29.0
Slovenia	8.6	34.7	1.4	0.9	4.6	25.7	2.6	0.5	54.1
Slovakia	14.7	41.8	2.6	0.6	2.6	19.5	7.5	0.1	17.9
Finland	38.3	:	0.3	1.6	21.4	:	-0.4	0.9	55.8
Sweden	66.6	28.0	2.5	1.4	44.4	22.5	1.4	0.9	66.7
United Kingdom	273.6	:	1.1	0.9	104.5	:	2.2	0.3	38.2
EU	1 767.9	23.7	2.8	0.8	862.4	16.2	3.7	0.4	48.8
Iceland	2.0	:	6.5	1.1	0.7	:	-8.2	0.4	37.7
Norway	29.4	:	2.7	1.1	14.5	:	2.7	0.6	49.3
Switzerland	36.0	:	9.4	0.8	16.8	:	12.9	0.4	46.6
Turkey	89.1	33.0	10.2	0.4	40.2	24.2	17.5	0.2	45.1
Israel	63.7	:	15.5	1.7	53.4	:	12.6	1.5	83.7
United States	1 265.1	:	2.2	0.9	869.0	:	1.1	0.6	68.7
Japan	660.5	:	0.1	1.0	485.3	:	0.1	0.7	73.5
China	1 484.0	:	7.6	0.2	922.7	:	8.6	0.1	62.2
South Korea	321.8	:	6.4	1.3	253.4	:	7.3	1.0	78.7

Science, Research and Innovation performance of the EU 2016
Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat, OECD
Notes: [(1)]IS, TR, JP, CN, KR: 2013; CH, IL, US: 2012. [(2)]The values refer to 2013. EU: The value was estimated from the available data and does not include BE, FI and UK. [(3)]US: 2007-2012; IS, TR, JP, CN, KR: 2007-2013; CH: 2008-2012; IL: 2011-2012.

Investment in ICT

Information and Communication Technologies (ICT) have become not only key sectors in modern economies, they are also fully integrated into all economic activities, becoming an important source of innovation, growth and jobs.

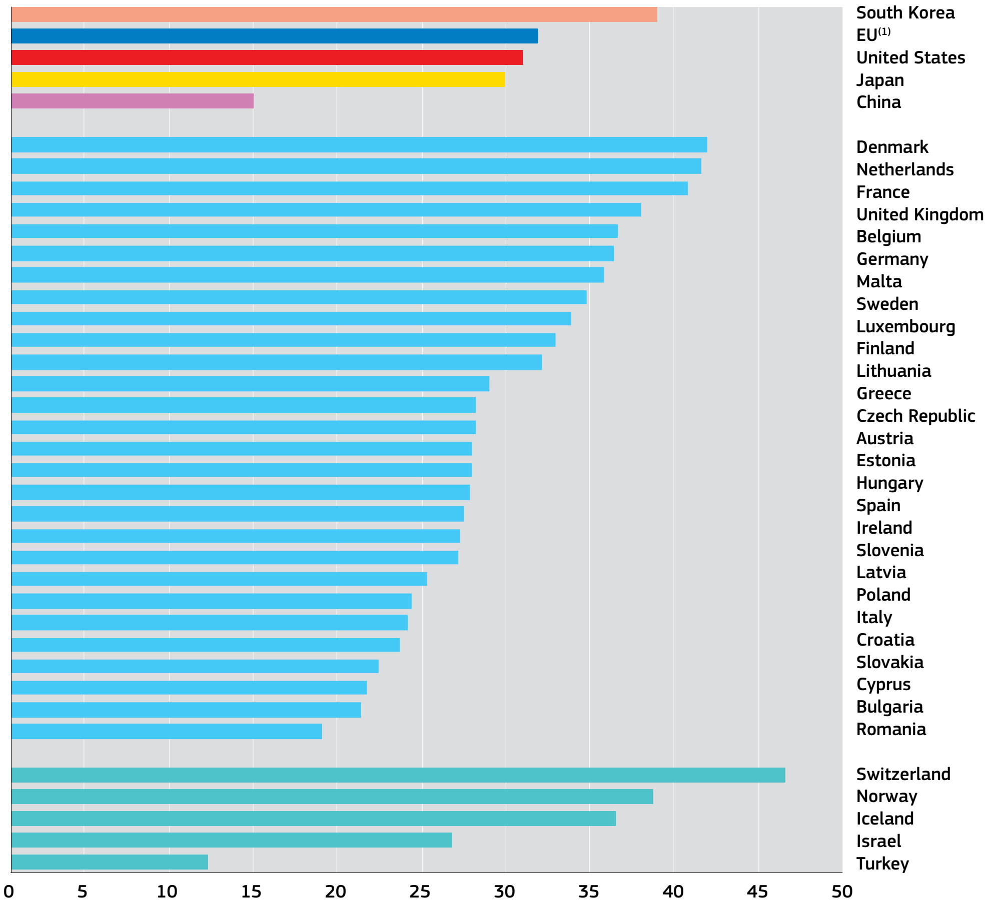
ICTs have revolutionised the way economic activities are organised as well as the way individuals communicate and they have been a source of innovation, in some cases of a disruptive nature, in all sectors of the economy. The economy has become increasingly digital as ICTs are integrated into all areas of activity. Several studies have shown the importance of ICTs as a key source of productivity growth [11] and job creation. It is expected that the ICT sector in itself will create 900 000 jobs in Europe by 2020.

ICT usage among the population in the EU is similar to other advanced economies, notably the United States and Japan, but large national differences in infrastructure quality, as measured for example by access to fixed broadband, exists in Europe.

Developing a solid and ubiquitous ICT infrastructure that enables fast access to digital services to businesses and citizens is crucial for reaping the potential benefits of ICT. EU rates of access to fast ICT networks, as measured by the availability of fixed broadband subscriptions, are on a similar level compared to other advanced economies such as the United States or Japan, but below South Korea, one of the world ICT leaders (see Figure I-2-27 below). However, large differences exist across Member States, which suggests the presence of a persistent digital divide in the EU, with countries such as Denmark, the Netherlands, France or the United Kingdom well above the EU average, while lagging countries in central and eastern Europe barely score above China. However, some of the central and eastern European Member States such as Lithuania, Latvia, Romania and Bulgaria show high fibre-to-home penetration rates, a fact that has stimulated local IT industries, at least in the capital cities.

(11) Cardona, M., Kretschmer, T. and Strobel, T (2013), ICT and productivity: conclusions from the empirical literature, Information Economics and Policy, Volume 5, Issue 3, 109-125.

Figure I-2-27 **Fixed (wired) broadband subscriptions per 100 inhabitants, 2014**



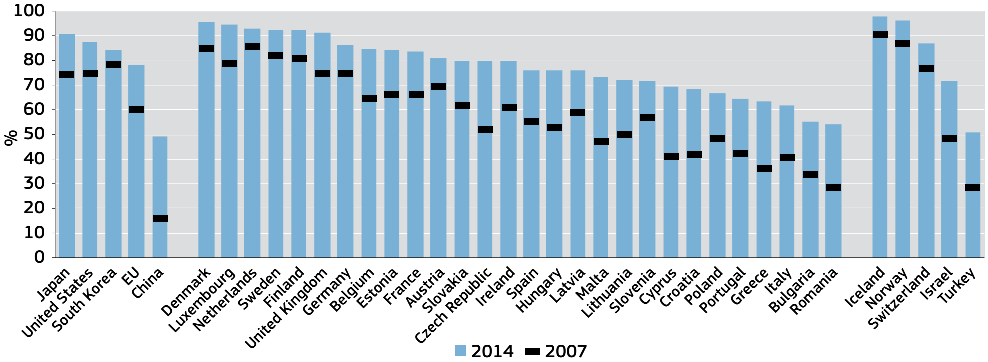
Science, Research and Innovation performance of the EU 2016

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: ITU
Note: (1)EU: The value was derived by DG Research and Innovation.

The European digital divide is also reflected in the share of the population using the internet, where considerable differences across Member States persist, despite a rapid progression in countries that are lagging behind.

The share of individuals using the internet in Europe (see Figure I-2-28 below) remains slightly below the levels of competitors. The differences between EU Member States remain stark, with the Nordic and some western European countries being world leaders, and some countries in central, eastern and southern Europe still showing low levels, though they are catching up.

Figure I-2-28 **Percentage of population aged 16-74[(1)] using the internet, 2007 and 2014**



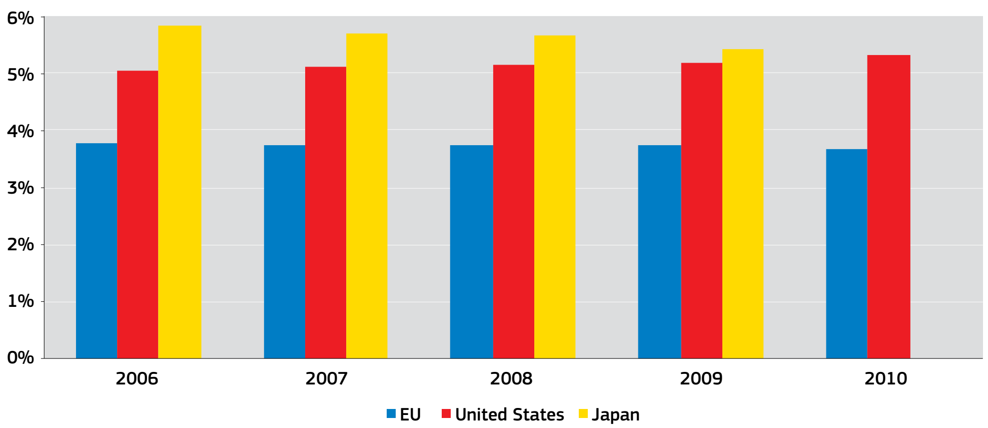
Science, Research and Innovation performance of the EU 2016

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: ITU
Note: [(1)]CH: Population aged 14+; IL: Population aged 20+; JP: Population aged 6+; KR: Population aged 3+.

In global terms, a large gap between the EU and other advanced economies exists in the share of the ICT sector in economic output. This evidence points to a lag in the production of ICT-related products and services in Europe, with Europe developing more into a consumer of ICT goods and services, rather than a producer of them.

Since the ICT revolution that peaked in the mid-1990s, Europe as a whole, with some notable exceptions among the Nordic countries, has lagged behind in the development of the ICT sector. While in the United States and Japan, the weight of the ICT sector is above 5% of GDP, in the EU this share stagnates at below 4% (see Figure I-2-29 below). This has implications for innovation, mainly through two factors. The first one, more direct, is that the ICT sector has been one of the most disruptive innovative economic activities of the past few years, where important first-mover advantages [(12)] have been reported. The second one, in an indirect manner, refers to the speed of adoption of ICT in other economic activities. As ICT-enabled innovations come about not only by the production of ICT, but also with the use, a closer presence or collocation of the ICT sector can help speed up the spillover effects and the reinvention of the production and delivery of traditional products and services.

Figure I-2-29 **ICT share of GDP, 2006-2010**



Science, Research and Innovation performance of the EU 2016

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: JRC-IPTS calculations and estimates based on EUROSTAT data, PREDICT project

(12) https://books.google.be/books?id=-YXYAgAAQBAJ&pg=PA113&lpg=PA113&dq=ICT+first+mover+advantage+OECD&source=bl&ots=dWF6Aw6FjP&sig=NMT1Cb_h7E5W-v-PA_e6uJYySEE&hl=en&sa=X&ei=4fZvVZSVBYvA7AbykIKwBg&redir_esc=y#v=onepage&q=ICT%20first%20mover%20advantage%20OECD&f=false

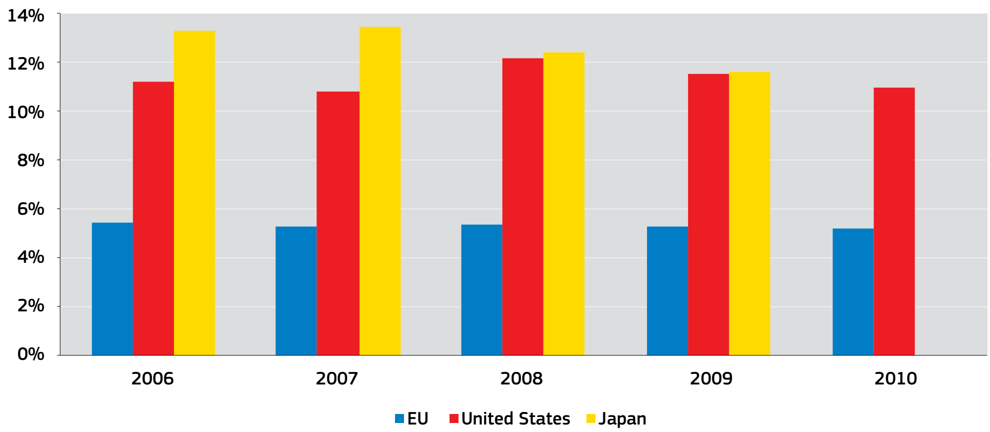
While it is difficult to prove a causal relationship between R&D expenditure on ICT and the development of the sector, both are correlated and Europe underinvests in comparison to other advanced economies.

Private R&D investment in ICT in the EU lags behind that of other advanced economies (see Figure I-2-30 below). Overall, for the past few years, private R&D intensity in the ICT sector of companies located in the EU was less than half that of those based in the United States or Japan. This highlights that the EU ICT industry not only lags behind in terms of its share in the economy, but also that Europe's ICT sector specialised less in R&D intensive activities (which include, for example, semiconductor production and software development) compared to other advanced economies. This can result in a potential lock-in effect, a difficulty for Europe to become a major player in the ICT sector, and a lack of positive spillover effects for the application of ICT in other sectors vof the economy.

However, there are large differences across Member States, with Nordic countries notably standing out and achieving investment intensities above or near third countries such as Japan and the United States [13].

Further analysis on the role and importance of ICT and R&D intensity in the ICT sector is provided in this report under the analysis of structural change in Europe.

Figure I-2-30 **ICT R&D intensity (BERD as % of value added), 2006-2010**



Science, Research and Innovation performance of the EU 2016
Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: JRC-IPTS calculations and estimates based on EUROSTAT data, PREDICT project.

In addition to lower investments in ICT-related R&D activities, the fragmentation of digital markets in Europe continues to affect the development of the sector and the ability of ICT enabled innovations and enterprises to develop and scale-up.

So far, there is no genuine single market where individuals and businesses can access and exercise online activities under conditions of fair competition and a high level of consumer and personal data protection. Fragmentation hinders the development of ICT activities in a potential EU market of over 500 million consumers.

(13) https://ec.europa.eu/digital-agenda/en/news/scoreboard-2014-eu-ict-sector-and-its-rd-performance-2014

Several actions to create a truly Digital Single Market in the EU have recently been put in place in order to address the fragmentation and create better conditions for the development of the sector and for enhancing spillover to the overall economy.

An ambitious Digital Single Market Strategy [14], creating the conditions for a vibrant digital economy and society, has been agreed upon as one of the key initiatives of the current European Commission to support jobs, growth and investment. This package encompasses measures aimed at complementing the telecommunications regulatory environment, modernising copyright rules, simplifying rules for consumers making online and digital purchases, and enhancing cyber-security and mainstreaming digitalisation. For that, the three main building blocks are as follows.

- Better access for consumers and businesses to online goods and services across Europe.
- Creation of the right conditions for digital networks and services to flourish.
- Maximising the growth potential of the European Digital Economy through more and better investment in ICT infrastructure and technologies.

Knowledge flows

Knowledge circulation is the process by which existing and new knowledge is disseminated throughout the economy and taken up by the different actors of the research and innovation systems. Collaborations between the public and private sectors as well as collaboration with international partners represent important sources of knowledge transfer and knowledge circulation.

There is a positive relation between the level of science-business collaboration and the quality of a research and innovation system. Although the European Union has improved its performance slightly, it still lags behind the United States.

Innovation is increasingly underpinned by intensive collaborations between different actors of the innovation process. In terms of public-private co-publications [15] per million population, the United States is the world's best performer followed by South Korea and Japan. Although the European Union has slightly increased its number of public-private co-publications between 2007 and 2012, it still lags behind, in particular in comparison with the United States.

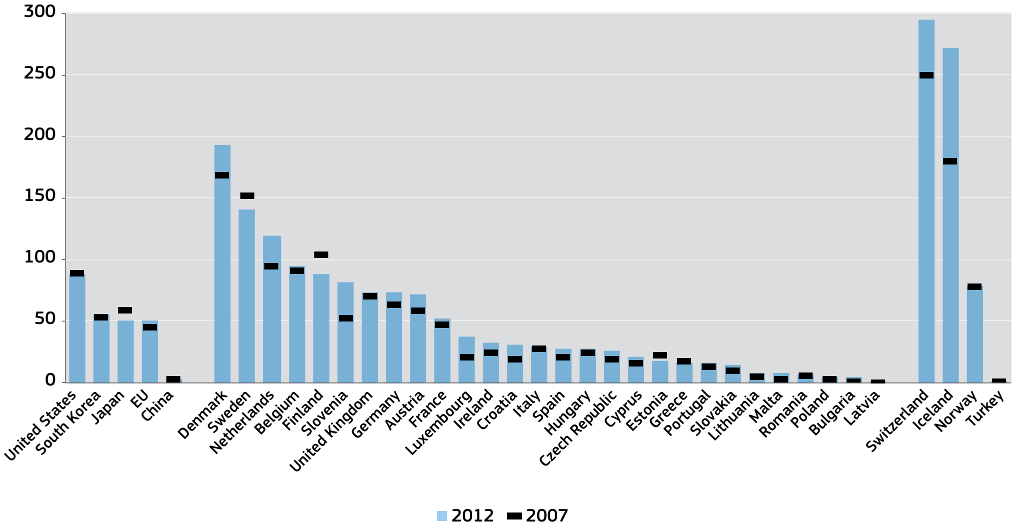
Significant differences exist among the Member States. Countries with higher levels of research quality [16] are also those with higher levels of co-publications between public and private sectors. While countries such as Switzerland, Iceland, Denmark, Sweden, the Netherlands, Belgium or Finland show strong science-business links and perform better than the United States, public-private co-publications are marginal in countries such as Latvia, Bulgaria, Poland, Romania and Malta (Figure I-2-31).

[14] http://ec.europa.eu/priorities/digital-single-market/docs/dsm-communication_en.pdf

[15] The definition of the 'private sector' excludes the private medical and health sector. Publications are assigned to the country/countries in which the business companies or other private organisations are located.

[16] See section on scientific outputs below.

Figure I-2-31 **Public-private co-publications per million population, 2007 and 2012**



Science, Research and Innovation performance of the EU 2016
Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Innovation Union Scoreboard 2015

While the level of public-private cooperation is correlated with business R&I intensity, there are countries such as Switzerland, Denmark and the Netherlands which perform better than expected given their level of private R&D investments.

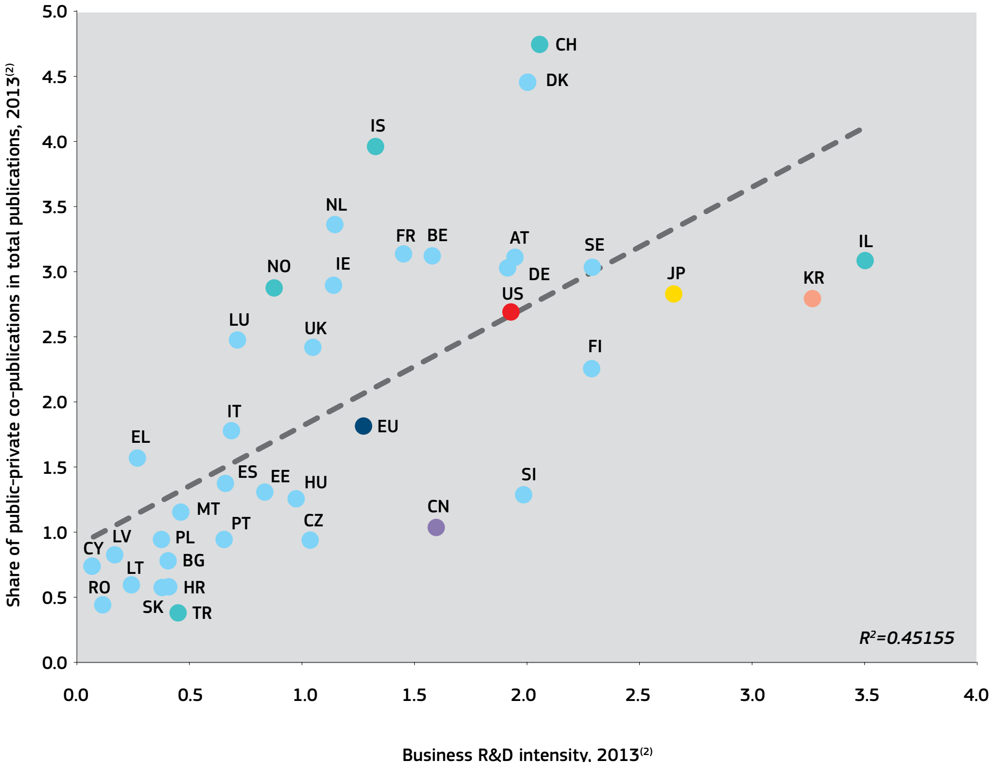
While there is a positive correlation between the level of private investment and the level of collaboration between public and private sectors, countries such as Switzerland, Denmark, the Netherlands and Iceland perform significantly better than would be expected based on their level of private investment.

To a lesser extent, in the United Kingdom, Germany, France and Austria the business sector collaborates more than expected with the public sector. On the contrary, in countries such as Finland or Slovenia the private and public sector collaborate less than what would be expected.

In general, countries with low levels of private investments have more difficulties in moving above the regression line, which may be related to the fact that public–private collaboration in research and innovation systems needs to be underpinned by a minimum level of private investment to build critical mass (Figure I-2-32).

The over-performing countries show that diversity in the levels of public-private collaboration in Europe is not only related to different business R&I intensities but also to the diverse capacities of each national research and innovation system to establish suitable framework conditions to boost public-private cooperation in research and innovation.

Figure I-2-32 **Share of public-private co-publications in total number of publications[(1)] versus business R&D intensity, 2013**



Science, Research and Innovation performance of the EU 2016

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat, SciVal (Elsevier) based on Scopus database
Notes: [(1)]Full counting method. [(2)]IS: 2011; IE, CH: 2012.

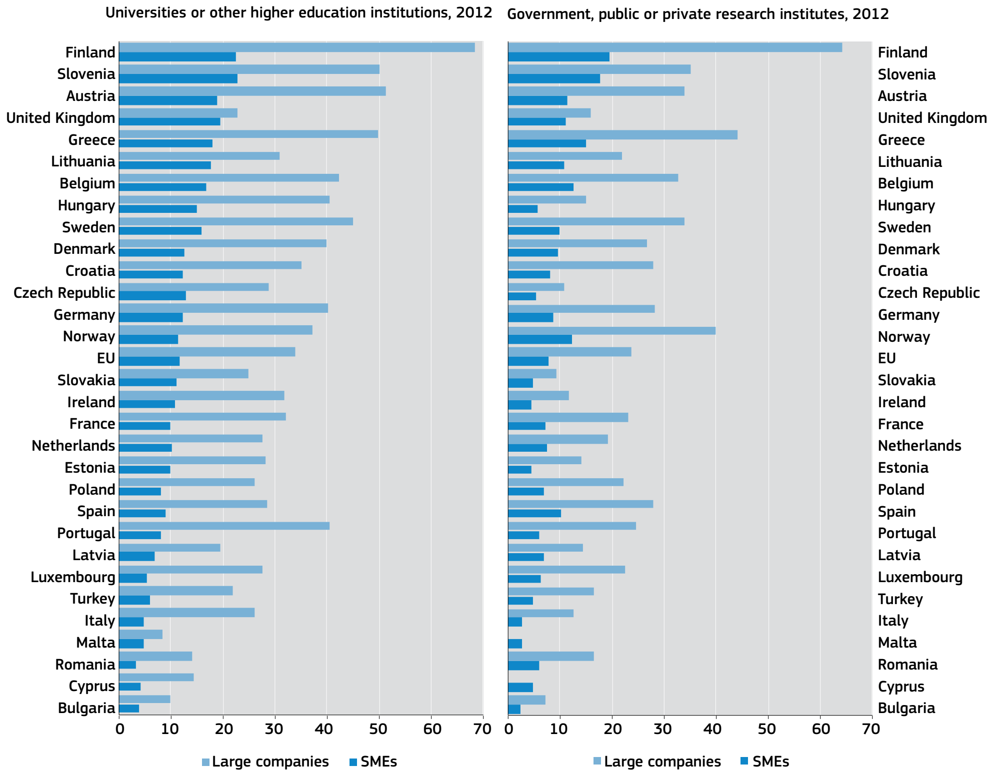
The national economic fabric plays a key role in building collaborations between the business sector and higher education or public research institutions.

The intensity of public-private collaboration varies in terms of the economic fabric of the countries. Large companies are more likely to engage in collaborations with higher education or public research institutions than small- and medium-sized enterprises. This partly explains why economies characterised mainly by a large number of SMEs show weaker science–business links.

In Finland, 70% of the large firms that innovate collaborate with the public sector, while only 20% of Finnish SMEs that innovate engage in some form of collaboration with the public sector. At the same time, in Slovenia and Austria, where more than half of all large firms that innovate collaborate with public institutions, one innovative SME out of five engages in the same type of collaboration (Figure I-2-33).

It is therefore clear that the nature of the economic fabric is an important aspect to be taken into consideration by policy-makers when designing policy measures and framework conditions aiming at boosting science–business links.

Figure I-2-33 **Enterprises cooperating with:**



Science, Research and Innovation performance of the EU 2016
Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat (CIS 2012)

Human resources mobility in science and technology is an important driver of knowledge transfer and spillover.

Knowledge transfer involves the processes for capturing, collecting and sharing not only explicit but also tacit knowledge, including skills and competence. This includes mobility of human resources in science and technology as a critical resource and a vehicle for success, competitiveness and growth.

Denmark, the United Kingdom, Norway, Iceland and Switzerland show intensive flows of highly skilled employees in science and technology which results in a better circulation and exchange of knowledge.

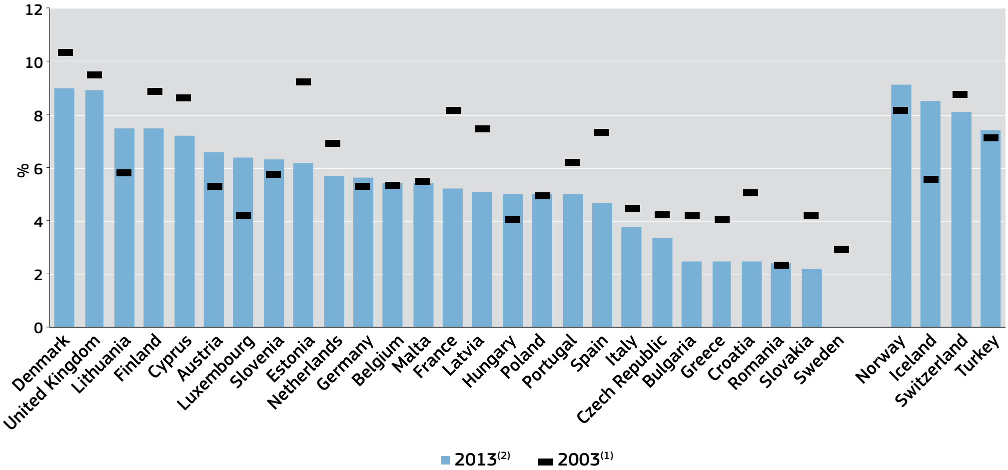
The flow of highly skilled employees in science and technology is an important mechanism to foster knowledge circulation. Mobility and the resulting capacity to circulate knowledge are key parts of the success of research and innovation systems. The job-to-job mobility of human resources in science and technology [17] is used as an indicator for the exchange and flow of knowledge in research and innovation systems.

Although the analysis is limited by the lack of comparable international data, the job-to-job data show more intensive flows of such workers in Denmark, the United Kingdom, Norway, Iceland and Switzerland, while countries such as Italy, the Czech Republic, Croatia, Romania and Slovakia have systems with less intensive flows (Figure I-2-34).

The negative trend in almost all European countries can be partially attributed to the crisis because of a lack of opportunities in the labour market or risk-adverse behaviour of employees.

(17) Job-to-Job mobile HRST are individuals who have changed employers during the last year, and fulfil the condition of being employed HRST, i.e., (i) they have successfully completed education at the third level and are employed in any kind of job, or (ii) they are not formally qualified as above but are employed in an occupation where the above qualifications are normally required.

Figure I-2-34 Job-to-job mobility of human resources in science and technology (HRST), 2003 and 2013

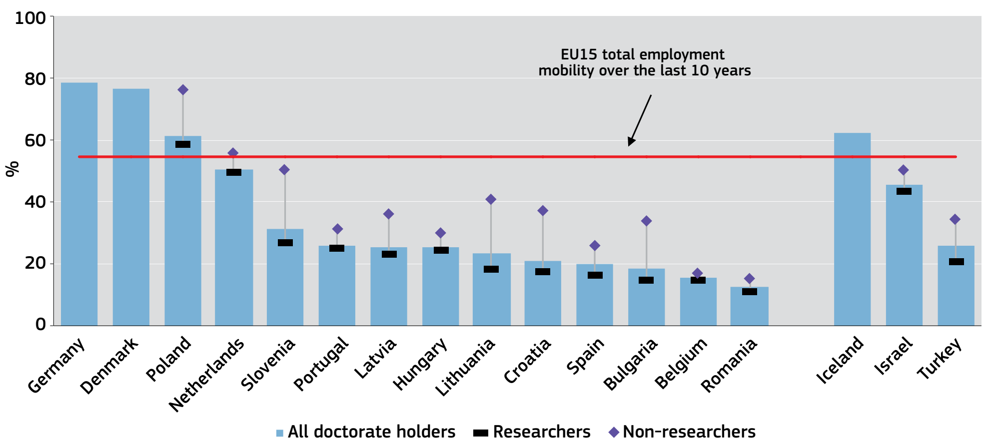


Science, Research and Innovation performance of the EU 2016
Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat
Notes: (1)FR, NL, TR: 2006; BG: 2008; CH: 2011; IE: Not available. (2)IE, SE: Not available.

Doctoral degree holders usually change jobs more frequently in higher quality research and innovation systems, such as Germany or Denmark.

Knowledge flows can also be measured through the analysis of the mobility [18] of PhD holders. In the United States, this mobility is more widespread than in the European Union, where only countries with a higher quality research and innovation system, such as Germany and Denmark, show significant mobility flows of PhD holders. Poland represents a positive exception to this as the mobility of its doctoral holders is high despite the overall quality of its system which is below the European average (Figure I-2-35).

Figure I-2-35 Doctorate holders who changed jobs in the last ten years(1), 2009(2)



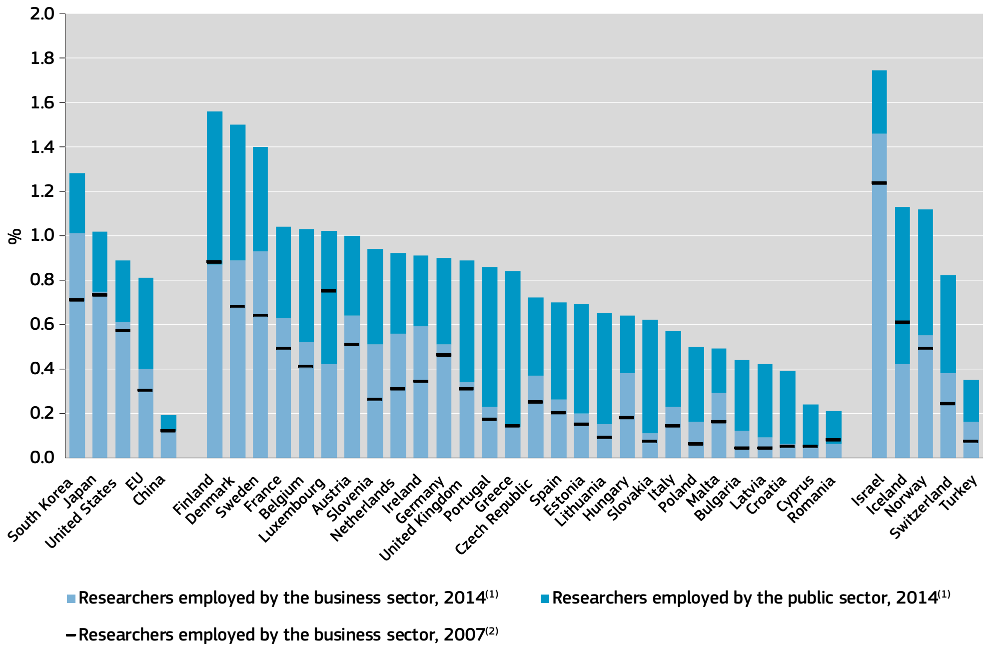
Science, Research and Innovation performance of the EU 2016
Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: OECD (STI Scoreboard, 2013)
Notes: (1)EU15 total employment mobility is computed on the basis of the OECD Job Tenure Database and corresponds to the share of 25-69 year-old employed individuals who have changed jobs in the last ten years. For ES, the sample has limited coverage of doctorate holders for the years 2007 and 2009. (2)DK, PL, RO: 2008.

(18) Mobility in terms of changing job position.

The business sector in the European Union is still not fully benefiting from the embedded knowledge of researchers trained by universities.

Intersectoral mobility is an important mechanism to foster knowledge circulation between universities and firms. Researchers employed by firms can easily spread the knowledge and skills acquired in higher education institutions to the private sector and bring them closer to the economy. The business sectors in South Korea, Japan and the United States profit to a larger extent from the embedded knowledge of researchers trained by universities. Within the European Union, only Finland, Denmark and Sweden perform significantly better than most of the international competitors (Figure I-2-36).

Figure I-2-36 **Total researchers (FTE) as % of total employment, 2007 and 2014**



Science, Research and Innovation performance of the EU 2016
Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat, OECD
Notes: (1) CH, IL, US: 2012; IS, TR, JP, CN, KR: 2013. (2) CH, US: 2008; IL: 2010.

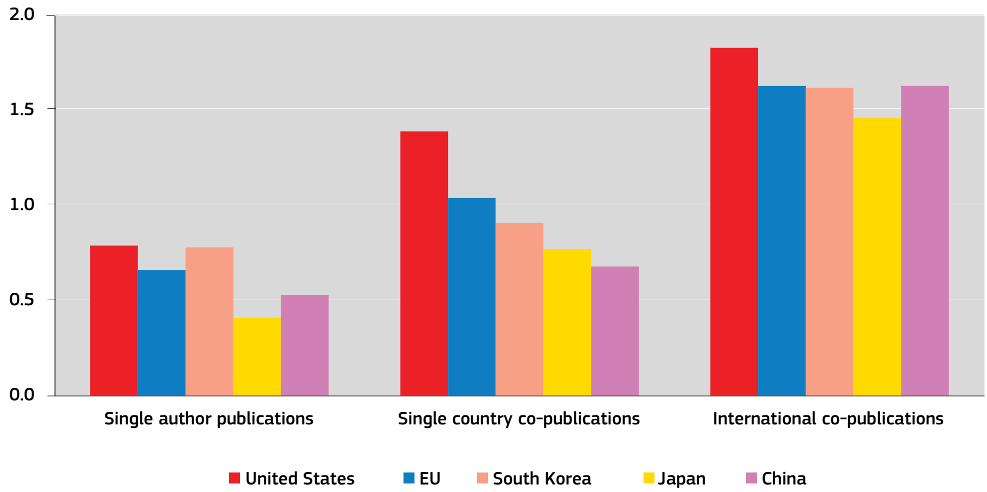
International collaboration plays a significant role both in improving the competitiveness of research and innovation systems and fostering new knowledge production worldwide.

The broader interaction between science and technology actors at the global level might be due to the emergence of new international players, such as China, with large research and innovation capacities, but also to a heightened political focus on addressing global challenges. Globalisation of R&I is not a new phenomenon but it has become more and more visible, particularly in terms of collaborative research, international technology production and worldwide mobility of researchers. In this context, an increasing role of science diplomacy as a tool for better incorporating science into global debates addressing key political and societal challenges can be anticipated.

Evidence shows that stronger international collaborations clearly have a positive impact on the overall performance of national research and innovation systems.

The Average Relative Citations of publications (ARC) is an indicator of the scientific impact of papers produced by a given entity (in this case, a country) relative to the world average [19]. For all R&I key players, the ARC of international co-publications is much higher than that of single-country co-publications or single-author publications. Furthermore, only the ARC of international co-publications scores above 1 in all countries and regions. This means that overall international co-publications have a higher scientific impact than the world average (Figure I-2-37).

Figure I-2-37 **Average Relative Citations (ARC) of publications by type of co-operation, 2010**



Science, Research and Innovation performance of the EU 2016

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Science-Metrix (Canada), based on Scopus database

International co-publications are becoming increasingly important in science both inside Europe and beyond.

At a global level, the European Union shows the highest share of international co-publications per total number of publications [20], closely followed by the United States. Even though China has increased its share of international co-publications, it still performs at a much lower level than its international competitors. This might partly explain China's lagging results in terms of highly cited scientific publications [21].

In the EU, the share of international publications has increased in almost all countries between 2007 and 2013, with the exception of Luxembourg, Cyprus, Bulgaria, Slovakia, Lithuania, Latvia and Romania. Small countries have a higher natural propensity to collaborate with international partners. Indeed, Iceland, Luxembourg and Cyprus are the countries with the highest shares of international co-publications per total number of publications.

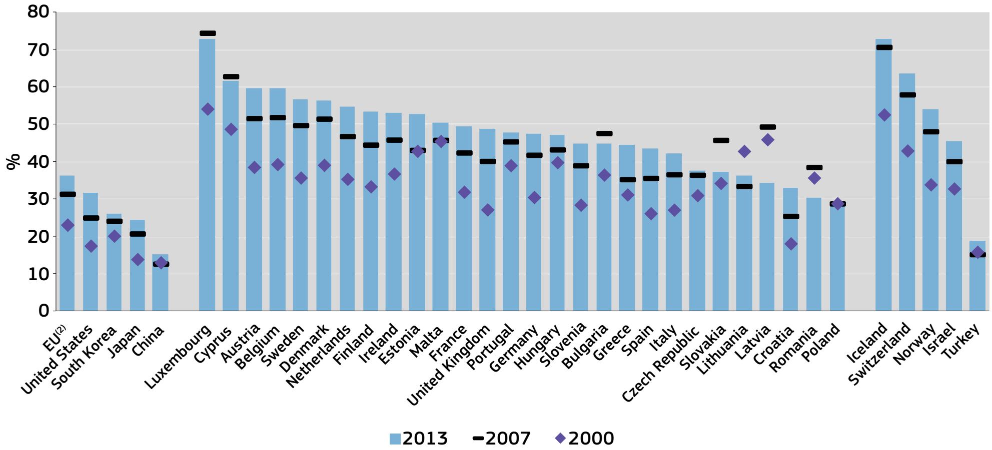
Although meaningful improvements are visible in almost all European countries, important differences still exist among the Member States. Countries such as Austria, Belgium, Sweden and Denmark seem to actively participate in international scientific networks while Poland, Romania, Croatia and Latvia still produce their scientific outputs mainly at the national level (Figure I-2-38). As a clear correlation between openness of research and innovation systems and quality of scientific results exist, countries that are still not taking full advantage of international scientific networks should further open their national R&I system in order to increase their overall scientific performance.

(19) The number of citations received by each publication is counted for the year in which it was published and for the three subsequent years. An ARC value above 1 means that a given entity is cited more frequently than the world average, while a value below 1 means the reverse.

(20) In this context, it is worth mentioning that, for each Member State, publications with another EU Member State are considered as international co-publications. On the contrary, at the EU 28 level, co-publications between EU Member States are no longer counted as international co-publications. This explains why the EU international co-publications are below that of all major EU scientific producers.

(21) See section on scientific output below.

Figure I-2-38 **International co-publications as % of total number of publications(1), 2000, 2007 and 2013**



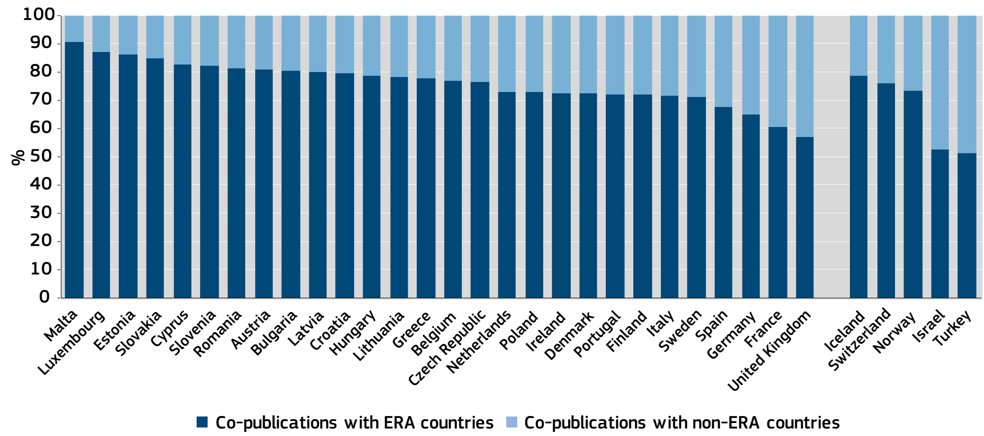
Science, Research and Innovation performance of the EU 2016

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Science-Metrix (Canada), based on Scopus database
Note: (1)Full counting method. (2)EU: International collaborations include intra-EU international collaborations.

Intra-European collaboration is more important than collaboration with non-European countries.

In almost all the Member States, at least 70% of all international co-publications are the result of collaborations between two or more European countries. This percentage is even higher for Eastern and Baltic countries while countries such as the United Kingdom, France, Germany and Spain are also quite active in collaborating with non-European countries (Figure I-2-39).

Figure I-2-39 **Co-publications with ERA countries and with non-ERA countries as % of total international co-publications(1), 2013**



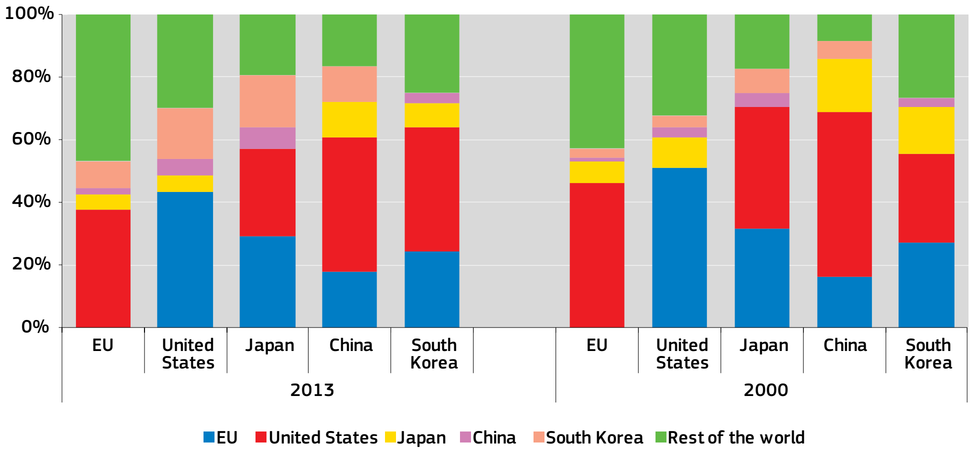
Science, Research and Innovation performance of the EU 2016

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Science-Metrix (Canada), based on Scopus database
Note: (1)Full counting method.

The United States remains the main partner in science collaboration for the European Union. However, the United States is profiting to a greater extent from the emerging research capacities of countries such as China.

In terms of international co-publications, the United States remains the main partner of the European Union, while China is becoming increasingly important as a strategic partner. While Japan collaborates equally with the EU and the United States, South Korea and China tend to collaborate more with the United States than with the EU. This seems to suggest that the United States have been able to take better advantage of the emerging research capacities of these economies than the European Union (Figure I-2-40).

Figure I-2-40 **International scientific collaborations, 2000 and 2013**



Science, Research and Innovation performance of the EU 2016

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: DG Research and Innovation, based on Scopus database
Note: [1]Elements of estimation were involved in the compilation of the data.

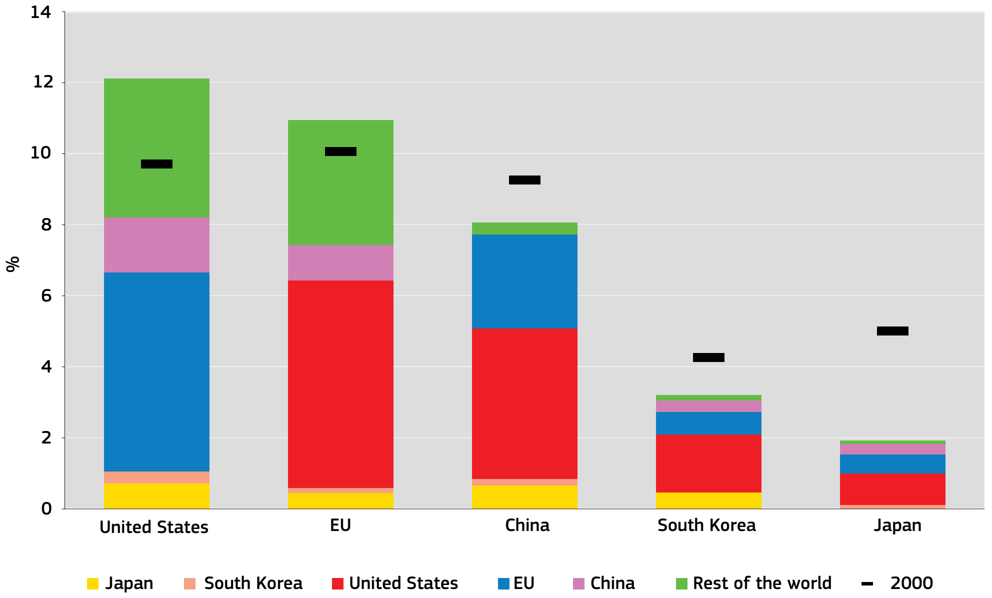
Despite the increasing internationalisation of technological collaborations, Europe is not taking full advantage of the international networks compared to the United States.

International technological collaborations play a key role in the innovation process by allowing firms to access a broader set of competences, resources and skills. Patents with foreign co-inventors may be used as a measure of the internationalisation of the research and innovation system and the knowledge exchange among R&I actors.

Technological collaboration at an international level has intensified in the last decade both in the United States and the European Union. The United States has overtaken the European Union in terms of share of patents resulting from international collaborations and the gap between the two countries seems to have increased over time. Countries such as China, South Korea and Japan rely relatively more on their own research and innovation systems than on international co-inventions, although in absolute terms the number of international co-inventions has significantly increased between 2000 and 2012 [22] (Figure I-2-41).

[22] China: from 140 (2000) to 1 598 (2012); South Korea: from 86 (2000) to 365 (2012); Japan: from 552 (2000) to 844 (2012).

Figure I-2-41 **Share (%) of patents with foreign co-inventor(s) in total patent applicatons (WIPO PCT), 2000 and 2012**

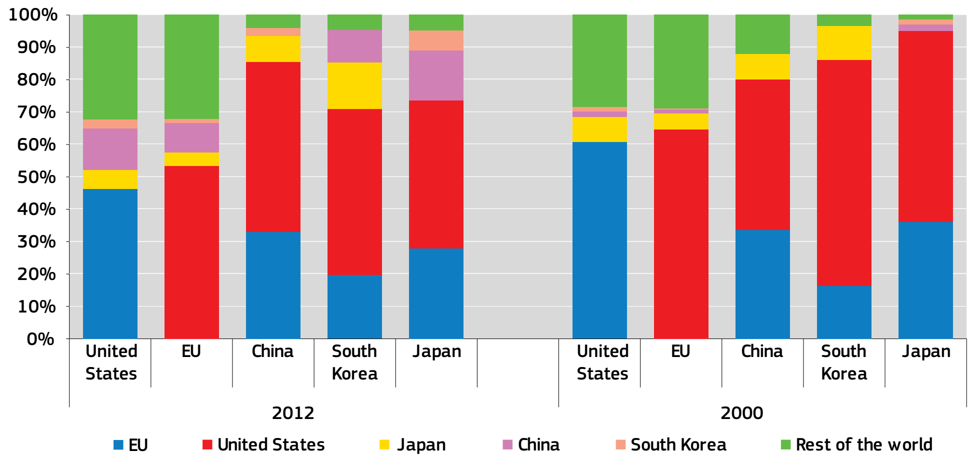


Science, Research and Innovation performance of the EU 2016
Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: OECD

China is becoming a key partner in terms of technological collaboration and the United States is taking better advantage than the European Union of this emerging innovative economy.

The European Union remains the main partner of the United States as regards technological collaboration, although the share of US-EU patents has decreased sharply from 60% to around 45% in the period from 2000-2012. At the same time, the share of US-China co-inventions has increased tremendously during the same period. Europe needs to further boost its innovation links with China in order to fully profit from this country's technological capacities (Figure I-2-42).

Figure I-2-42 **Patents with foreign co-inventor(s), 2000 and 2012**



Science, Research and Innovation performance of the EU 2016
Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: OECD

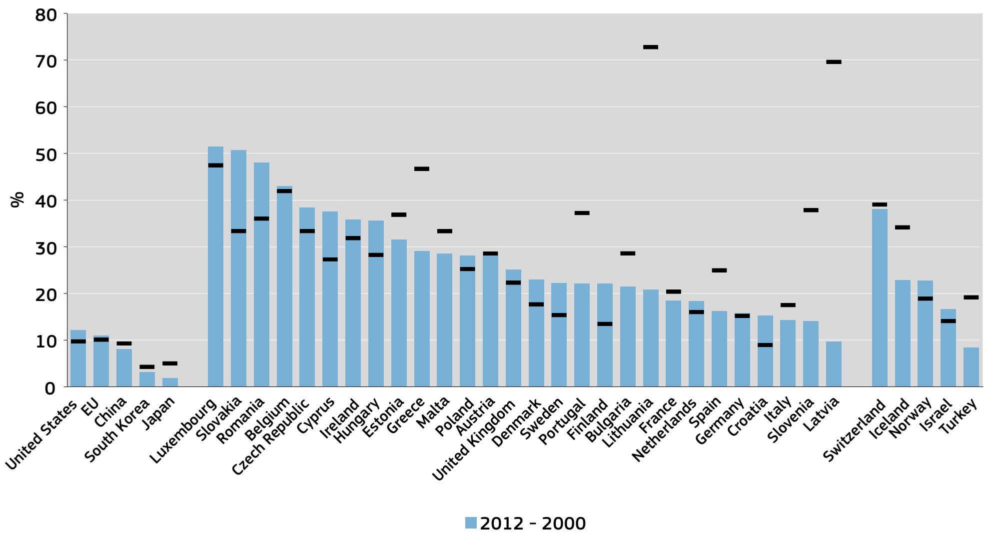
Although international co-inventions have increased overall, significant differences still persist at the Member State level.

While the analysis of co-inventions suggests that, at the global level, technological inventions increasingly rely on international collaborations, this trend cannot be clearly observed at the Member State level (Figure I-2-43) [23], where significant differences across countries exist. Indeed, the share of patents with a foreign co-inventor ranges from 50% in Luxembourg and Slovakia to less than 10% in Latvia.

Moreover, between 2000 and 2012, countries such as Slovakia, Romania, Cyprus and Hungary registered a strong increase in the share of international patents while in Latvia, Lithuania and Slovenia the share dramatically decreased.

In general, it appears that countries owning a large share of international co-inventions also have large multinational firms. The tax environment is also likely to play a role in the location of the inventions and different technology fields may also involve different degrees of international collaboration.

Figure I-2-43 **International patents with foreign co-inventor(s) as % of total number of patent applications, 2000 and 2012**



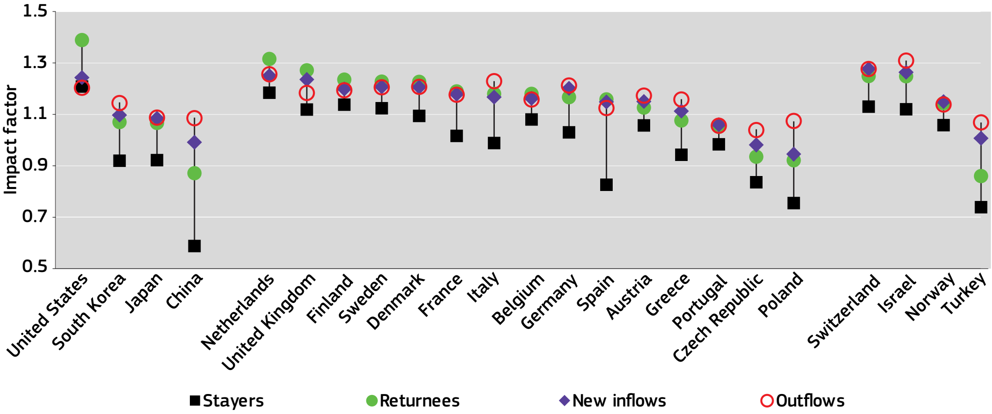
Science, Research and Innovation performance of the EU 2016
Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: OECD

Brain circulation at an international level is an important mechanism to boost the quality of research and innovation systems.

The international mobility of researchers yields positive impacts in terms of scientific quality, innovation and growth. As clearly shown in Figure I-2-44, the impact of authors who never moved is lower than the scientific impact of authors who spent some time abroad. By contrast, returnees, as well as new inflows, usually help increase the quality of scientific outputs. For those countries where the outflows show the largest impact factors, it would be vital to put in place policies aiming to reintegrate those researchers into their system of origin. This might also stimulate those who remain to raise their productivity levels.

(23) EU data in figure I-2-43 is lower than the sum of the data for all Member States because intra-EU foreign co-inventions are not included

Figure I-2-44 **Impact of scientific authors by category of mobility(1), 1996-2011**



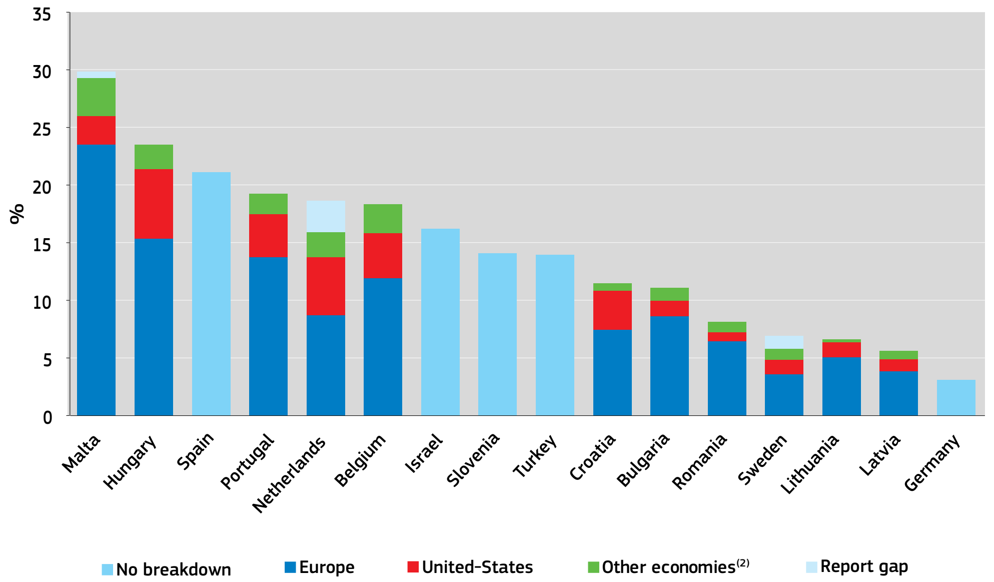
Science, Research and Innovation performance of the EU 2016

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: OECD (STI Scoreboard, 2013)
Note: (1)International mobility of scientific researchers is inferred from authors listed in the Scopus Custom database of peer-reviewed scientific publications, with at least two documents over the reference period, based on changes in the location of their institutional affiliation. Stayers maintain an affiliation in a given reference country over the period. Outflows are defined on the basis of the first affiliation. New inflows are defined on the basis of the final affiliation and exclude individuals who "return" to their original country of affiliation. The latter group are defined as "returnees". A proxy measure of scientific impact for researchers with different mobility patterns is estimated by calculating, for each author and mobility profile, the median across the relevant journals' Source-Normalized Impact per Paper (SNIP) over the entire period. A SNIP impact value that is higher than one means that the median attributed SNIP for authors of that country / category is above average.

European doctoral holders tend to choose another Member State as their main destination.

The international mobility of researchers is a key source of knowledge circulation among and beyond Europe. As shown in Figure I-2-45, European citizens holding a doctorate mainly tend to move to another European country. This results in the spillover generated through this mobility remaining in Europe and reinforcing the European research and innovation system.

Figure I-2-45 **National citizens with a doctorate having lived / stayed abroad in the past ten years[1], 2009**



Science, Research and Innovation performance of the EU 2016

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: OECD, based on OECD / UNESCO Institute for Statistics / Eurostat data collection
Notes: [1]The data reported are for a minimum length of stay abroad to three months, except for Germany where the data reported refer to a minimum length of six months. [2]Other economies refer to those located in Africa, America (excluding the United States), Asia, Europe and Oceania.

3. Scientific, technological and innovation outputs

Effective and efficient research and innovation systems are those that succeed in producing strong scientific and technological outputs, both in terms of quality and relevance, to address the economic and social challenges of societies.

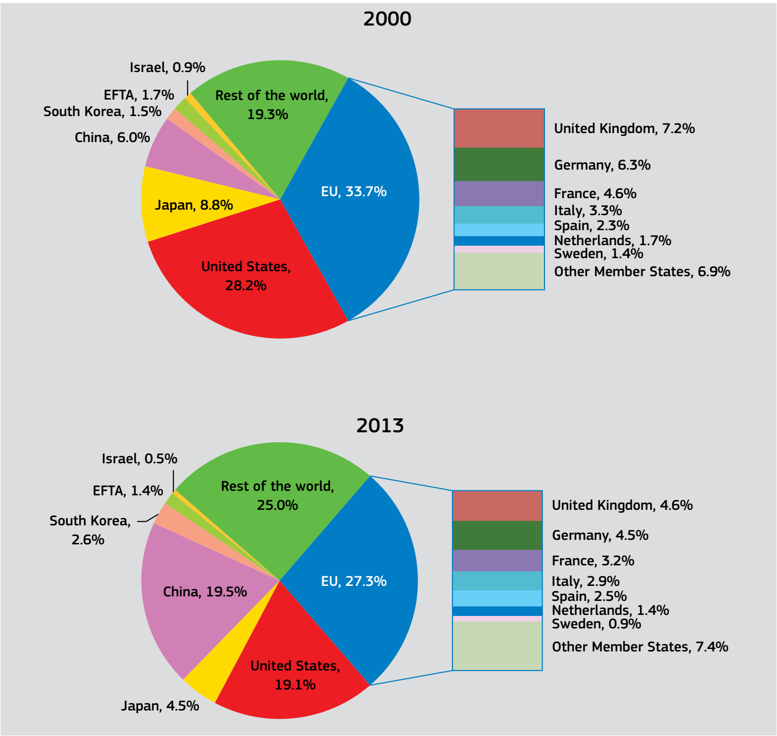
This section of the report assesses Europe's ability to boost scientific and technological excellence as well as the evolving nature of these results, especially in areas that are particularly promising due to their broad applicability to different scientific and technological fields.

Scientific outputs

As a result of an increasingly multipolar global research landscape, a growing number of international partners have been expanding their scientific production. Emerging countries such as China have become key world players in terms of knowledge production, while Europe remains the main producer in terms of scientific knowledge, ahead of the United States.

In the last decade, geographical distribution of knowledge production has changed significantly. While in the past it was mainly concentrated in the United States and the European Union, nowadays other geographical areas have emerged as knowledge production centres. In particular, China has increased its share of world publications from 6% to 19.5% between 2000 and 2013, thus overtaking the United States as the second knowledge producer worldwide. In this changing and challenging landscape, Europe has been able to preserve its world leadership in terms of scientific publications (Figures I-3-1).

Figure I-3-1 **World share of scientific publications(1), 2000 and 2013**



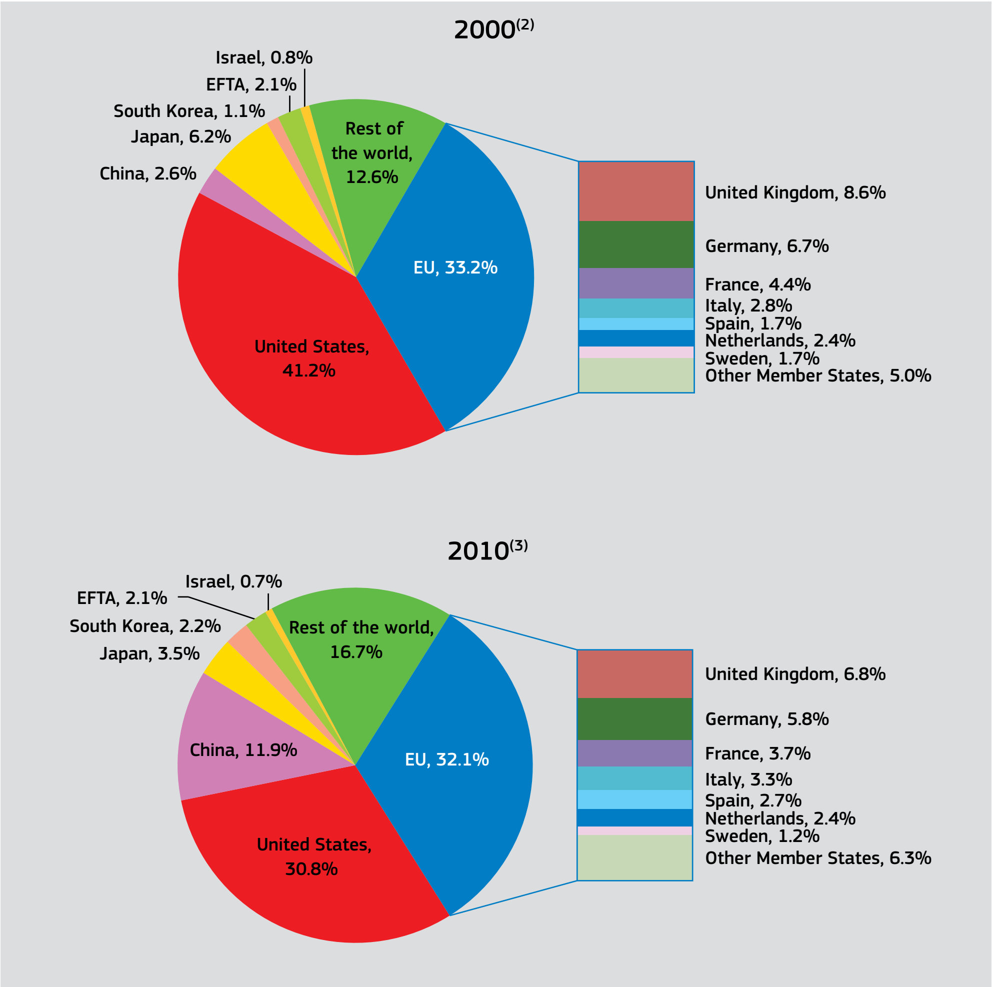
Science, Research and Innovation performance of the EU 2016

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Science-Metrix (Canada), based on Scopus database
Note: (1)Fractional counting method.

The same trend can be observed while looking at the world share of highly cited publications. China now ranks third at the global level only preceded by the EU and the US. In this context of increased competition, Europe has managed to maintain its role of key player as well as overtake the US, thus becoming the world leader in the production of high quality scientific papers.

Between 2000 and 2010, China increased its world share of highly cited publication from 2.6% to 11.9%, thus overtaking Japan as the third producer of high quality scientific papers at the global level. At the same time, China has succeeded in eroding the world portion of excellent scientific publications produced by the EU and the US. Nevertheless, while the US has significantly reduced their world share of highly cited publications from 41.2% to 30.8% in a decade, the EU has been able to better maintain its role of key player. With its 32.1% of world share, Europe has become the first producer of excellent scientific papers in the world (Figures I-3-2).

Figure I-3-2 **World share of highly cited scientific publications[1], 2000 and 2010**



Science, Research and Innovation performance of the EU 2016

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Science-Metrix (Canada), based on Scopus database
Notes: [1]Fractional counting method. [2]Scientific publications 2000, with citation window 2000-2003. [3]Scientific publications 2010, with citation window 2010-2013.

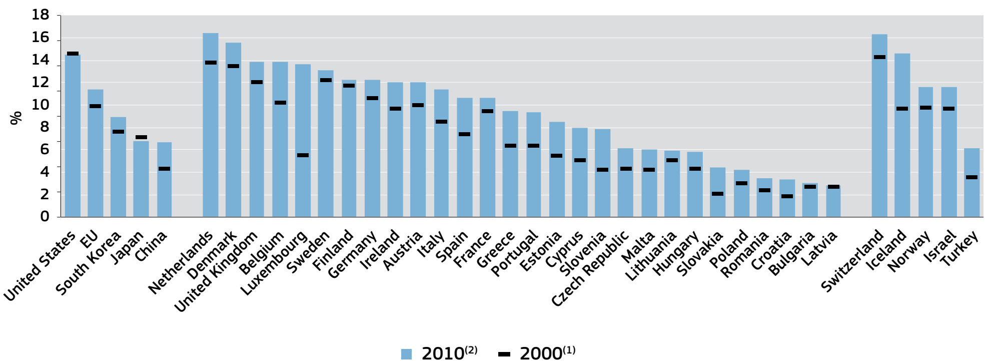
However, the United States still exhibits a higher capacity to produce high-impact scientific publications than the European Union. Even so, the EU is closing the gap slightly, despite large and persisting differences between the Member States.

Even though the level of scientific quality in the United States has remained stable overall in recent years, it is still outperforming the European Union in the ratio of highly cited publications among the total number of publications (Figure I-3-3). Japan, South Korea and China show lower levels of high quality scientific production; however, South Korea and China are rapidly bridging the gap with the EU.

Looking at the European Research Area, important differences persist among countries. Scientific quality is concentrated in a group of leading countries (i.e. Switzerland, the Netherlands, Denmark, Iceland, the United Kingdom, and Belgium), while Southern, Eastern and Baltic countries still rank at the bottom, despite some progress in recent years.

While all the Mediterranean countries and some Eastern and Baltic Countries, such as Slovenia, Estonia and Slovakia, are actively catching up, countries such as Poland, Romania and Croatia, which are well below the EU average in terms of scientific quality, have only slightly improved their performance. Moreover, worrisome trends can be observed in Bulgaria and Latvia, the last two countries in the ranking, where the ratio of highly cited scientific publications out of the total number of publications has stagnated between 2000 and 2010.

Figure I-3-3 **Highly cited scientific publications, 2000 and 2010**
Scientific publications within the 10% most cited scientific publications worldwide as % of total scientific publications of the country



Science, Research and Innovation performance of the EU 2016

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Science-Metrix (Canada), based on Scopus database
Notes: (1)Fractional counting method; scientific publications 2000, with citation window 2000-2003. (2)Fractional counting method; scientific publications 2010, with citation window 2010-2013.

It is evident that, despite the EU's overall positive trend as regards scientific output, obtaining higher scientific quality from public research and innovation investments remains a key challenge for many EU Member States.

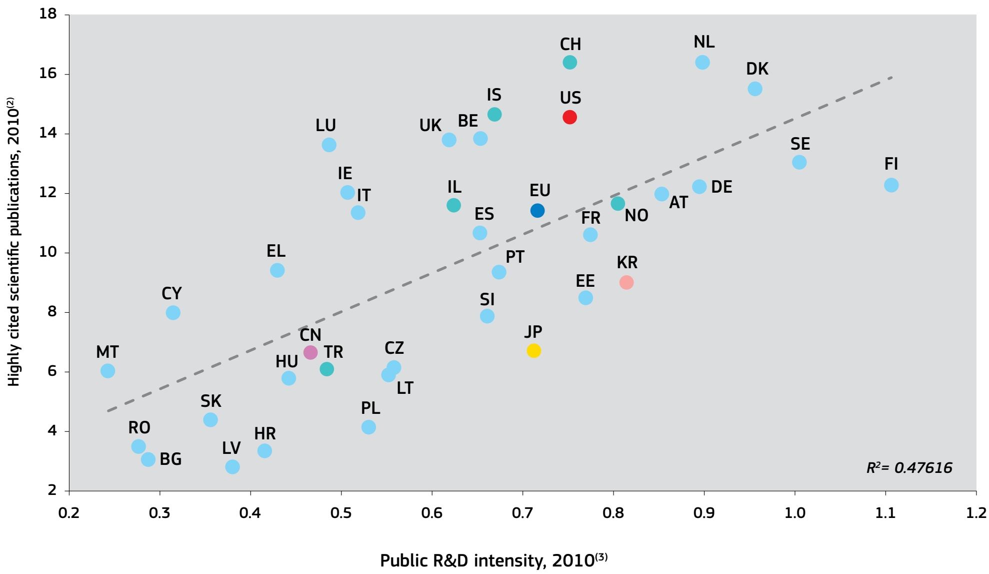
At a global level, the United States obtains a higher ratio of highly cited publications by investing slightly more than the European Union (Figure I-3-4). Conversely, Japan or South Korea show relatively low levels of scientific quality in relation to their public investments. Those trends give a rather fair idea of the level of productivity of the different research systems.

In the EU, countries that invest more, such as the Netherlands, Denmark, Finland and Sweden, also have better systems in terms of scientific quality. On the contrary, Eastern countries, where the investments are still below the EU average, show low levels of scientific excellence. Therefore, a positive correlation between investments and scientific quality is apparent.

It should also be noted that countries such as the Netherlands, Switzerland, Denmark, Iceland, the United Kingdom or Belgium perform significantly better than what would be expected from their public R&D investments. By contrast, countries such as Estonia, Slovenia, the Czech Republic, Lithuania, Poland, Croatia or Latvia are clearly underperforming in terms of scientific quality given their public R&D investments.

Diversity in research quality in Europe is, therefore, partially related to the different levels of public R&I intensity but also depends on the diverse capacities of the national research systems to obtain the most value from these investments.

Figure I-3-4 **Highly cited scientific publications[1] versus public R&D intensity, 2010**



Science, Research and Innovation performance of the EU 2016

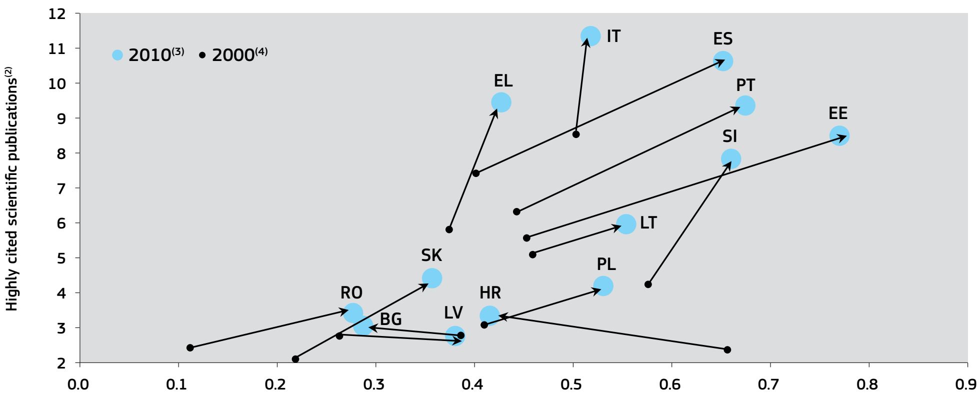
Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat, Science-Metrix (Canada), based on Scopus database
Notes: [1]Scientific publications within the 10% most cited scientific publications worldwide as % of total scientific publications of the country. [2]Fractional counting method; scientific publications 2010, with citation window 2010-2013. [3]EL: 2011.

The catching-up process in certain EU Member States might be at risk of slowing down due to the decrease in the level of investments (Mediterranean countries) or sustainability issues arising from a high reliance on the Structural Funds for research and innovation investments (Baltic and Eastern countries). In such a context, structural reforms aiming at improving the productivity of the national R&I systems play a key role.

The Mediterranean countries boosted (Spain and Portugal) or preserved (Greece and Italy) their research and innovation investments between 2000 and 2010 [24] with a positive impact on the quality of their scientific production (Figure I-3-5). Similar improvements in scientific quality have, in recent years, occurred in a number of Baltic and Eastern European countries, such as Estonia, Slovenia, Slovakia, and Poland, thanks to a sharp increase in R&D activities supported by Structural Funds.

While the catching-up process might be jeopardised by the recent negative trend in R&I investments in Mediterranean countries, in Baltic and Eastern countries a possible reduction of Structural Funds in the future might affect the sustainability of their research and innovation systems.

Figure I-3-5 **Highly cited scientific publications[1] versus public R&D intensity, 2000 and 2010**



Science, Research and Innovation performance of the EU 2016

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat, Science-Metrix (Canada), based on Scopus database
Notes: [1]Scientific publications within the 10% most cited scientific publications worldwide as % of total scientific publications of the country. [2]Fractional counting method; scientific publications 2010, with citation window 2010-2013; scientific publications 2000, with citation window 2000-2003. [3]EL: 2011. [4]EL: 2001; HR: 2002.

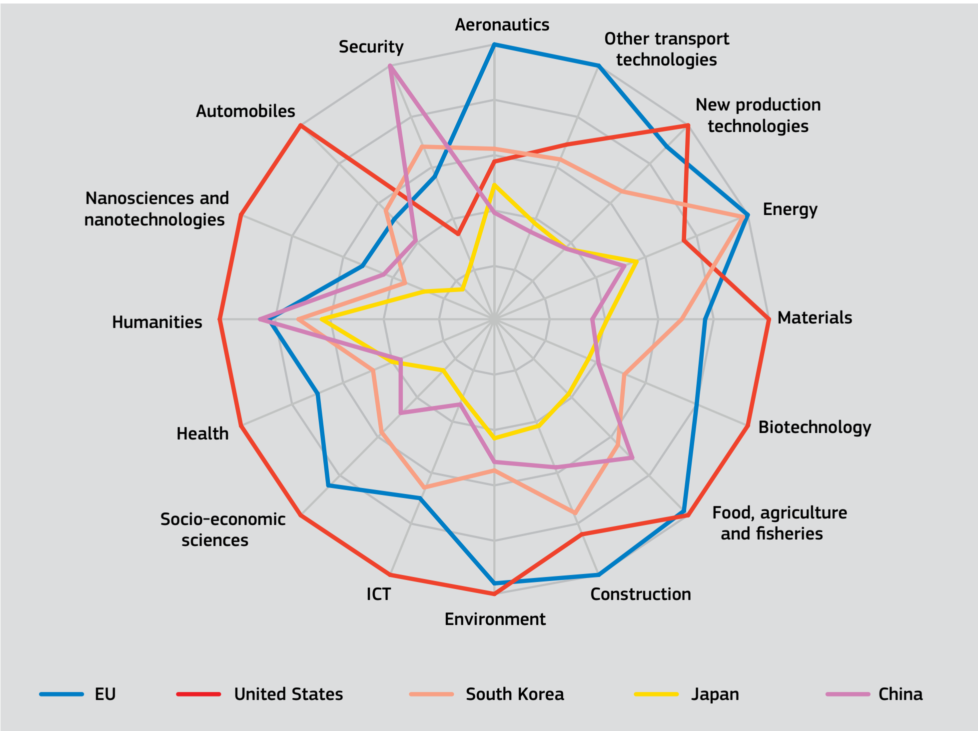
[24] See section on R&D Investments above.

There is a clear need for investments in research and innovation to be as smart and effective as possible. This requires clear strategies at the national level for investing in research and innovation coupled with high quality R&I programmes and strong institutions able to implement those programmes. In this context, it is vital that Member States are equipped with framework conditions able to leverage business investments in research and innovation

In terms of scientific specialisation, Europe underperforms in comparison to the United States in strategic areas such as nanosciences and nanotechnologies, ICT, materials or biotechnology.

The United States is more specialised in most strategic areas such as nanosciences and nanotechnologies, ICT, materials and biotechnology. Europe shows its strengths in aeronautics, other transport technologies, energy, and construction. Asian countries are still below the EU and the US levels in all scientific areas, with the exception of security, where China is the world leader (Figure I-3-6).

Figure I-3-6 **Highly cited scientific publications[(1)] by sector, 2010[(2)]**



Science, Research and Innovation performance of the EU 2016

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

Data: Science-Metrix (Canada), based on Scopus database

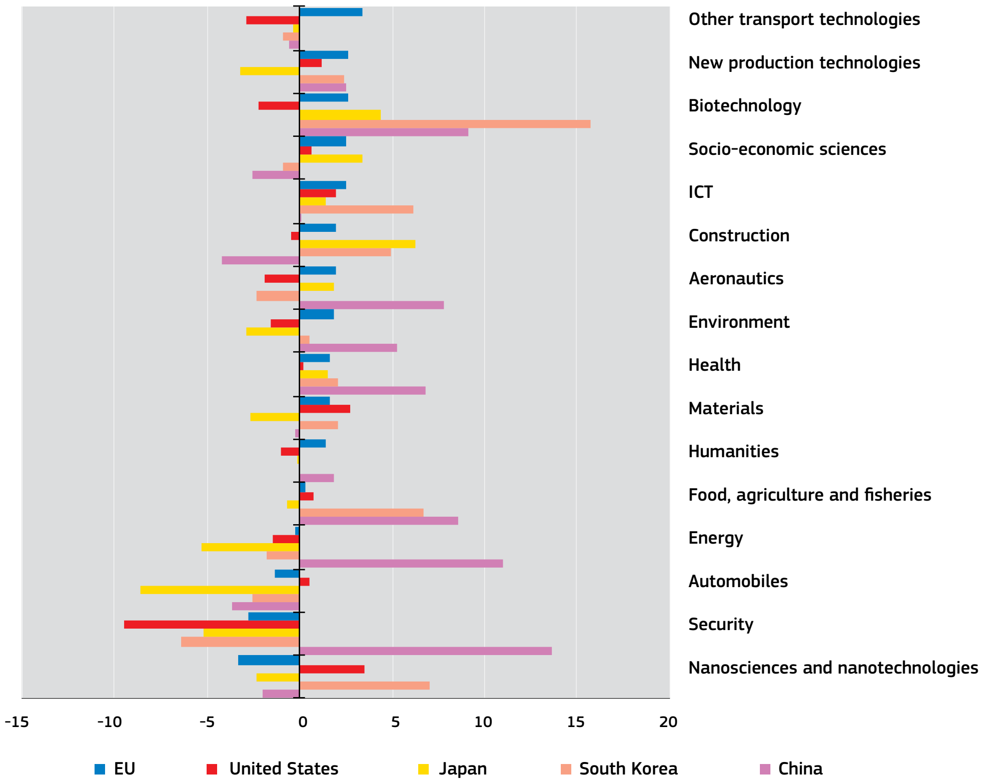
Notes: [(1)]Scientific publications within the 10% most cited scientific publications worldwide as % of total scientific publications of the country. [(2)]Fractional counting method; scientific publications 2010, with citation window 2010-2013.

China and, notably, South Korea have been increasing the number of highly cited publications in strategic fields, such as biotechnology or ICT, at a higher speed than Europe and the United States.

The annual average growth of highly cited publications clearly shows that, in recent years, China and South Korea have focused their efforts on a few strategic fields. Between 2000 and 2010, China has significantly improved the quality of its scientific publications in areas such as security, energy, and biotechnology, whereas South Korea has increased its world competitiveness in areas such as biotechnology, nanosciences and nanotechnologies, and ICT.

On the contrary, Europe has a much broader approach to science. Indeed, between 2000 and 2010, the EU increased the number of highly cited publications in almost all scientific fields, although at a lower speed than South Korea or China. Therefore, a particular focus on specific scientific areas seems to be missing. A similar pattern applies to the United States; however, they have not increased their highly cited publications at the same pace as the EU and they even show negative trends in different scientific fields (Figure I-3-7).

Figure I-3-7 **Compound annual growth (%) of highly cited publications by FP7 thematic priorities, 2000-2010[1]**



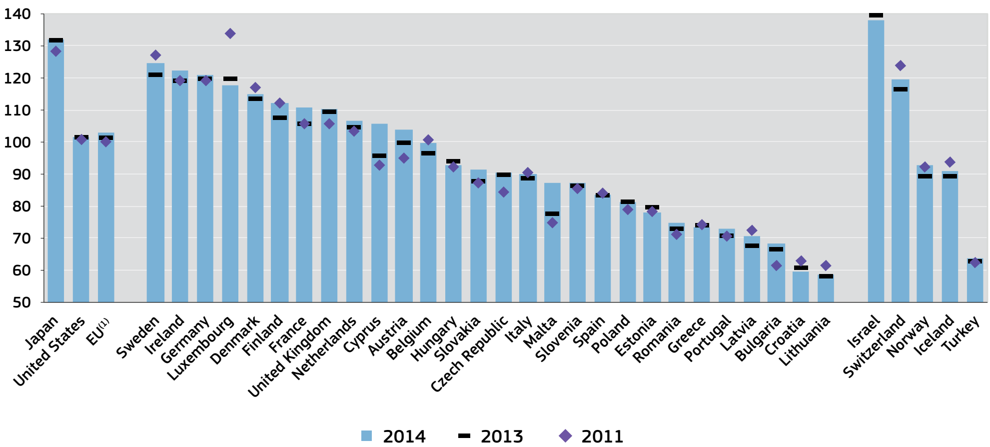
Science, Research and Innovation performance of the EU 2016

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Science-Metrix (Canada), based on Scopus database
Note: [1]Fractional counting method; scientific publications 2010, with citation window 2010-2013; scientific publications 2000, with citation window 2000-2003.

Innovation outputs

As regards key innovation outputs the EU performs at a similar level as the US, but is clearly outperformed by Japan. Progress in the EU in recent years has slow.

Figure I-3-8 **Innovation output indicator (EU2011 = 100), 2011, 2013 and 2014**



Science, Research and Innovation performance of the EU 2016

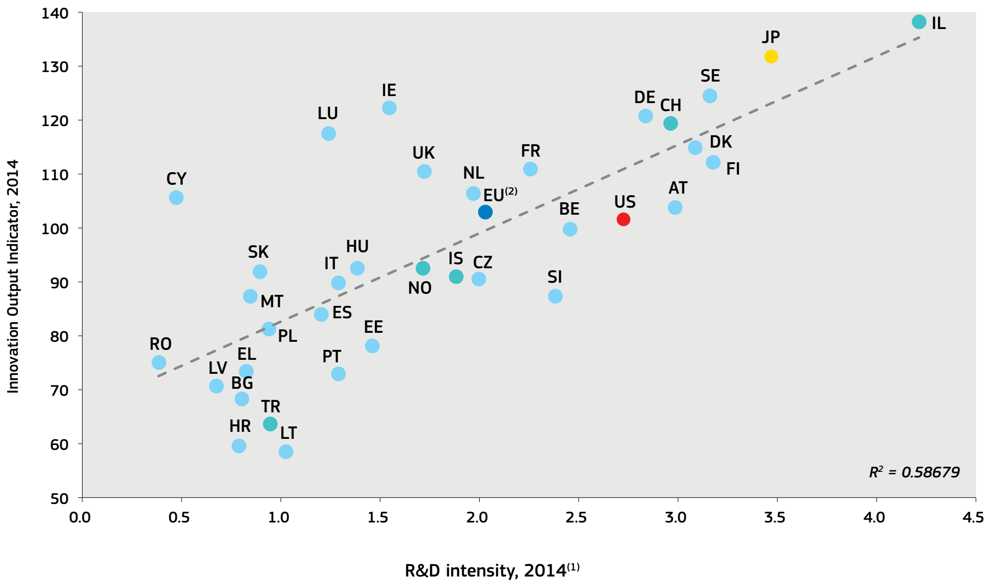
Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies

Data: Eurostat, OECD, Innovation Union Scoreboard 2015, 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 corresponding EU value for European comparison for 2014 is 103.6.

Innovation outputs are broadly linked to investment in R&D (inputs) (see Figure I-3-9 below) and correlated with GDP per capita (productivity) and economic outcomes. However, there are time lags and spillover effects and economic structures also play a role. The strong performance differences between Member States (see Figure I-3-8 above) imply that there is room for improvements, including of framework conditions.

Figure I-3-9 **Innovation Output Indicator score versus R&D intensity, 2014**



Science, Research and Innovation performance of the EU 2016

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat, JRC
Notes: [1]CH: 2012; TR, IL, US, JP: 2013. [2]EU: Two sets of values are available for the Innovation Output Indicator - values for Worldwide comparison and values for European comparison. The 2014 value for Worldwide comparison is shown on the graph. The corresponding EU value for European comparison is 103.6.

According to the Innovation Output indicator (IOI), 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 performs at a similar level as the US, but is clearly outperformed by Japan. Europe and Japan have improved performance since 2010, while the US performance has remained unchanged. Sweden is the best performing EU country, followed by Ireland and Germany. Bulgaria, Croatia and Lithuania are the lowest EU performers. In relative terms Cyprus and Malta have improved most since 2010.

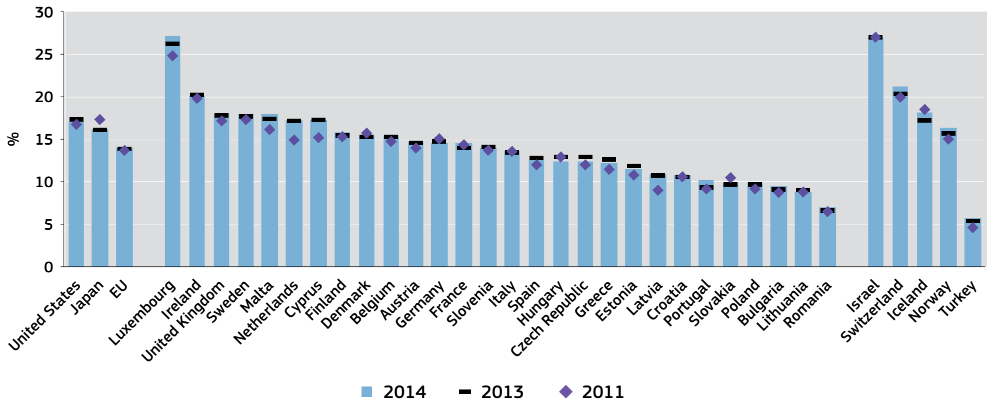
As regards the different components of the IOI, Finland, Sweden and Germany perform best in PCT patents, as shown in the section on patents below, while south-eastern European countries perform lowest in this field, partly as a result of a lack of global players in patent-intensive manufacturing sectors.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

As regards employment in knowledge-intensive activities, the EU is outperformed by both the US and Japan. Modern service-based economies, such as Luxembourg and Ireland, show the best results in the EU.

When it comes to employment in knowledge-intensive activities [25], the second component of the indicator and an important economic outcome of innovation, Luxembourg (financial services), Ireland (financial services, software) and the United Kingdom perform best, while south-eastern European countries are among the lowest performers. The EU is outperformed by both the US and Japan.

[25] For the list of NACE sections covered by knowledge-intensive activities and by knowledge-intensive business activities, see Eurostat: http://ec.europa.eu/eurostat/cache/metadata/Annexes/htec_esms_an8.pdf

Figure I-3-10 **Employment in knowledge-intensive activities in business industries as % of total employment**



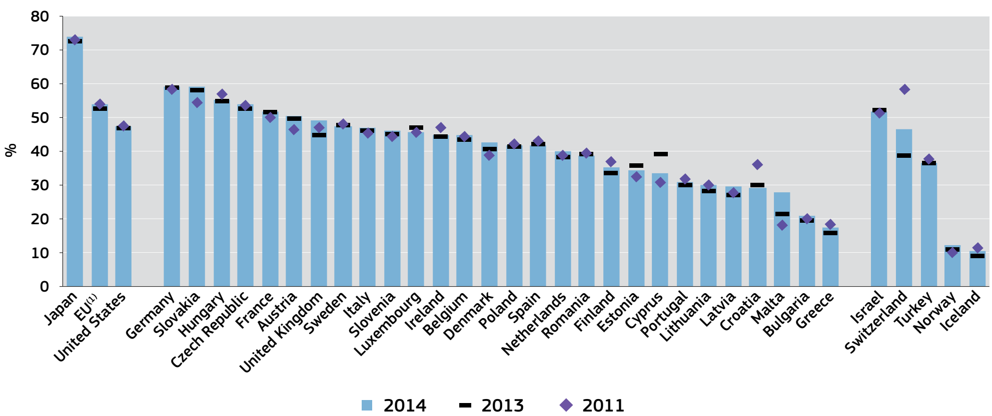
Science, Research and Innovation performance of the EU 2016

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat, JRC, Innovation Union Scoreboard 2015

Central and eastern European countries, together with Germany, show the best performance in the EU in medium and high-tech exports. This is partially a result of high exports of cars and automobile parts.

As regards the export share of medium and high-tech products (MHT) some eastern European countries perform well as a result of high exports of cars and machinery. It should hereby be noted, that these products are often just assembled in foreign affiliate enterprises in these countries, while the related R&D mostly takes place in the headquarter countries of global enterprises. The EU slightly outperforms the US in MHT exports, but clearly lags behind Japan.

Figure I-3-11 **Share (%) of medium-tech and high-tech products in total exports**

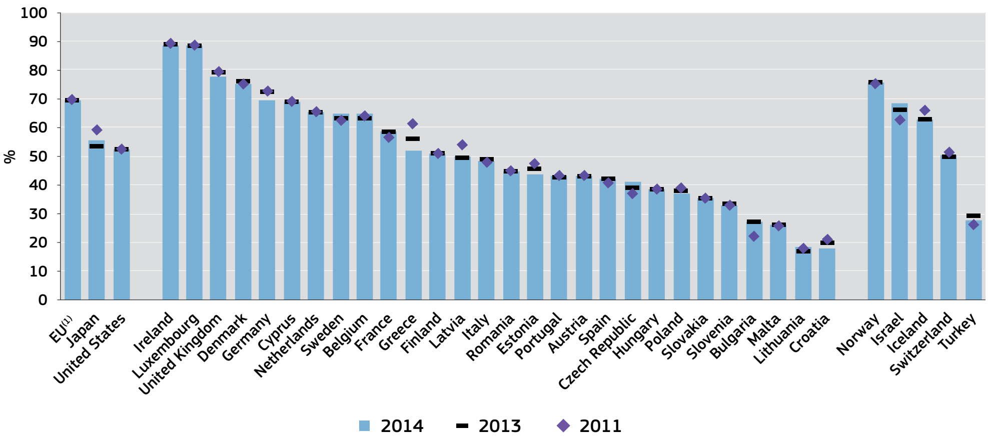


Science, Research and Innovation performance of the EU 2016

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat (COMEXP), JRC, UN (COMTRADE)
Note: [1]EU does not include intra-EU trade in order to facilitate international comparison. The value for the EU for 2014 when intra-EU trade is included is 48.8%.

As regards knowledge-intensive service exports, the EU outperforms the US and especially Japan. Countries with a high share of financial services and ICT services in their economy perform best in the EU.

Figure I-3-12 **Knowledge-intensive services exports as % of total service exports**



Science, Research and Innovation performance of the EU 2016

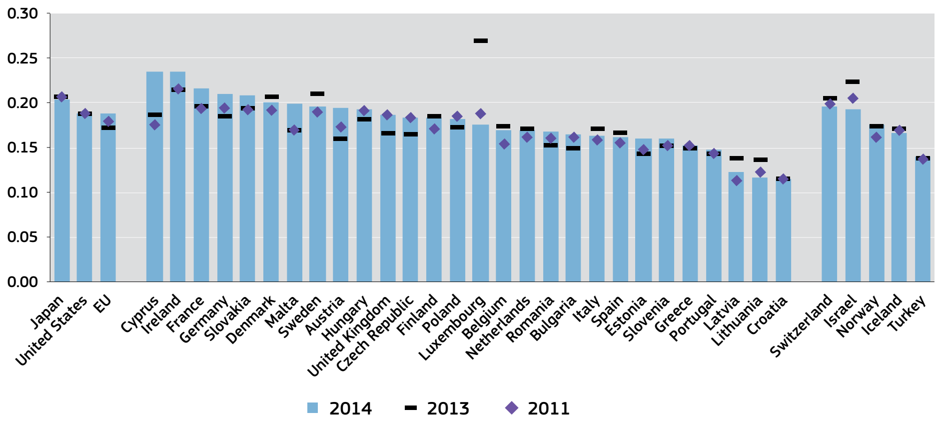
Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat (EBOPS), JRC
Note: [1]EU does not include intra-EU trade in order to facilitate international comparison. The value for the EU for 2014 when intra-EU trade is included is 63.1%.

When it comes to knowledge-intensive service exports, Ireland, Luxembourg and the United Kingdom take the lead in the EU, a result of high shares of financial and ICT services exports in these countries.

As regards the innovativeness of fast-growing enterprises, performance patterns are different from other innovation outputs, with good performance found both in Eastern and Western Europe.

The final component of the IOI relates to the innovativeness of fast-growing enterprises. Here, Cyprus (results related to a small number of fast growing enterprises only) and Ireland are in the lead, since fast-growing enterprises in the two countries are over-represented in innovative sections of the economy. Latvia, Lithuania and Croatia, which have a high share of fast growing enterprises perform at a low level, since these enterprises are concentrated in sectors characterised by low innovation scores, such as construction and retail.

Figure I-3-13 **Average innovativeness scores of fast growing enterprises[(1)]**



Science, Research and Innovation performance of the EU 2016

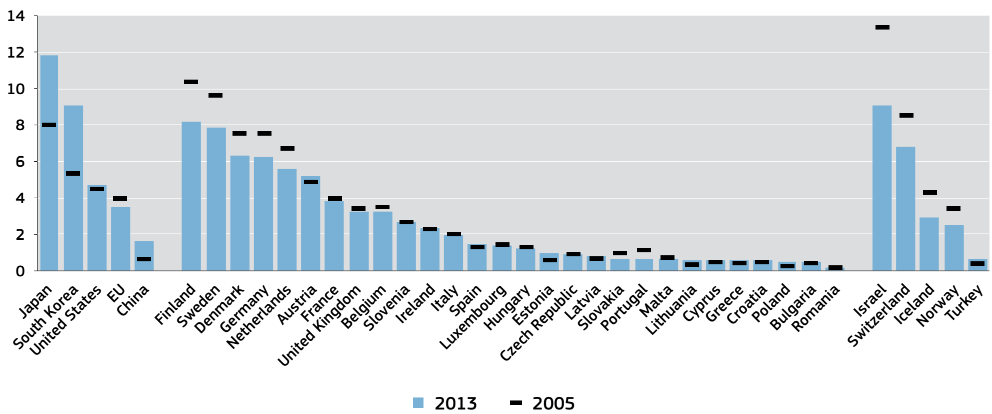
Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat, JRC
Note: [(1)]Imputed scores for the countries with missing data (EL, HR, IS, CH, TR, US, JP) are included.

The Innovation Union Scoreboard (IUS) is another, larger, composite indicator on innovation and its outputs that is based on 25 indicators. The 2015 edition of the IUS shows Sweden, Denmark, Finland and Germany as Innovation Leaders in Europe, while Romania, Bulgaria and Latvia are in the lowest category of modest innovators.

Technological outputs

The EU performs on a similar level in international patent applications as the US, but is outperformed by Japan and South Korea. Performance differences between EU Member States are very large.

Figure I-3-14 **Total patent applications (WIPO-PCT) per billion GDP (PPS€), 2005 and 2013**



Science, Research and Innovation performance of the EU 2016

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat, OECD

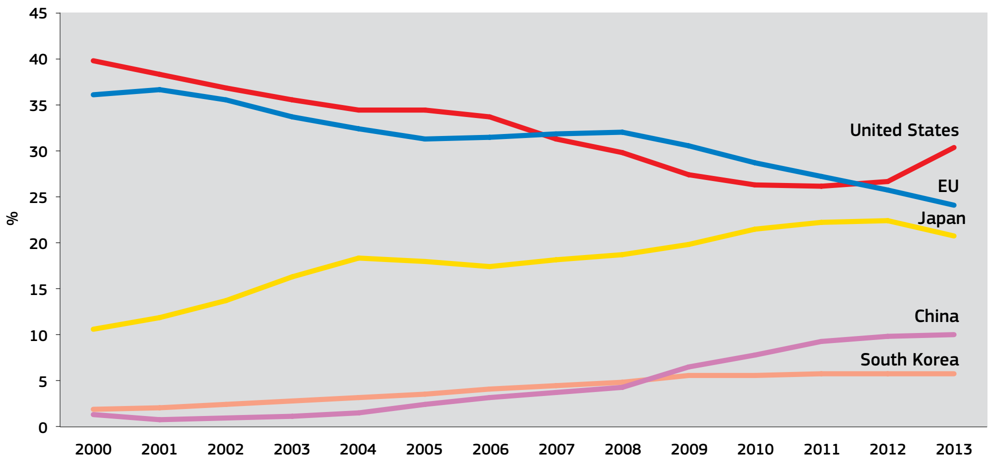
Patents are a frequent component of composite indicators on innovation, often used to measure technological output. For timeliness reasons data on applications are used rather than patents granted. When analysing performance as regards patent applications, structural differences of economies have to be taken into account. Patent propensity is linked to the share of manufacturing in GDP (companies in the manufacturing sector 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 (software industry is patent intensive) and to the enterprise structure of a country (larger enterprises tend to have a higher patent propensity). Patenting is also linked to the location of the headquarters of a company (R&D tends to be carried out in the headquarter country).

Innovation leaders, such as Finland, Germany and Sweden, are also strong performers in regard to patents, while moderate and modest innovators, such as Lithuania, Malta and Romania show low levels of patenting, especially as regards PCT patents. It will be important to reduce the innovation divide in Europe to catch up with the patenting level of competitors.

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

In many European countries, the number of international and national patent applications has declined in the recent past, while patenting is expanding quickly in East Asian countries. As a result, Asian countries, especially China, are catching up in world patent shares, while Europe's share is declining. The share of the US, long in decline, has stabilised in recent years.

Figure I-3-15 **World share (%) of PCT patent applications, 2000-2013**



Science, Research and Innovation performance of the EU 2016

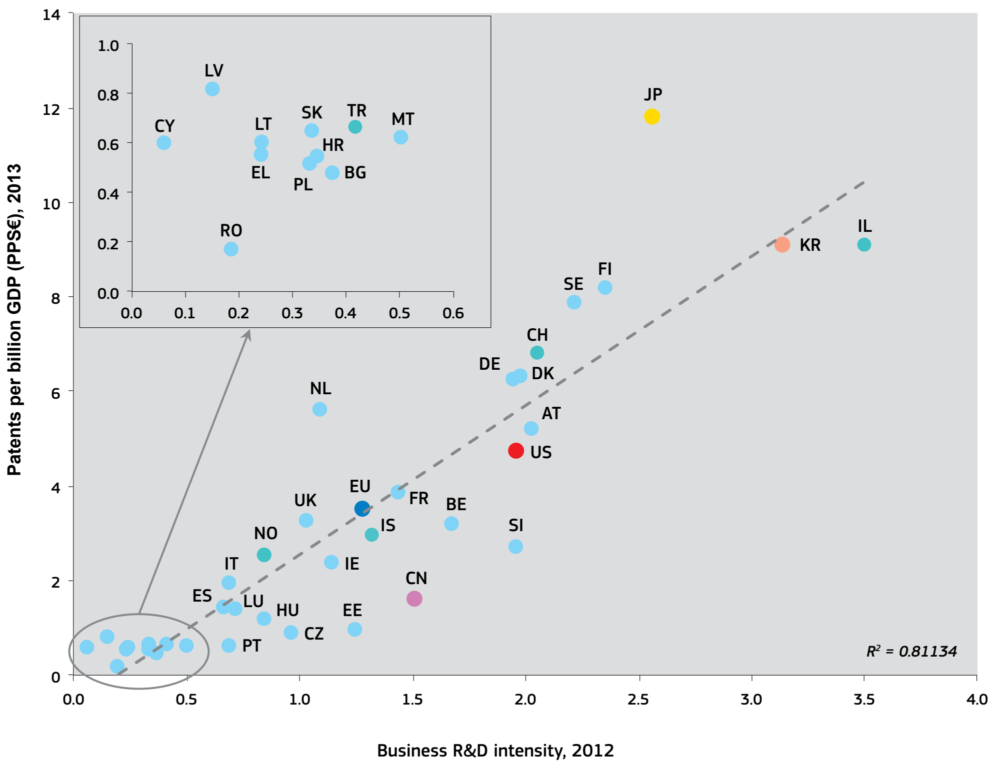
Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies

Data: OECD

Europe is relatively efficient in translating business R&D expenditure into technological outputs, especially compared to the US. However, in this respect the EU is still outperformed by Japan.

The EU, as a whole, and most of the innovation leaders in the EU do a relatively good job as regards translating business R&D expenditures into technological output (as measured by patent applications). The Netherlands stands out in this context with a particularly good level of performance. On the other hand, the EU is outperformed by Japan, which shows a high level of patenting even when compared to its high level of business expenditures on R&D.

Figure I-3-16 **Patent applications per billion GDP (PPS€), 2013 versus business R&D intensity, 2012**



Science, Research and Innovation performance of the EU 2016

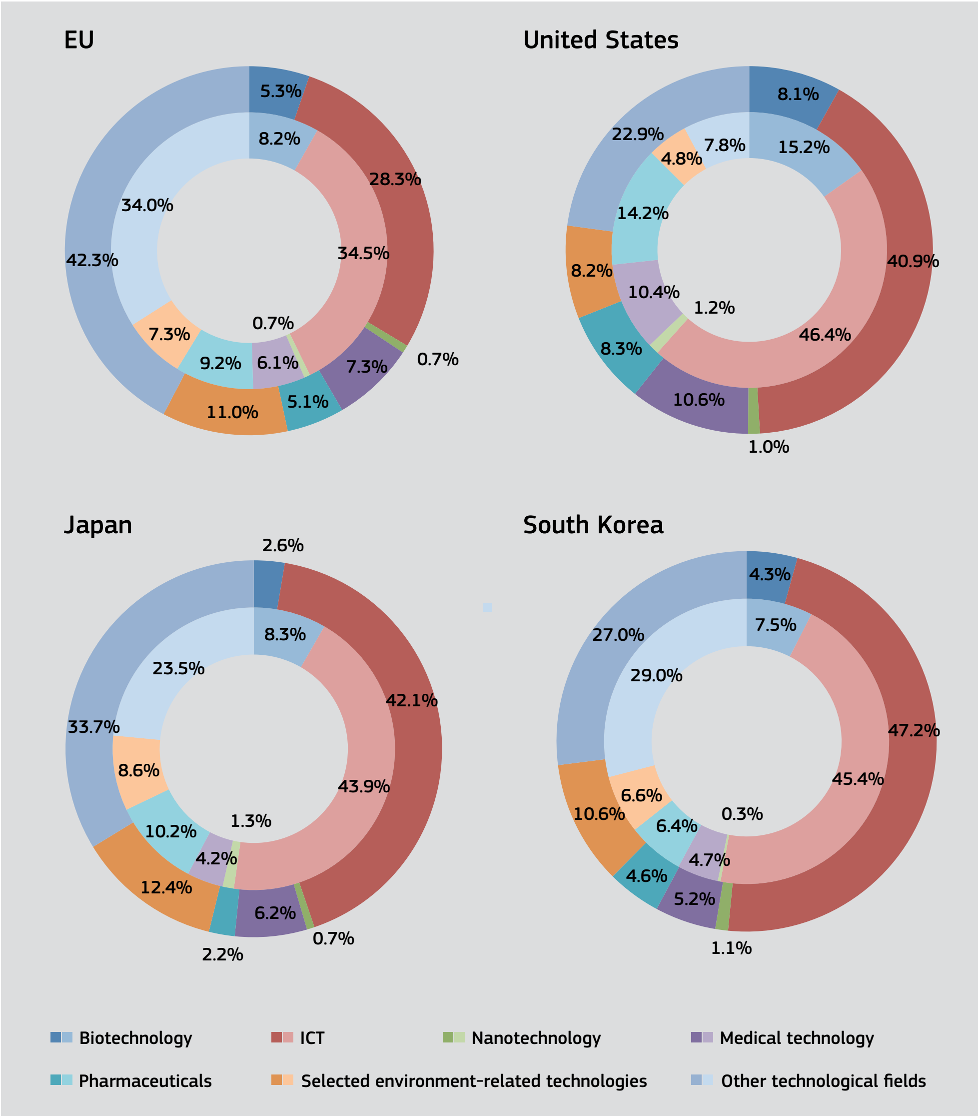
Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies

Data: Eurostat, OECD

Note: (1)Elements of estimation were involved in the compilation of the data.

The EU is less technologically specialised than the US, Japan or South Korea. Japan and South Korea have strengths in ICT, while the US, in addition, has strengths in medical technology and pharmaceuticals.

Figure I-3-17 Shares of patent applications by technology fields, 2013 (exterior) versus 2000 (interior)



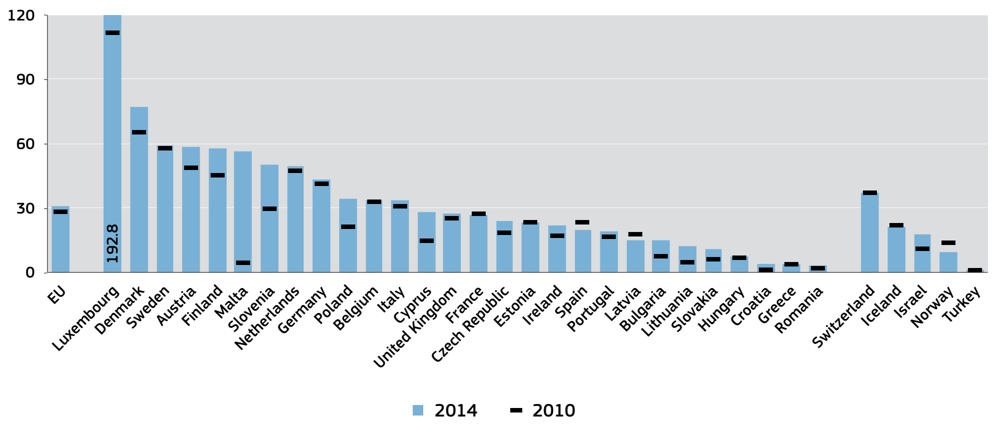
Science, Research and Innovation performance of the EU 2016

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

Specialisation patterns differ between countries and change over time. The comparison between 2000 and 2011 (see Figure I-3-17 above) shows less specialisation in Europe in ICT, with a lower share compared to competitors, and in pharmaceuticals (whose share is declining everywhere). The data also show the growing importance of inter-disciplinary fields and of environmental and energy issues and the fact that the share of patents for medical technology is increasing in Europe, the US and Asia. While Europe has relative strengths in 'other technology fields', the US has strengths in pharmaceuticals, medical technology and ICT, Japan and South Korea have relative strengths in ICT and environmental technologies. In general, the EU is less specialised than key competitors in fields that have a high patent propensity (ICT, biotechnology, pharmaceuticals).

As regards Community Design applications, performance patterns also reflect factors outside research and innovation. Some eastern European countries perform relatively well compared to technological innovation outputs such as patents, showing that it is easier to advance in non-technological outputs than more traditional innovation outputs.

Figure I-3-18 **Community Design applications per million population, 2010 and 2014**



Science, Research and Innovation performance of the EU 2016
Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat

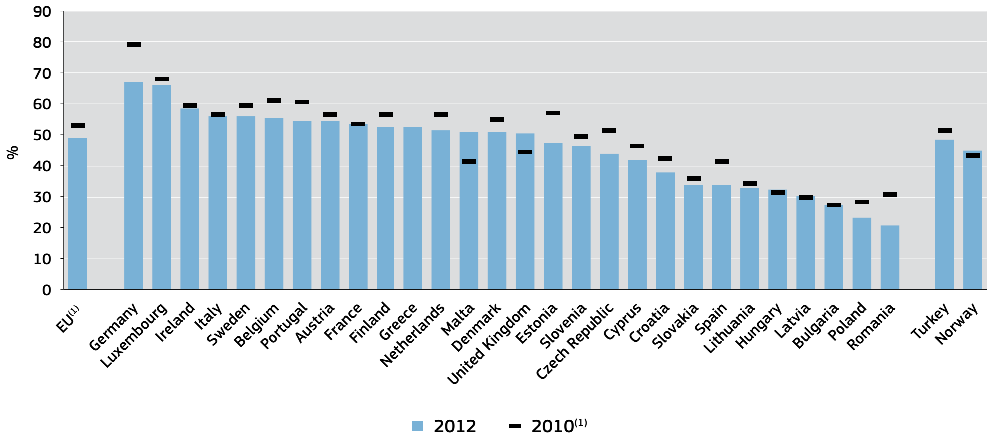
Performance in Community Designs (see Figure I-3-18 above) is not only influenced by the quality of the innovation system, but also by differences in taxation and regulation. In particular, for very small Member States (Luxembourg, Malta) designs do not necessarily reflect the quality of national R&I systems. However, countries performing traditionally well in innovation outputs, such as Sweden, Denmark and Finland, also perform well in Community Designs. Some eastern European countries rank much higher in this area than in patents, with high growth rates in recent years, implying that it is easier to advance in this less technology-oriented area, where costs are also lower and time lags shorter. Nevertheless, not all countries are grasping the opportunities here, with several south-eastern European countries showing low performance.

Performance in Community Trade Marks is similar to the one shown by Community Designs and is also affected by factors outside innovation such as differences in taxation and regulation. In particular, for very small Member States (Luxembourg, Cyprus, Malta) Trade Mark propensity does not necessarily reflect the quality of national R&I systems. However, countries performing traditionally well in innovation outputs, such as Sweden, Denmark and Germany, also perform well in Community Trade Marks. For the other countries, performance patterns are similar to technological outputs such as patents, with Estonia and Spain being notable exceptions.

Innovative enterprises

The share of innovative enterprises is broadly linked to GDP per capita (productivity) levels. The share has fallen in most countries since 2008-2010.

Figure I-3-19 **Share (%) of innovative enterprises in total number of enterprises, 2010 and 2012**



Science, Research and Innovation performance of the EU 2016

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat (CIS 2010, CIS 2012)
Note: [(1)]EU: Greece is not included in the EU value for 2010.

Germany, Luxembourg, Ireland — all countries with a GDP per capita and productivity level above the EU average — show the highest shares of innovative enterprises (see Figure I-3-19 above), while Bulgaria, Poland and Romania, countries with a below EU-average GDP per capita, show the lowest shares. The share of innovative companies is also linked to economic structures, with countries having a high share of medium-high and high-tech manufacturing companies or a high share of knowledge-intensive services (ICT, finances) naturally showing a high share of innovative enterprises. However, it is worrying that the share of innovative enterprises has declined in many EU countries since 2008-2010, as evidenced by results of the Community Innovation Survey, an enterprise survey. Since innovations are linked to investment, this could be interpreted as further evidence of investment levels still being too low in Europe.

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.

As regards the different types of innovation activities (see Figure I-3-20 below), leading innovation countries perform well both in product and process innovations as well as in marketing and organisational innovations of their enterprises. Countries with overall low innovation levels perform low in all innovation activities, but particularly low in product innovations, which typically require more resources to generate than other types of innovations.

Figure I-3-20 **Innovation activities (% of total enterprises), 2010-2012**

	Product and / or process innovative enterprises	of which:		Organisation and / or marketing innovative enterprises	of which:	
		Product innovative enterprises	Process innovative enterprises		Orrganisation innovative enterprises	Marketing innovative enterprises
Belgium	46.5	31.5	31.1	37.9	29.3	21.9
Bulgaria	16.9	10.8	9.3	18.6	12.4	14.2
Czech-Republic	35.6	25.3	24.0	31.6	20.5	22.4
Denmark	38.2	24.8	23.0	41.8	32.2	29.5
Germany	55.0	35.8	25.5	47.6	32.2	34.4
Estonia	38.4	20.7	23.8	31.8	21.7	21.9
Ireland	42.3	27.8	25.9	50.8	21.8	35.7
Greece	34.3	19.5	25.6	45.4	30.2	36.8
Spain	23.2	10.5	15.1	23.4	19.4	13.2
France	36.7	24.2	24.1	42.3	34.2	25.4
Croatia	25.0	16.4	19.0	31.8	22.9	23.5
Italy	41.5	29.1	30.4	45.3	33.5	31.0
Cyprus	29.8	20.9	28.2	36.1	26.1	29.5
Latvia	19.5	10.3	12.7	23.9	16.9	16.5
Lithuania	18.9	11.6	13.1	26.2	17.5	19.3
Luxembourg	48.5	30.3	32.8	53.5	46.8	32.4
Hungary	16.4	10.6	8.3	26.5	16.5	19.7
Malta	35.9	23.9	26.4	44.4	34.7	32.6
Netherlands	44.5	31.9	25.9	35.7	27.3	23.2
Austria	39.3	26.6	28.7	46.1	36.4	29.5
Poland	16.1	9.4	11.0	15.5	10.4	10.6
Portugal	41.3	26.0	33.5	43.6	32.8	32.8
Romania	6.3	3.4	4.6	18.8	14.1	13.8
Slovenia	32.7	23.6	22.5	37.6	26.3	28.5
Slovakia	19.7	14.4	13.5	27.7	18.6	19.3
Finland	44.6	31.0	29.3	38.4	29.7	26.5
Sweden	45.2	31.5	23.9	39.1	25.3	30.4
United-Kingdom	34.0	24.0	14.1	39.1	34.2	16.8
EU	36.0	23.7	21.4	37.1	27.5	24.3
Norway	31.2	19.1	11.9	33.0	21.7	23.2
Turkey	27.0	17.7	20.4	43.7	31.7	34.7

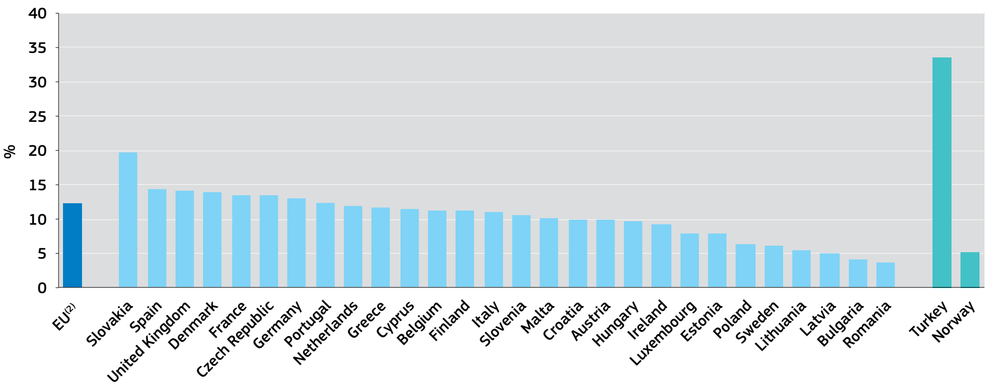
Science, Research and Innovation performance of the EU 2016
Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat (CIS 2012)

The share of innovation turnover does not appear to be directly correlated to the share of innovative enterprises.

As regards the share of innovation turnover (see Figure I-3-21 below) in total turnover the share does not appear to be directly correlated to the share of innovative enterprises. Therefore, it has to be taken into account that the results relating to the share of companies is dominated by small- and medium-sized companies, while as regards turnover larger companies play a bigger role, including foreign affiliates, who often import innovations from the headquarter country.

According to the latest CIS results Slovakia has the highest share among EU countries, which might have to do with foreign companies producing goods such as cars and ICT products in the country, which are characterised by short product cycles. On the other hand, the lowest performers Latvia, Bulgaria and Romania also perform low in the share of innovative enterprises.

Figure I-3-21 **Share (%) of innovation turnover in total turnover, 2012[(1)]**



Science, Research and Innovation performance of the EU 2016

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat (CIS 2012)
Notes: [(1)]IE: 2010. [(2)]EU: Ireland is not included.

4. Framework conditions for research and innovation

Boosting innovation requires that framework conditions are sound and supportive, so that an effective allocation and reallocation of production resources can be ensured towards innovative activities. This requires fair levels of competition in the producti markets, dynamic labour markets, or well-functioning financial institutions that ensure easier access to finance for new firms. Open markets, a competitive and dynamic business sector, a culture of healthy risk-taking and creative activity, coupled with well-functioning public institutions, including an effective legal system, are therefore crucial for the uptake and development of innovation. The importance of framework conditions is such that it has been recognised as one of the five key policy principles for innovation under the OECD Innovation Strategy [26], and represents one of the key policy priorities for the European Commission.

Against this backdrop, based on existing indicators, this section analyses the soundness of these framework conditions against other advanced economies, such as the United States, and the internal differences across Member States. More precisely, this section will highlight the regulatory conditions by assessing the ease of doing business, the levels of competition in the product markets, the functioning of the labour markets, Intellectual Property Protection, the level of entrepreneurial spirit, and the ease of accessing finance, notably for innovation activities.

Regulation and market efficiency

The regulatory framework in which businesses operate is a key factor in their competitiveness, growth and employment performance. Therefore, a key objective of government policy is to ensure that the regulatory environment is simple and creates the right incentives. One can distinguish between general regulations affecting the general business environment, innovation-specific rules and incentives to innovate, and sector-specific regulations (Pelkman & Renda 2014). This chapter focuses on the general regulations affecting the business environment.

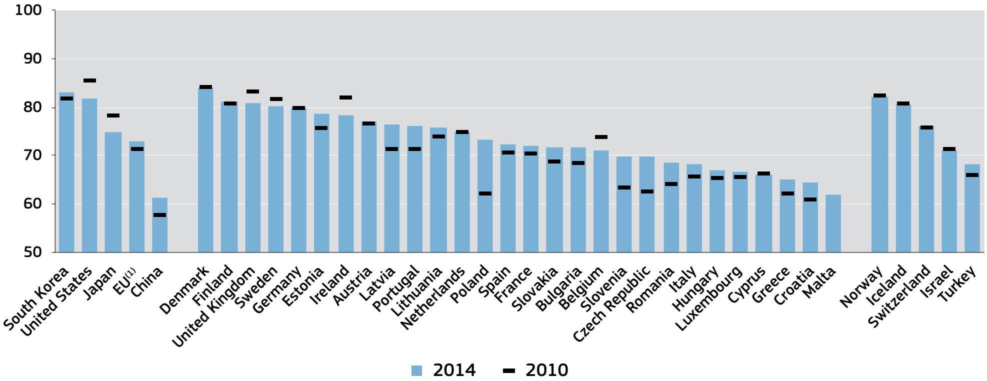
It is easier to do business in the United States, Japan and South Korea than in the European Union. While the West-East divide continues to exist in Europe, several Eastern European countries such as Poland, the Czech Republic, Slovenia or Latvia have improved their regulatory environments substantially. Southern countries affected by the global financial crisis such as Greece, Italy, Portugal and Spain have maintained a steady pace of regulatory reform, which picked up in the aftermath of the crisis.

The World Bank annual report 'Doing Business' ranks since 2003 countries according to how attractive they are to companies. A key component of the measure involves the setting up of a fictional company in each jurisdiction and working out how long it would take for these companies to become incorporated, pay taxes, etc. In total, the index contains ten components:

1. Starting a business,
2. Dealing with construction permits,
3. Getting electricity,
4. Registering property,
5. Getting credit,
6. Protecting minority investors,
7. Paying taxes,
8. Trading across borders,
9. Enforcing contracts,
10. Resolving insolvency.

[26] http://www.oecd.org/sti/OECD-Innovation-Strategy-2015-CMIN2015-7.pdf

Figure I-4-1 **Ease of doing business, 2010 and 2014**



Science, Research and Innovation performance of the EU 2016

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Ease of Doing Business Indicator (World Bank)
Note: [1]EU: The value is the unweighted average of the values for the Member States.

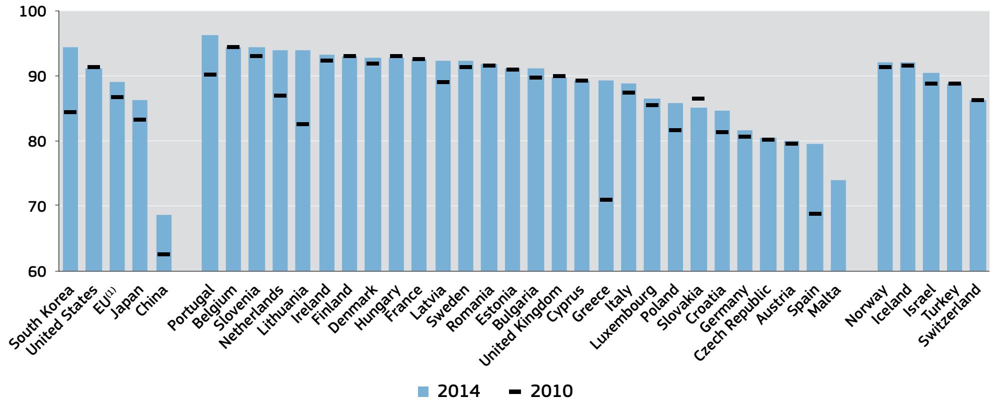
The World Bank composite indicator shows that it is easier to do business in the United States, Japan, and South Korea than in the EU, although the gap seems to be narrowing since 2010, notably against the United States and Japan (see Figure I-4-1). Some Eastern European economies, by actively reducing the complexity and cost of regulatory processes and strengthening legal institutions, are narrowing the gap with the regulatory frontier at a faster pace than the rest of the European Union, in their efforts to spur business activity and attract foreign direct investments. Poland has improved substantially, but Slovenia, the Czech Republic, Latvia, Romania and Croatia have all shown improvement, as well. In 2012, Poland was the economy that had narrowed the gap with the regulatory frontier the most over the previous year, among all 185 economies ranked by the World Bank (World Bank 2013). This suggests that the economic integration in the European Union over the past decade might have been an effective mechanism in promoting convergence. In fact, Poland is now classified as a high-income economy, a remarkable achievement in two decades.

Greece, Italy, Portugal and Spain—all among the economies most adversely affected by the global financial crisis—have maintained a steady pace of regulatory reform. The pace picked up in the aftermath of the crisis and the trend has continued. In 2013/14 Spain reformed in four areas of business regulation measured by 'Doing Business', and Greece in three. These economies, by actively reducing the complexity and cost of regulatory processes and strengthening legal institutions, are narrowing the gap with the regulatory frontier (World Bank 2014).

In fostering entrepreneurship and lowering the barriers to starting a business, the United States and South Korea fare better than the EU. Within the EU, starting a business is the easiest in Portugal and has improved substantially in Greece, Spain and Lithuania.

Portugal, which has the highest score on this World Bank sub-indicator, made starting a business easier by eliminating the requirement to report to the Ministry of Labour (see Figure I-4-2). In Portugal, cutting the time and cost of firm registration increased the number of business start-ups by 17% and created about seven new jobs a month per 100 000 inhabitants in eligible industries (Branstetter et al. 2013). Greece made starting a business easier by lowering the cost of registration. In 2012, Greece introduced a simpler type of limited liability company, called a private company, that is cheaper to incorporate. A year later, Greece abolished the minimum capital requirement. Spain also made starting a business easier by simplifying business registration through the introduction of an electronic system that links several public agencies. Lithuania made starting a business easier by creating a new form of limited liability company with no minimum capital requirement. In Poland, entrepreneurs no longer have to register new companies at the National Labor Inspectorate and National Sanitary Inspectorate.

Figure I-4-2 **Starting a business, 2010 and 2014**



Science, Research and Innovation performance of the EU 2016

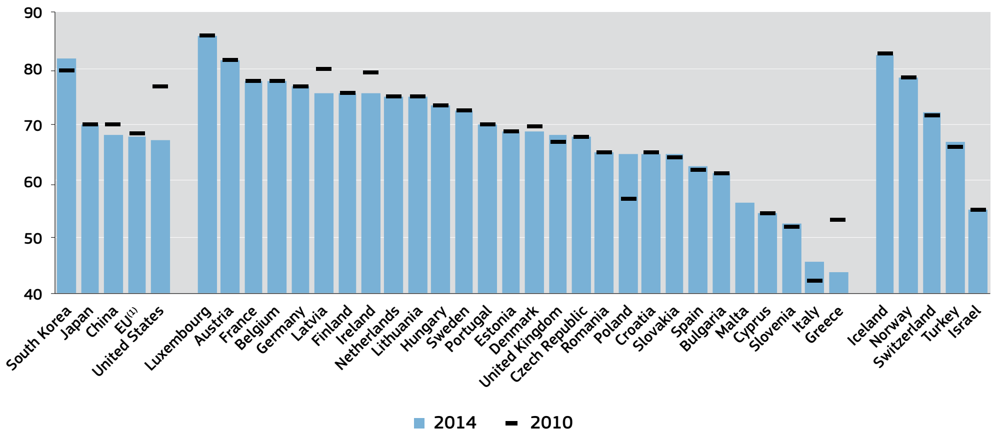
Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Ease of Doing Business Indicator (World Bank)
Note: (1)EU: The value is the unweighted average of the values for the Member States.

Several EU countries have made strides to improve the functioning of their legal systems, notably in important areas such as enforcing contracts, led by Poland, or in resolving insolvency, led by the Czech Republic. However, several Member States continue to score very low levels, which hampers their ability to improve the overall business environment, and the conditions for innovation.

Countries where it is quick and easy to enforce contracts or wrap up failing firms are usually more attractive to investors than places with lethargic legal systems. Since 2009, Poland has made the most progress in regulatory practice in enforcing contracts (see Figure I-4-3). Poland has benefited from implementing a case management system, introducing an electronic court in Lublin, deregulating the bailiff profession, increasing the number of judges, and amending the Civil Procedure Code. Portugal made enforcing contracts easier by adopting a new code of civil procedure designed to reduce court backlog, streamline court procedures, enhance the role of judges, and speed up the resolution of standard civil and commercial disputes. Greece worsened its performance in enforcing contracts over the period 2010 to 2014 in terms of the time needed to enforce a contract through the Greek court system. However, recently Greece made enforcing contracts easier by introducing an electronic filing system for court users (World Bank 2014).

Italy has made some progress in enforcing contracts by regulating attorney fees and streamlining some court proceedings, but it still remains at the bottom of the ranking, which is a serious impediment to entrepreneurship and innovation. Slovenia, Cyprus, and Bulgaria have not made substantial progress and continue to score very low on enforcing contracts, too. Since June 2012, Italy has reduced attorney fees the most among all the economies measured. Judges were given an official fee schedule to determine attorney fees when agreements are not reached between attorneys and clients, which contributed to the adjustment of the market price for legal services and cut attorney fees by 6.8 percentage points, to 15% of the value of the claim (World Bank 2013).

Figure I-4-3 **Enforcing contracts, 2010 and 2014**



Science, Research and Innovation performance of the EU 2016

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

Data: Ease of Doing Business Indicator (World Bank)

Note: [(1)]EU: The value is the unweighted average of the values for the Member States.

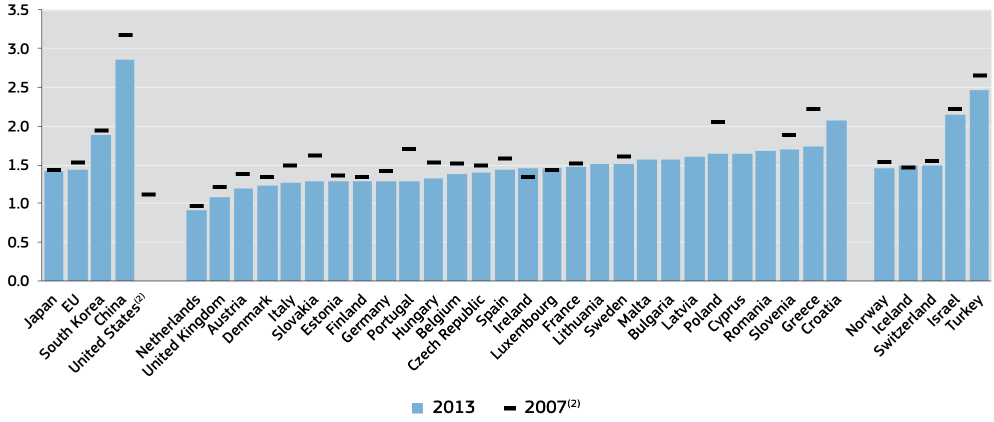
the Czech Republic has made the most progress in regulatory practice in resolving insolvency since 2009. A new insolvency law went into effect in 2008 and declared reorganisation the preferred method of resolving insolvency. Liquidation and reorganisation proceedings were streamlined, and insolvency representatives became subject to educational and professional requirements as well as stricter government oversight. Application of the new regulations identified some inefficiencies that led to further reforms in 2009 and 2012. By 2011, reorganisation was the most common insolvency procedure in the Czech Republic, and survival of distressed but viable companies was the prevailing outcome. By 2013, the time to complete insolvency proceedings had fallen by 4.4 years compared with 2008. The recovery rate of creditors in the Czech Republic more than tripled over the past six years (World Bank 2013). Spain made resolving insolvency easier by introducing new rules for out-of-court restructuring as well as provisions applicable to pre-packaged reorganisations (World Bank 2014).

In terms of Product market regulation, the EU is less competition-friendly than Japan and the United States, which hampers a potential reallocation of resources towards more productive, innovation-driven activities.

Triggered by the economic crisis, Greece, Portugal, Poland and Slovakia have implemented important reforms, but the gap still persists.

A competitive product market environment that allows new firms to challenge incumbents, efficient firms to grow, and inefficient ones to exit, helps boost economic growth. The OECD indicators of product market regulation (PMR) measure the economy-wide regulatory and market environments and the degree to which policies promote or inhibit competition in areas of the product market where competition is viable. In Figure I-4-4, a high score corresponds to a less competition-friendly environment compared to the OECD average. The most competition-friendly countries in the EU are the Netherlands, United Kingdom, Austria and Denmark. Several EU Member States have implemented important reforms over the past five years, often triggered by the economic crisis. The country with the largest improvement in the overall PMR score is Greece, which is still among the OECD countries with relatively strict product market regulations, followed by Portugal, Poland and Slovakia. In Italy and Spain, which have also faced strong market pressures for structural reforms since 2011, progress has been more modest (Koske et al. 2015).

Figure I-4-4 **Product market regulation[1], 2007 and 2013**



Science, Research and Innovation performance of the EU 2016

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: OECD
Notes: [1]A high score corresponds to a less competition-friendly environment compared to the OECD average. [2]US: Data are not available for 2013. [3]EE, SI, IL: 2008.

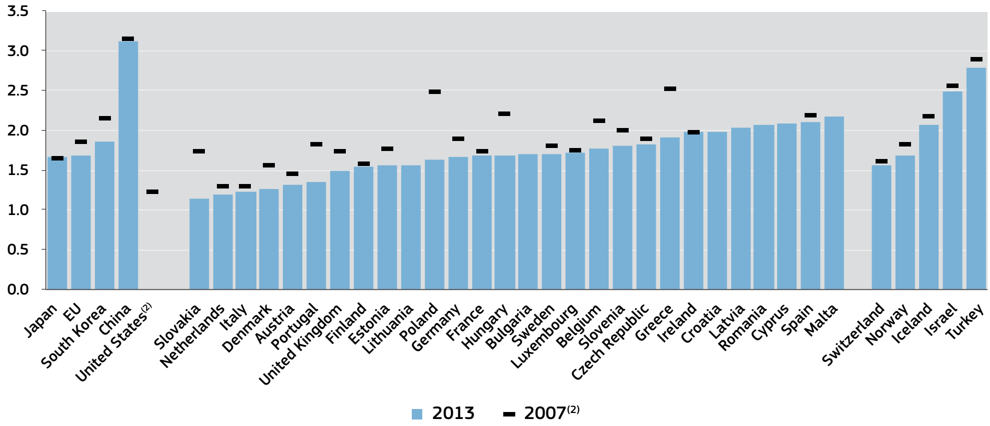
Reforms over the past five years have not been concentrated in particular fields of regulation, but have been spread out quite evenly across the three major regulatory domains covered by the indicators [27]. Some countries have eased restrictions on trade and investments (in particular, by lifting barriers to foreign direct investment and phasing out differential treatments of foreign suppliers). A number of countries have lifted barriers to entrepreneurship (in particular, by modernising licence and permit systems, streamlining administrative procedures for start-ups, simplifying rules and procedures, and improving access to information about regulation). Finally, a number of countries have reduced the level of state control (in particular, by removing special voting rights and legal or constitutional restrictions to the sale of government stakes and/or by abolishing price controls or improving their design) (Koske et al. 2015).

On the Product Market Regulation sub-indicator 'Barriers to entrepreneurship', the EU performed worse than Japan and the United States in 2007, which hinders the potential to entry of new players and the dynamic changes of the enterprise community. Overall, the EU improved its performance between 2007 and 2013.

The lowest barriers to entrepreneurship are found in Slovakia, the Netherlands, Italy and Denmark (see Figure I-4-5). Poland, Slovakia, and Greece improved substantially, but Portugal and Hungary improved, as well.

(27) The aggregated indicator is composed of 3 components: 1) State control: Public ownership, Involvement in business operations; 2) Barriers to entrepreneurship: Complexity of regulatory procedures, Administrative burdens on start-ups, Regulatory protection of incumbents; 3) Barriers to trade and investment: Explicit barriers to trade and investment, Other barriers to trade and investment.

Figure I-4-5 **Barriers to entrepreneurship[1], 2007 and 2013**



Science, Research and Innovation performance of the EU 2016

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: OECD
Notes: [1]A high score corresponds to a less competition-friendly environment compared to the OECD average. [2]US: Data are not available for 2013. [3]EE, SI, IL: 2008.

Adjusting the level and composition of the workforce to adapt to changing demand conditions and technology is vital for effective businesses operations and, therefore, for productivity and economic growth.

For economies to thrive on innovation, labour needs to be continuously reallocated within and across firms and sectors. Employment protection legislation that is too rigid has been found to significantly decrease the ability of innovative firms to attract resources. Stringent employment protection legislation (EPL) hinders the redirection of resources towards their most productive uses and, therefore, hinders productivity growth. As a result, EPL was found to reduce R&D expenditure, hampering firms that engage in innovation and need skilled personnel and complementary resources to implement and commercialise them (Andrews and Criscuolo, 2013).

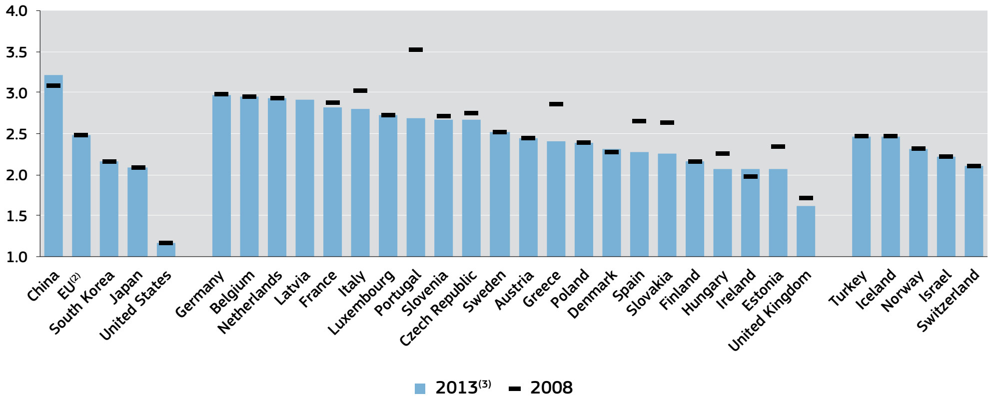
However, job displacement entails significant costs for the workers concerned in terms of earning losses and the possible obsolescence of their job-specific skills and experience. Social costs are also important. For example, greater financial distress associated with job loss may entail health problems. To minimise these costs, public policies such as unemployment benefits, job-search assistance and active labour market programmes are put in place by governments. Nevertheless, these policies are financed by the society through higher taxes. Striking an adequate balance between allowing an efficient reallocation of labour resources and the need to protect employees is therefore a key priority for policy-makers (OECD 2013). The goal should not be to lessen workers' insurance against labour market risks, but rather to shift the burden of that insurance away from firms and towards society more widely. This is where 'flexicurity' type policies — active labour market policies, unemployment insurances — play an important role (ECB 2014).

The level of employment protection legislation in the EU is much higher than in the US, Japan, and South Korea. The countries which reduced their protection of permanent workers against individual and collective dismissals the most in the time period from 2008-2013 are Portugal, Greece, Spain and Slovakia.

The level of employment protection legislation differs across EU Member States, with Germany, Belgium and the Netherlands having the most restrictive EPL (see Figure I-4-6). The countries which reduced their protection of permanent workers against individual and collective dismissals the most in the time period from 2008-2013 are Portugal, Greece, Spain and Slovakia.

Furthermore, regulation on temporary forms of employment is more restrictive in the EU than in the US, Japan and China (see Figure I-4-7). Estonia decreased its protection of permanent workers against individual and collective dismissals, while it increased the restrictions with regard to temporary forms of employment. In addition to reducing the protection of permanent workers against dismissals, Greece and Spain reduced the restrictions on temporary forms of employment between 2008 and 2013.

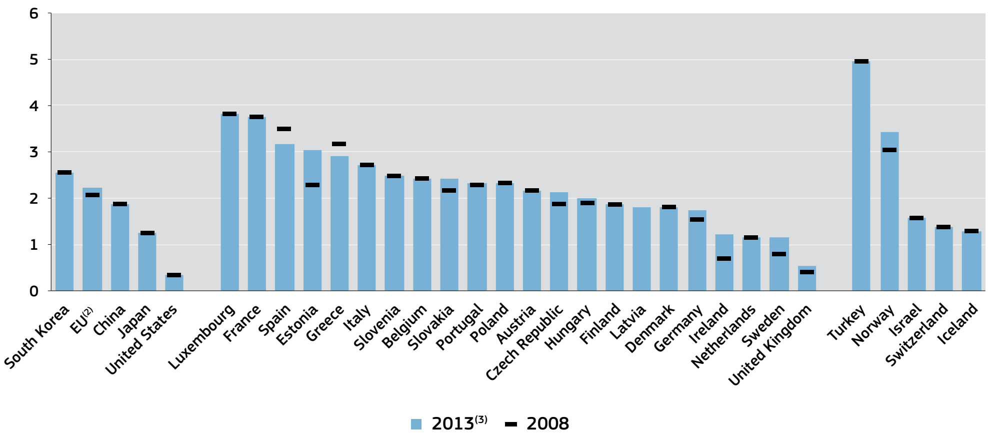
Figure I-4-6 **Protection of permanent workers against individual and collective dismissals[1], 2008 and 2013**



Science, Research and Innovation performance of the EU 2016

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: OECD (Indicators of Employment Protection)
Notes: [1]The values scale from 0 (least restrictions) to 6 (most restrictions). [2]EU: The value is the unweighted average of the values for the available Member States. [3]CN: 2012.

Figure I-4-7 **Regulation on temporary forms of employment[1], 2008 and 2013**



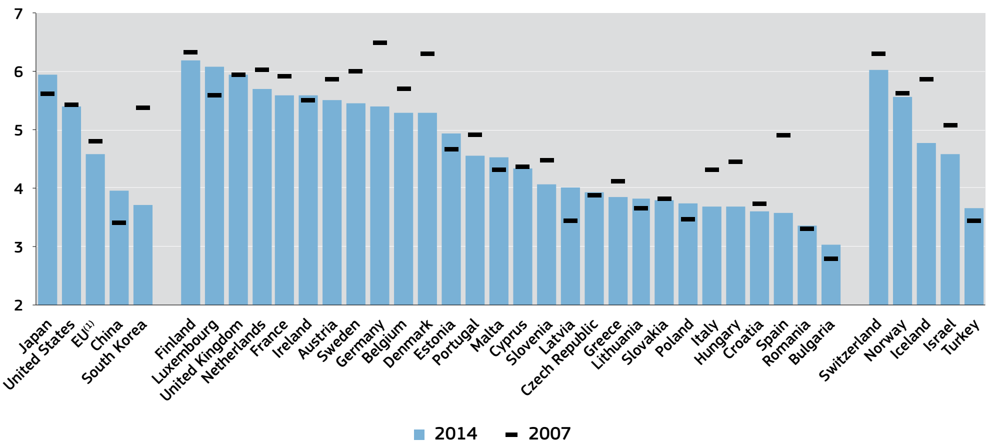
Science, Research and Innovation performance of the EU 2016

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: OECD (Indicators of Employment Protection)
Notes: [1]The values scale from 0 (least restrictions) to 6 (most restrictions). [2]EU: The value is the unweighted average of the values for the available Member States. [3]CN: 2012.

Intellectual property protection (IPP) in the EU is lower than in Japan and the United States and the trend between 2007 and 2014 is even decreasing.

When it comes to business dynamics, innovation, and the framework conditions enabling and fostering them, the importance of the efficiency of civil justice and insolvency/pre-insolvency procedures goes hand in hand with that of the efficiency with which intellectual property rights are defended. European companies rely on intellectual property rights (IPRs) to recoup their increasingly intensive R&I but also risky investments in innovation and the benefits from introducing new or substantially improved products and processes into the market, and would prefer a form of reassurance that their intellectual property rights will be protected in all EU countries to the same extent. IPRs play a crucial role in Europe's industrial strategy; approximately 40% of GDP and 25% of employment are generated by IPR-intensive industries in the EU [28].

Figure I-4-8 **Intellectual property protection, 2007 and 2014**



Science, Research and Innovation performance of the EU 2016

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Global Competitiveness Index, World Economic Forum
Note: [1]EU: The value is the unweighted average of the values for the Member States.

The intellectual property protection indicator of the World Economic Forum Global Competitiveness Index demonstrates that intellectual property protection (IPP) in the EU is lower than in Japan and the United States and the trend between 2007 and 2014 is even decreasing (World Economic Forum 2014). Within the EU, there are large disparities (see Figure I-4-8). The countries with the highest IPP are Finland, Luxembourg, the United Kingdom, the Netherlands and France, while Bulgaria and Romania (the countries with the lowest R&I performance according to the Innovation Union Scoreboard 2015) have the weakest intellectual property protection among the EU countries.

Finance for innovation

Access to finance for innovation is crucial to translate new ideas into innovations.

In order to transform new ideas into innovations that are brought into the market, entrepreneurs and existing companies require access to financial resources. In some cases, these resources may exist internally to the company; however, on many occasions, notably for SMEs, they need

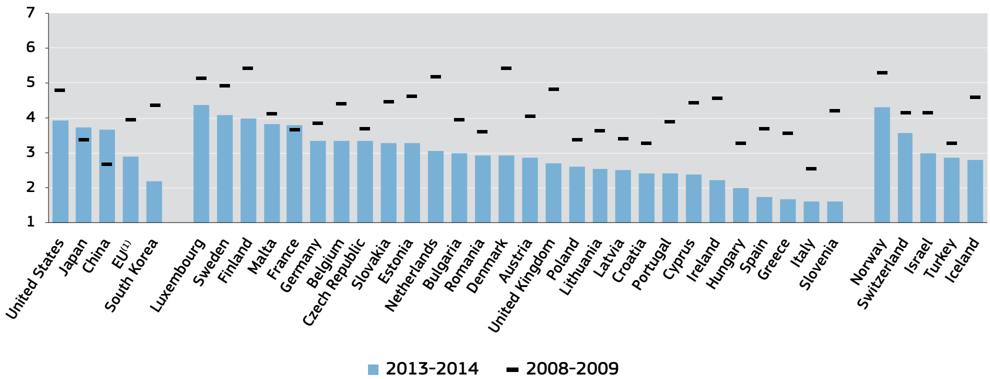
[28] Intellectual property rights intensive industries: contribution to economic performance and employment in the European Union, EPO/OHIM, September 2013

to go into the financial markets to obtain the required resources that can help them transform their ideas into prototypes, new products, and processes that can be brought successfully into the market. There are many channels that can be used to do so, and some novel methods such as crowd-funding have gained traction in the past few years. However, as of today, access to finance and, notably, access to venture capital continue to be some of the most widely used mechanisms to finance innovation.

The financial and economic crisis has affected the ability of firms to gain overall access to external finance, most notably in certain Member States.

The financial and economic crisis of the past few years has largely affected the ease of accessing loans in most of the developed world, including the United States; however, the effect has been particularly marked in the EU, and most notably in those countries that were more severely affected by the crisis, such as Spain, Greece, Portugal, Ireland or Slovenia (see Figure I-4-9).

Figure I-4-9 **Global Competitiveness Index - ease of access to loans (scale 1 - 7 (best)), 2008-2009 and 2013-2014**



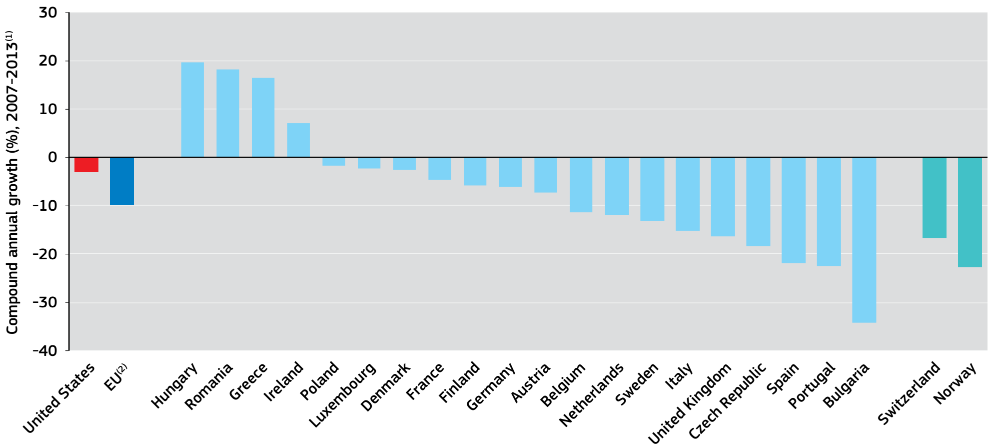
Science, Research and Innovation performance of the EU 2016

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Global Competitiveness Index, World Economic Forum; Executive Opinion Survey; www.weforum.org/gcr
Note: [1]EU: The value was estimated by DG Research and Innovation.

This is particularly important in instruments that are crucial for innovation, such as venture capital, where the negative effect has been sharper in Europe.

Since the explosion of the financial crisis, the volumes of venture capital investment decreased in both the United States and Europe overall, but the effects have been particularly marked in the EU. The United States have suffered a slight decrease of around 3% in terms of GDP from 2007 to 2013, while the drop in the EU reached nearly 10% in the same period (see Figure I-4-10). This decrease affected all of the innovative powerhouses in Europe, with significant decreases in countries such as Germany, the Netherlands, and the United Kingdom. Only a handful of European countries, whose initial values were very low, managed to increase their volumes of venture capital, but the very low levels of initial volumes make it hard to conclude that a real and sustained improvement happened during this period.

Figure I-4-10 **Venture Capital as % of GDP - compound annual growth, 2007-2013**



Science, Research and Innovation performance of the EU 2016

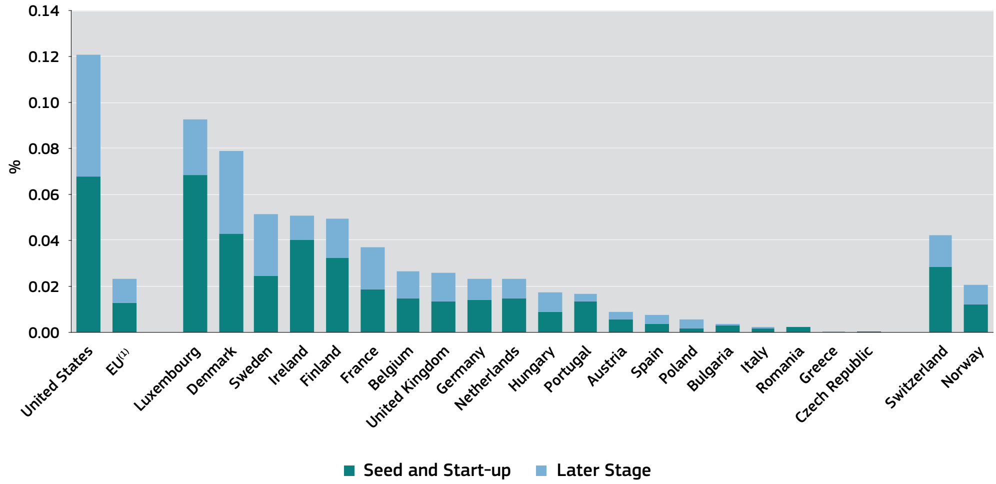
Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat, National Venture Capital Association
Notes: [1]BG: 2008-2013. [2]EU does not include EE, HR, CY, LV, LT, MT, SI, SK.

The EU as a whole, and all individual Member States, continue to lag behind the United States in both seed and start-up, and later stage venture capital, though strong differences across Member States exist.

The negative evolution in recent years has emphasised the persistent gap that continues to exist in terms of venture capital availability between the United States and the EU, both for seed and start-up companies, and also for later stage development, which is crucial for innovative firms to grow, increasing their revenue levels, market shares, and employment opportunities. The size of the gap between the United States and the EU is a 6:1 ratio, in terms of GDP.

Only a handful of small EU Member States, notably Luxembourg, the Nordic countries and Ireland, managed to achieve venture capital investment levels above or close to 0.05% of their GDP, while for all the other Member States, venture capital investment remains low (see Figure I-4-11). Of particular interest is the later stage venture capital investment, where the gap against the United States is even more pronounced in most EU Member States.

Figure I-4-11 **Venture Capital as % of GDP, 2013**



Science, Research and Innovation performance of the EU 2016

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat, National Venture Capital Association
Note: (1)EU does not include EE, HR, CY, LV, LT, MT, SI, SK.

While the reasons for the persistent lack of financing for innovation in Europe may be a combination of both supply, i.e. lack of available funding, and demand, i.e. lack of sufficiently robust innovation projects deemed worthwhile to obtain funding, the financial and economic crisis appears to have aggravated the situation.

It is hard to disentangle the full reasons and interrelationships behind this lack of venture capital investment in Europe. While the lack of financing may be one of the reasons, other forces may also play an important role, including the lower capacity of European entrepreneurs or companies to develop innovative projects, restrictive market regulations that may hinder the ability of innovators to fully develop their innovation, fragmentation of the European market that can hinder the development of sufficient lead markets for innovations, or weaker overall framework conditions, including insufficient access to talent or product and labour market regulations that are too stringent, hindering the ability of innovators to enter and disrupt the existing markets.

In all likelihood, the solution should encompass both supply and demand measures.

Both national and European initiatives are being adopted to address the lack of sufficient supply of funding for improving access to finance in general, and for innovative projects in particular.

The Quantitative Easing policy adopted by the European Central Bank has managed to increase the overall availability of financing that is improving access to finance for firms, even if the flow and price of this access does not seem to be homogeneous across the European Union, due to the fragmentation of the banking system in Europe. In addition, the European Investment Bank (through its activities to provide financing to support innovative SMEs), the Capital Markets Union (which aims to create deeper and more integrated capital markets in EU Member States), and the European Fund for Strategic Investment (EFSI) (that foresees enhancing the financial support for innovative projects and programmes such as InnovFin) are European initiatives that aim at improving the availability of financing for European innovations.

5. Economic and social impacts

The quest for innovation, which is not an end goal in itself, is justified by the economic and social impacts that it can bring about. As mentioned in the introduction, innovation can drive increases in productivity and long-term sustainable growth, and generate high-quality jobs.

In this context, this section analyses how Europe's economic structure is shifting towards more knowledge-intensive activities; if high-growth innovative firms [29], that have been identified as the main driver of structural changes, are starting up and growing their operations, what are the consequences for the creation of productive jobs in Europe and its implications on skills development?

Structural change

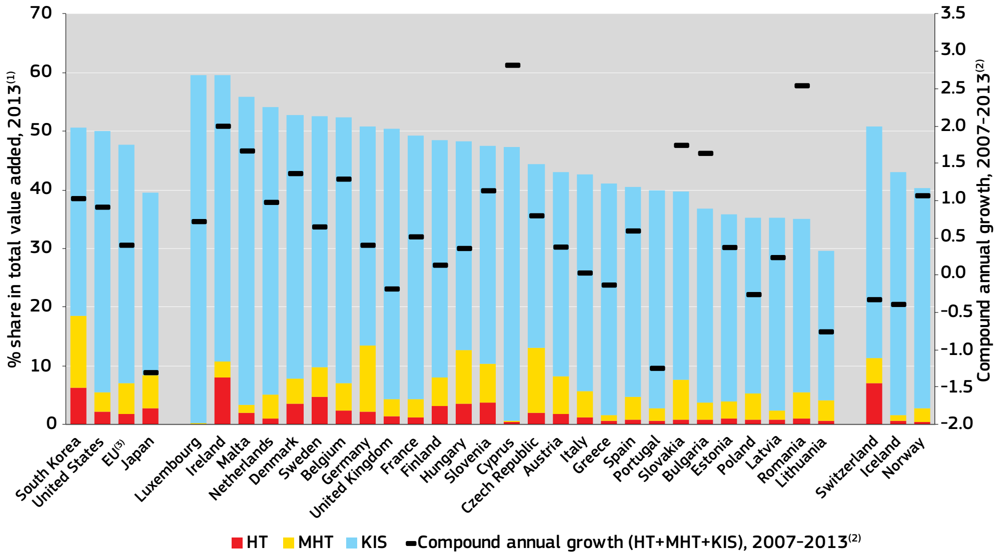
The concept of structural change refers to the long-term dynamics of the economy, through which the types and nature of existing production, consumption and trade transform through the integration of higher levels of knowledge. A structural change towards a more knowledge-intensive economy in Europe is crucial for productivity growth and competitiveness and for fostering high-quality jobs and innovation in Europe.

Compared to other advanced economies, the European Union's economy is less knowledge and technology intensive and is specialised in medium-high-tech sectors. In the past few years, this gap has widened even further in comparison to the United States and South Korea.

The value added in high-tech (HT) and medium-high-tech (MHT) manufacturing and knowledge-intensive services (KIS) as the percentage of total value added in the EU is lower than in the US and South Korea (see Figure I-5-1). Moreover, the gap in these economies, for the 2007 to 2013 period, is widening, despite the slight improvement overall. Within the EU, there are vast disparities across Member States. Luxembourg, Ireland, Malta, and the Netherlands have the highest share of HT, MHT manufacturing and KIS, while Central and Eastern European countries such as Lithuania, Romania, Latvia and Poland, continue to lag behind. In dynamic terms, large disparities can also be observed. Countries such as Ireland and Malta continue to shift towards more knowledge and technology-intensive activities, at a similar compound annual growth rate as Slovakia and Bulgaria, while Cyprus and Romania show the highest growth rates. Among those countries more seriously affected by the recession of the past few years, in addition to the already mentioned Ireland, only Spain seems to have engaged in a process of economic structural change, while Portugal, Greece or Italy, score negative or close to zero in terms of changes. Finally, it is worth noting the drop in Poland and the United Kingdom, despite the robust economic growth of the past few years.

(29) http://www.bruegel.org/publications/publication-detail/publication/430-europes-missing-yollies/

Figure I-5-1 **Value added in high-tech (HT), medium-high-tech (MHT) and knowledge-intensive services (KIS) as % of total value added, 2013 and compound annual growth, 2007-2013**



Science, Research and Innovation performance of the EU 2016

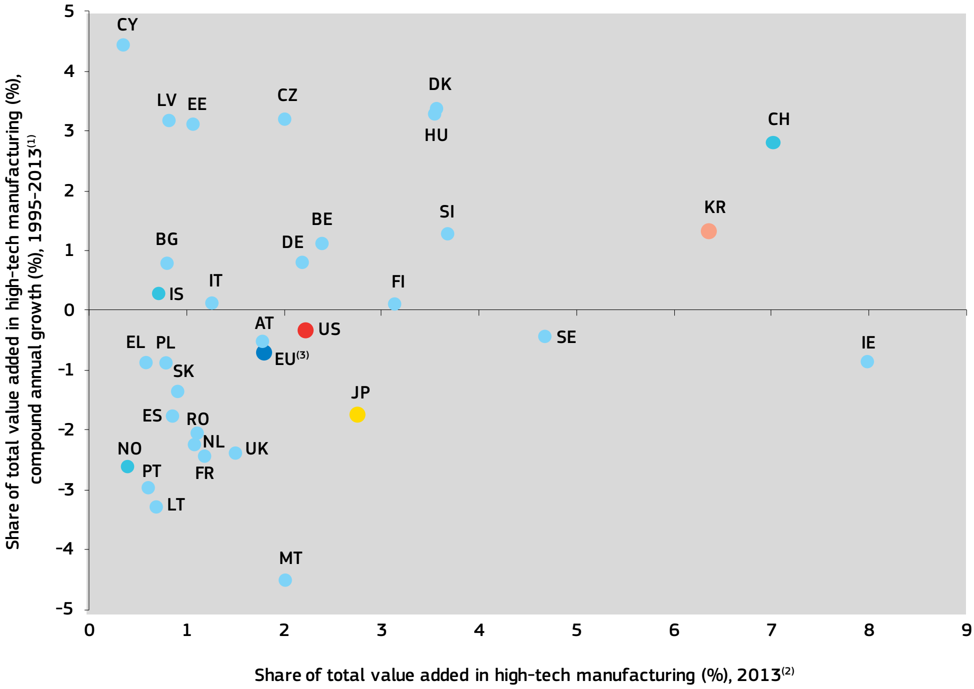
Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat, OECD
Notes: [1]JP: 2009; CH, US, KR: 2011; BE, DE, ES, IT, LV, PL, SE, UK, EU: 2012; CZ, MT, NL, AT, FI, NO: 2014. [2]JP: 2007-2009; CH, US, KR: 2007-2011; BE, DE, ES, IT, LV, PL, SE, UK, EU: 2007- 2012; CZ, MT, NL, AT, FI, NO: 2007-2014. [3]EU: Croatia is not included. [4]MT, SE, NO, CH, US, JP, KR: Complete data in the required breakdown were not available. [5]Elements of estimation were involved in the compilation of the data.

Value added in high-tech manufacturing as percentage of total value added in the EU is lower than in the US, and has been decreasing at a faster pace over the time period 1995-2013.

Looking into each of the components, the specialisation patterns become clearer. Value added in high-tech manufacturing as percentage of total value added in the EU in 2013 is lower than in the US and Japan and much lower than in South Korea (see Figure I-5-2). The long-term gap is widening in comparison to South Korea and the United States. This is due to the decrease in computer, electronic, and optical products, which decreased from 1.22% in 1997 to 0.84% in 2012, while the share of pharmaceuticals, medicinal chemical, and botanical products in the EU increased from 0.77% in 1997 to 0.95% in 2012. This trend can be observed in Japan and in the US. In the US, computer, electronic and optical products decreased from 1.82% in 1995 to 1.51% in 2011, while pharmaceuticals, medicinal chemical, and botanical products increased from 0.52% in 1995 to 0.72% in 2011. In South Korea, however, the trend is the opposite.

There are vast disparities within the EU. The value added in high-tech manufacturing as percentage of total value added in 2013 was led by Ireland, followed by Sweden, Slovenia, Denmark and Hungary, although due to a lack of available data, as will be presented below, it is difficult to determine in which segments of the value-added chain of these sectors these countries are specialising in. In dynamic terms in Ireland, the value added of pharmaceuticals, medicinal chemical, and botanical products as percentage of total value added increased between 1995 and 2013, while the share of computer, electronic, and optical products decreased during that time period, leading to an overall negative growth rate. A negative growth rate can also be observed in Sweden, where the shares in both HT sectors decreased. In Denmark and Slovenia, the share of pharmaceuticals, medicinal chemical, and botanical products increased between 1995 and 2013, while the share of computer, electronic, and optical products decreased. In Hungary, both the share of pharmaceuticals, medicinal chemical, and botanical products and the share of computer, electronic, and optical products increased between 1995 and 2013.

Figure I-5-2 **Value added in high-tech manufacturing as % of total value added, 2013 and compound annual growth, 1995-2013**



Science, Research and Innovation performance of the EU 2016

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat, OECD
Notes: (1)JP: 1995-2009; US, KR: 1995-2011; DE, ES, SE: 1995-2012; CZ, MT, NL, AT, FI, NO: 1995-2014; CH: 1997-2011; UK, EU: 1997-2012; IS: 1997-2013; LV: 2000-2012; BG, EE: 2000-2013; PL: 2003-2012; LT: 2005-2013. (2)JP: 2009; CH, US, KR: 2011; DE, ES, LV, PL, SE, UK, EU: 2012; CZ, MT, NL, AT, FI, NO: 2014. (3)EU: BG, EE, HR, LV, LT, LU, PL are not included. (4)MT, SE, NO, US: Complete data in the required breakdown were not available. (5)Elements of estimation were involved in the compilation of the data.

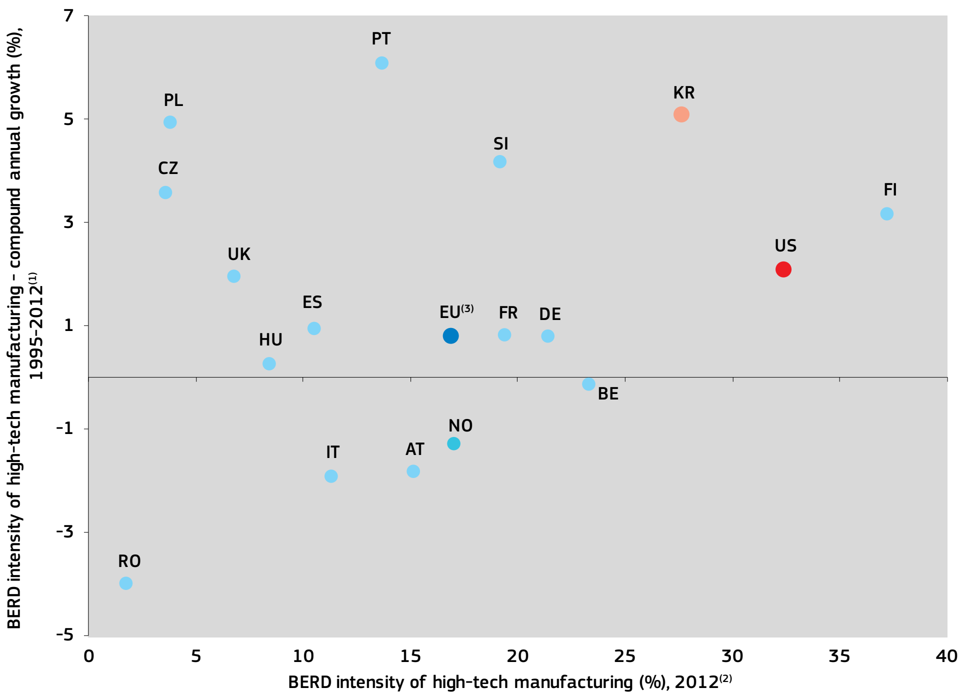
The EU as a whole, and a number of European countries depict negative CAGR in value added in HT manufacturing as percentage of total value added. The most significant decrease can be observed in Malta, Lithuania and Portugal, which all show strong decreases in particular in computer, electronic, and optical products. This is also the case for France, the United Kingdom, and the Netherlands, where a negative CAGR for the period from 1995-2007 can be observed mainly due to decreases in computer, electronic, and optical products. In France and the Netherlands, pharmaceuticals, medicinal chemical, and botanical products also demonstrate negative growth rates.

BERD intensity (business enterprise expenditure on R&D as % of value added) in high-tech manufacturing is higher in the US and South Korea than in the EU, which might suggest that the EU lags behind in terms of the highest value added activities within these sectors. This might hamper the EU's ability to foster structural change towards these activities, although large differences across Member States exist.

BERD intensity in the US grew between 1995 and 2012 at a higher pace than in the EU. However, in the time period from 2007 to 2012 the trend was reversed, with the US showing a negative growth rate (see Figures I-5-3 and I-5-4). Within the EU, BERD intensity in high-tech manufacturing in 2012 was by far highest in Finland, where computer, electronic, and optical products demonstrate very high increases in BERD intensity (more than 50 percentage points) between 1995 and 2012. This can be explained by the decrease in gross value added in computer, electronic, and optical products, linked to the downfall of Nokia.

In Germany, BERD intensity has increased in both computer, electronic, and optical products and in pharmaceuticals, medicinal chemical, and botanical products; however its overall BERD intensity, as in the case of countries such as Belgium or France, has remained far behind the US and South Korea. Starting from a relatively low level, BERD intensity in HT manufacturing grew the fastest in Portugal, Poland and Slovenia between 1995 and 2012. In Portugal, the strong growth comes from pharmaceuticals, medicinal chemical, and botanical products. BERD intensity in HT manufacturing in Poland is still one of the lowest in the EU, but growing fast, in particular in computer, electronic, and optical products. In Romania, Italy and Austria BERD intensity shows negative growth rates between 1995 and 2012, mainly due to decreases in BERD intensity in pharmaceuticals, medicinal chemical, and botanical products. Between 2007 and 2012, Ireland and Estonia also showed strong decreases in BERD intensity in HT. In Ireland, a particular strong decrease in BERD and BERD intensity can be observed in pharmaceuticals, medicinal chemical, and botanical products. In Estonia, the decrease in BERD intensity was in computer, electronic, and optical products, where BERD decreased while value added increased significantly. In Slovakia, both BERD and value added in HT manufacturing decreased significantly over the time period from 2007-2012.

Figure I-5-3 **BERD intensity of high-tech manufacturing, 2012 and compound annual growth, 1995-2012**



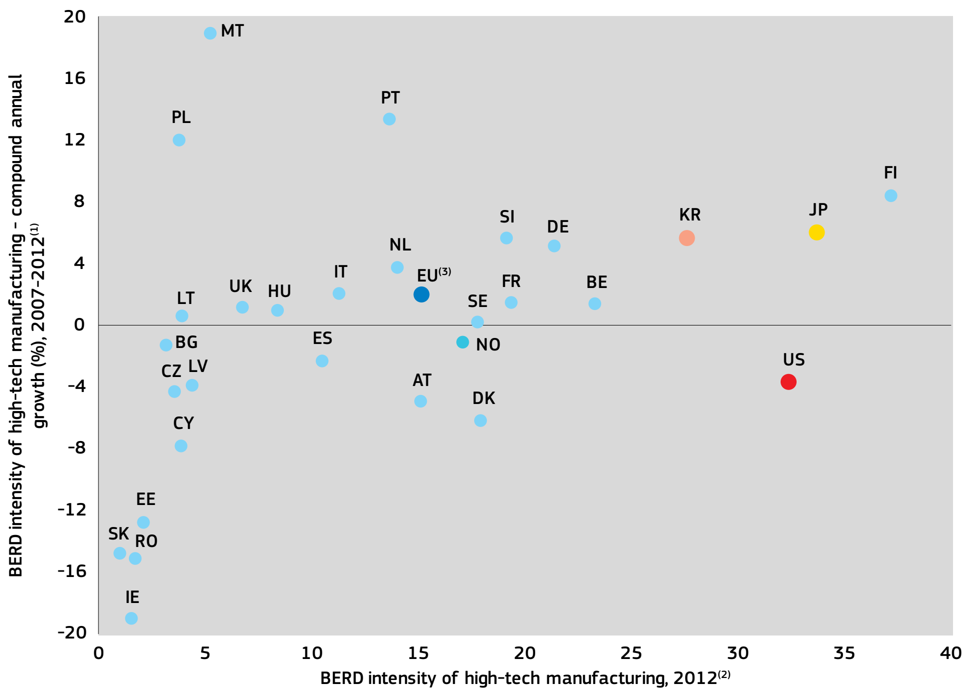
Science, Research and Innovation performance of the EU 2016

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

Data: Eurostat, OECD

Notes: (1)US, KR: 1995-2011; SI, FI, NO: 1995-2013; CZ: 1996-2013; UK: 1997-2012; BE, AT: 1998-2011; EU: 1998-2012; PT: 2004-2012; RO: 2004-2013; PL: 2005-2012. (2)BE, AT, US, KR: 2011; CZ, RO, SI, FI, NO: 2013. (3)EU includes BE, CZ, DE, ES, FR, IT, HU, AT, SI, FI, UK. (4)FR, UK: Compound annual growth was calculated from data classified by product field. (5)NO, US: Complete data in the required breakdown were not available. (6)Elements of estimation were involved in the compilation of the data.

Figure I-5-4 **BERD intensity of high-tech manufacturing, 2012 and compound annual growth, 2007-2012**



Science, Research and Innovation performance of the EU 2016

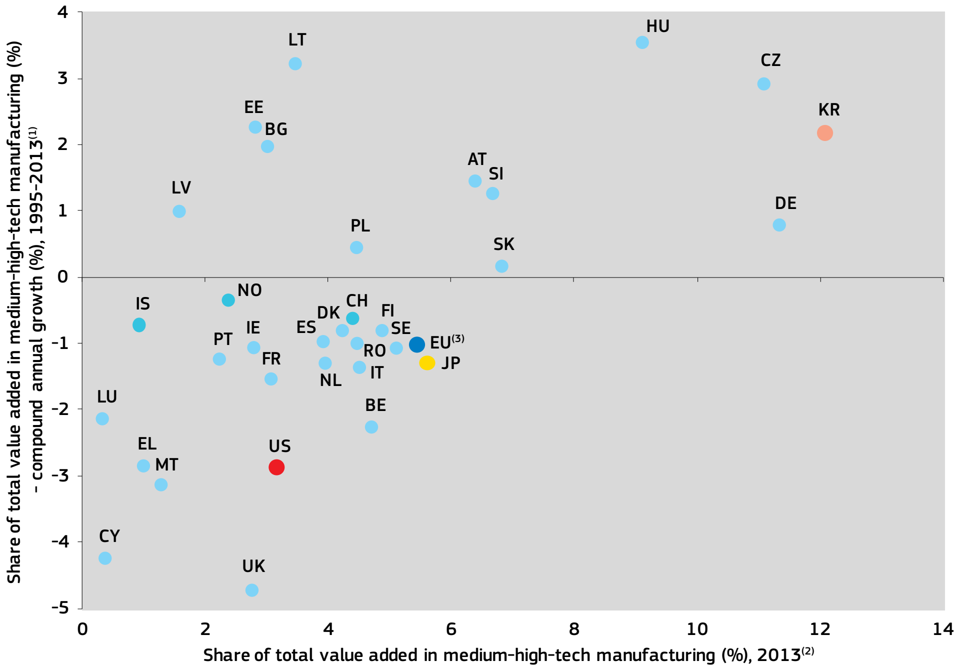
Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies

Data: Eurostat, OECD

Notes: (1)JP: 2007-2009; BE, AT, US, KR: 2007-2011; CZ, EE, RO, SI, NO: 2007-2013; CY, LV, LT, MT: 2008-2012; NL, FI: 2008-2013; IE: 2009-2011; DK, UK: 2009-2012; SK: 2010-2013. (2)JP: 2009; BE, IE, AT, US, KR: 2011; CZ, EE, NL, RO, SI, SK, FI, NO: 2013. (3)EU: EL, HR, LU are not included. (4)EE, MT, SE, NO, US: Complete data in the required breakdown were not available. (5)Elements of estimation were involved in the compilation of the data.

As previously mentioned, the EU is specialised in MHT sectors in comparison to the United States, and value added in MHT manufacturing as percentage of total value added in the EU is higher than in the US, but much lower than in South Korea (see Figure I-5-5). Both in the EU and in the US, the shares of total value added in MHT demonstrate negative growth rates. However, within the EU there are strong disparities. The share of total value added in MHT manufacturing is the highest in Germany, the Czech Republic and Hungary with positive growth rates between 1995 and 2013. In Germany, strong increases in the share can be observed in motor vehicles, trailers, and semi-trailers, and other transport equipment, as well as in machinery and equipment, while the share of chemicals and chemical products and electrical equipment demonstrate negative CAGRs for the years 1995-2013. In the Czech Republic and Hungary, motor vehicles, trailers, and semi-trailers, and other transport equipment, machinery and equipment and electrical equipment demonstrate increases in their shares, while only chemicals and chemical products show declining shares. In the United Kingdom and Cyprus, the countries with the strongest drop, all MHT sectors show decreasing shares.

Figure I-5-5 **Value added in medium-high-tech manufacturing as % of total value added, 2013 and compound annual growth, 1995-2013**



Science, Research and Innovation performance of the EU 2016

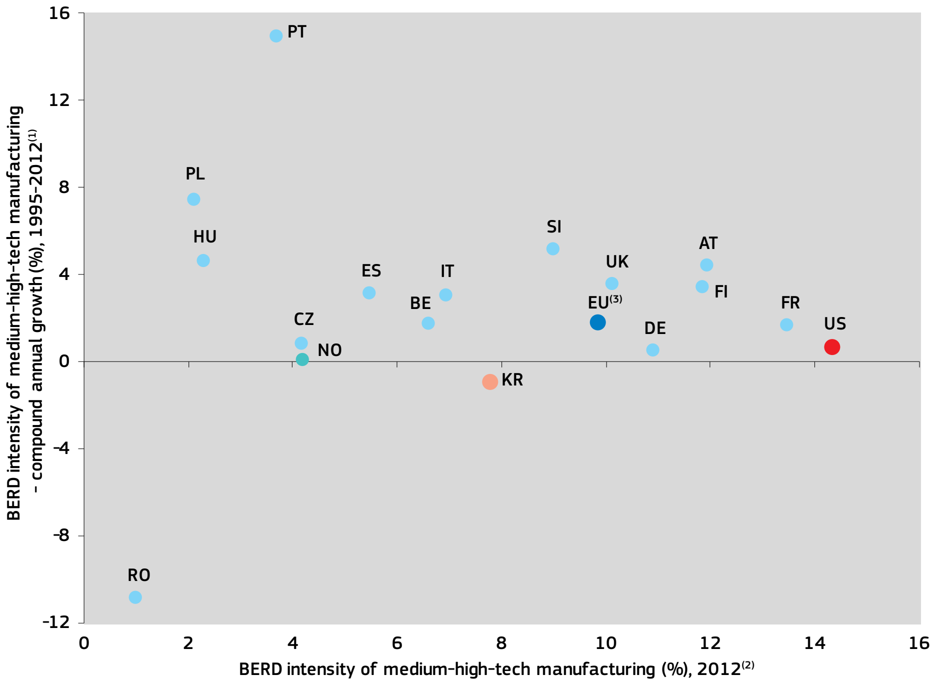
Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat, OECD
Notes: (1)JP: 1995-2009; US, KR: 1995-2011; DE, ES, SE: 1995-2012; CZ, MT, NL, AT, FI, NO: 1995-2014; CH: 1997-2011;UK, EU: 1997-2012; IS: 1997-2013; LV: 2000-2012; BG, EE, LU: 2000-2013; PL: 2003-2012; LT: 2005-2013. (2)JP: 2009; CH, US, KR: 2011; DE, ES, LV, PL, SE, UK, EU: 2012; CZ, MT, NL, AT, FI, NO: 2014. (3)EU: BG, EE, HR, LV, LT, LU, PL are not included. (4)SE, NO, CH, US: Complete data in the required breakdown were not available. (5)Elements of estimation were involved in the compilation of the data.

Despite the EU's specialisation in MHT, BERD intensity in MHT manufacturing is higher in the US than in the EU, suggesting that Europe might be lagging in those activities that require higher levels of technological development.

BERD intensity in MHT manufacturing is higher in the US than in the EU. Between 1995 and 2012, BERD intensity in the EU grew slightly faster than in the US, as demonstrated by the Compound Annual Growth rate (see Figure I-5-6). However, between 2007 and 2012 the growth rate in the EU was lower than in the United States (see Figure I-5-7). This can be explained by a decrease in value added of MHT in the US between 2007 and 2011, while BERD increased during that time period. Another possible explanation is that within MHT, the US is specialised in those activities that require higher levels of technological development. In the US, the MHT sector which demonstrates an increase in BERD intensity is machinery and equipment, which more than doubled between 1995 and 2012. BERD intensity in motor vehicles, trailers and semi-trailers, and other transport equipment increased substantially between 1995 and 2009 and then declined again strongly. Only electrical equipment shows a negative growth rate.

Most EU Member States show a positive evolution of their BERD intensities in MHT manufacturing between 1995 and 2012. Only in Romania did BERD intensity show a significant drop, due to increases in value added and decreases in BERD. Between 2007 and 2012, Malta and Cyprus also showed negative growth rates. Within the EU, Sweden and France have the highest BERD intensities in MHT manufacturing, followed by Denmark, Austria, Finland and Germany. In Sweden, all MHT sectors show increases in BERD intensity. While the highest BERD intensity is in motor vehicles, the highest growth rate in BERD intensity could be observed for electrical equipment. In France, all MHT sectors demonstrate increases in BERD intensity with motor vehicles, trailers, and semi-trailers, with other transport equipment having the highest BERD intensity and electrical equipment showing the highest growth rate in BERD intensity. In Germany, the highest and increasing BERD intensity between 1995 and 2013 is in motor vehicles, trailers and semi-trailers, and other transport equipment. Positive growth can also be observed in machinery and equipment, while electrical equipment and chemicals and chemical products have decreasing BERD intensities. The growth rate in BERD intensity in MHT manufacturing is the highest in Portugal (1995-2012), with increases in all MHT sectors, and in Bulgaria (2007-2012). Starting from a very low level, BERD in MHT in Portugal increased rapidly between 2004 and 2012, while value added in MHT decreased.

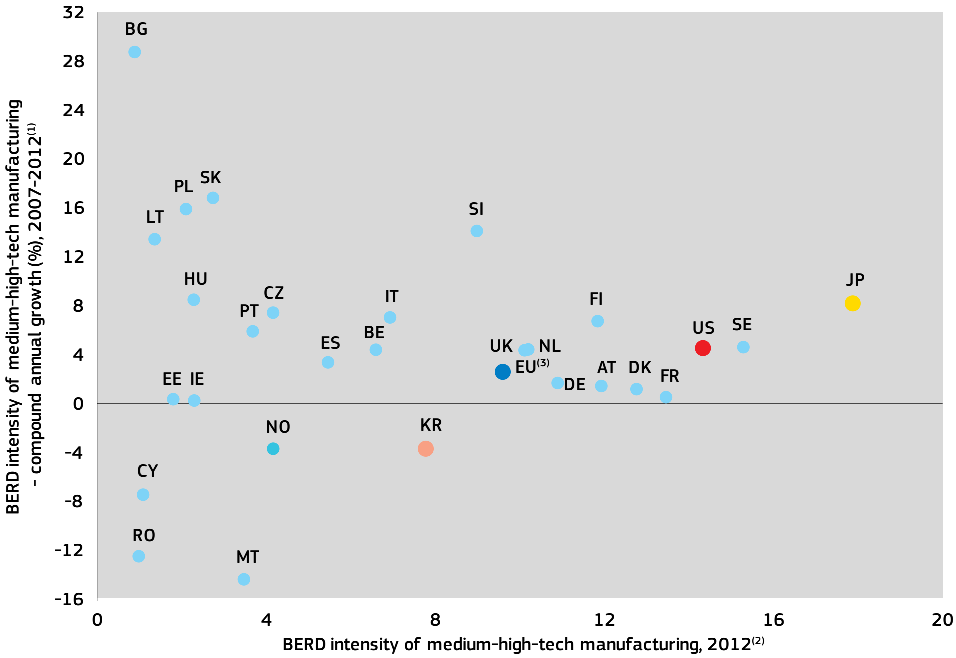
Figure I-5-6 **BERD intensity of medium-high-tech manufacturing, 2012 and compound annual growth, 1995-2012**



Science, Research and Innovation performance of the EU 2016

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat, OECD
Notes: (1)US, KR: 1995-2011; SI, FI, NO: 1995-2013; CZ: 1996-2013; UK: 1997-2012; BE, AT: 1998-2011; EU: 1998-2012; PT: 2004-2012; RO: 2004-2013; PL: 2005-2012. (2)BE, AT, US, KR: 2011; CZ, RO, SI, FI, NO: 2013. (3)EU includes BE, CZ, DE, ES, FR, IT, HU, AT, SI, FI, UK. (4)FR, UK: Compound annual growth was calculated from data classified by product field. (5)NO, US: Complete data in the required breakdown were not available. (6)Elements of estimation were involved in the compilation of the data.

Figure I-5-7 **BERD intensity of medium-high-tech manufacturing, 2012 and compound annual growth, 2007-2012**



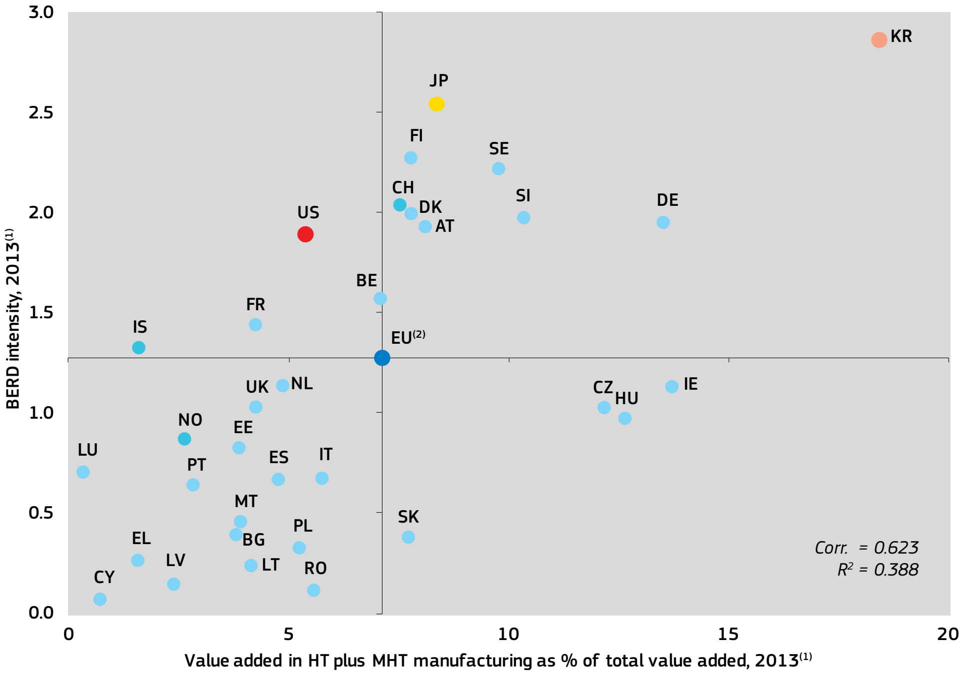
Science, Research and Innovation performance of the EU 2016

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat, OECD
Notes: (1)JP: 2007-2009; BE, AT, US, KR: 2007-2011; CZ, EE, RO, SI, NO: 2007-2013; CY, LT: 2008-2012; NL, FI: 2008-2013; IE: 2009-2011; BG, DK, UK: 2009-2012; SK: 2009-2013; MT: 2010-2012. (2)JP: 2009; BE, IE, AT, US, KR: 2011; CZ, EE, NL, RO, SI, SK, FI, NO: 2013. (3)EU: EL, HR, LV, LU are not included. (4)BG, EE, SE, NO, US: Complete data in the required breakdown were not available. (5)Elements of estimation were involved in the compilation of the data.

BERD intensity is correlated with value added in HT and MHT, with both reinforcing each other. Many EU countries managed to increase value added of HT and MHT in their economies and, at the same time, increase their BERD intensity.

BERD intensity is correlated with value added in HT and MHT. However, EU countries are positioned differently (see Figure I-5-8). Some countries have margins to increase their R&D intensity within the existing economic sector structure, while others need to simultaneously push through complementary policy measures to change the sector composition of their economies, favouring industry segments in which demand for research and skilled labour is high.

Figure I-5-8 **BERD intensity versus value added in high-tech (HT) and medium-high-tech (MHT) manufacturing as % of total value added, 2013**



Science, Research and Innovation performance of the EU 2016

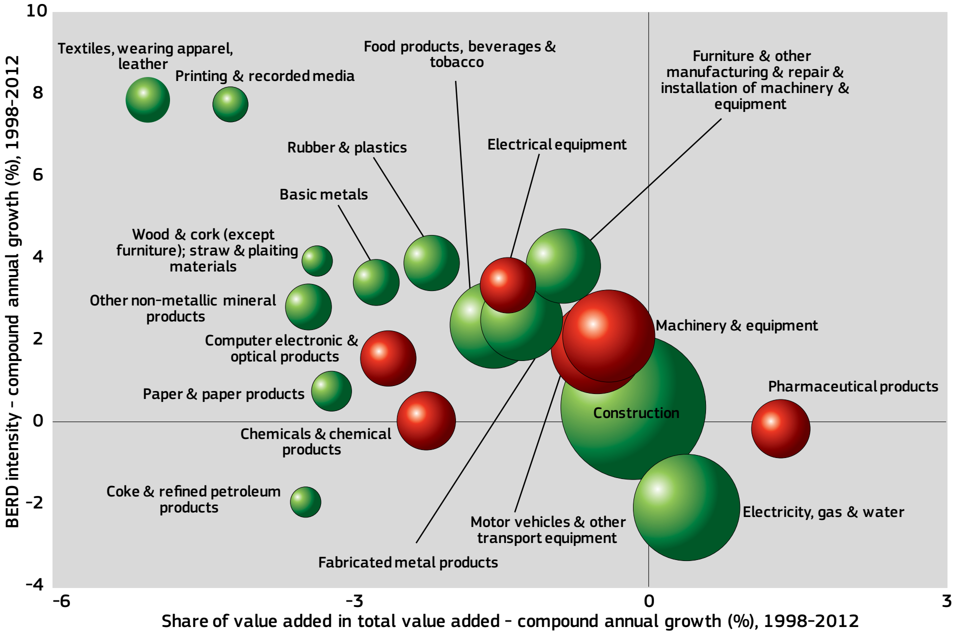
Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat, OECD
Notes: (1)JP: 2009; IS, CH, US, KR: 2011; DE, IE, ES, LV, PL, SE, UK, EU: 2012. (2)EU: Croatia is not included. (3)MT, SE, NO, CH, US: Complete data for value added in the required breakdown were not available. (4)Elements of estimation were involved in the compilation of the data.

The economic crisis might have triggered structural changes in the EU and the United States and increased the importance of HT and MHT sectors in their economies.

In the EU, between 1998 and 2012, among all HT and MHT sectors only pharmaceutical products increased their shares in total value added (see Figure I-5-9) [30]. Electrical equipment, machinery and equipment, motor vehicles and other transport equipment, and computer, electronic and optical products did not increase their share in value added but demonstrated increases in BERD. However, looking at the time period from 2008 to 2012, motor vehicles and pharmaceutical products increased their shares in total value added (see Figure I-5-10). It is possible that these sectors turned out to be more crisis-resistant. Machinery and equipment, computers, electronic and optical products, electrical equipment, and other transport demonstrate increases in BERD between 2008 and 2012.

(30) The size of the bubble for each sector is determined by the weight of the sector in the total value added (2012) of all of the sectors on the graph.

Figure I-5-9 **Evolution of R&D intensity and industrial structure[1] in the EU[2][3], 1998-2012**



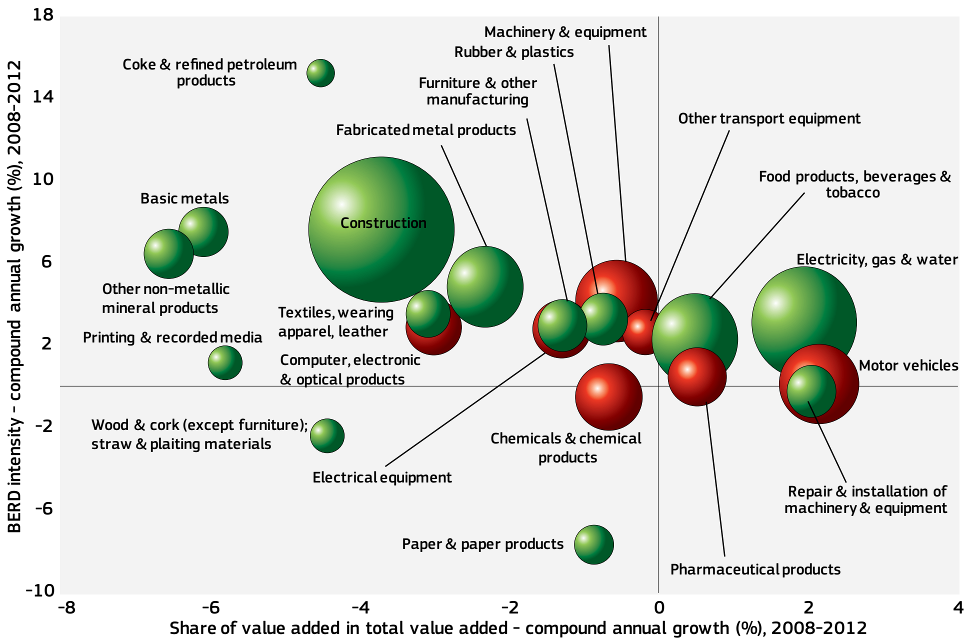
Science, Research and Innovation performance of the EU 2016

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

Data: Eurostat, OECD

Notes: [1]High-tech and medium-high-tech sectors (NACE Rev. 2 - 2 digit level) are shown in red. [2]EU includes BE, CZ, DE, ES, FR, IT, HU, AT SI, FI, UK. [3]FR, UK: Product Field classification was used for BERD. [4]Elements of estimation were involved in the complilation of the data.

Figure I-5-10 **Evolution of R&D intensity and industrial structure[1] in the EU[2], 2008-2012**



Science, Research and Innovation performance of the EU 2016

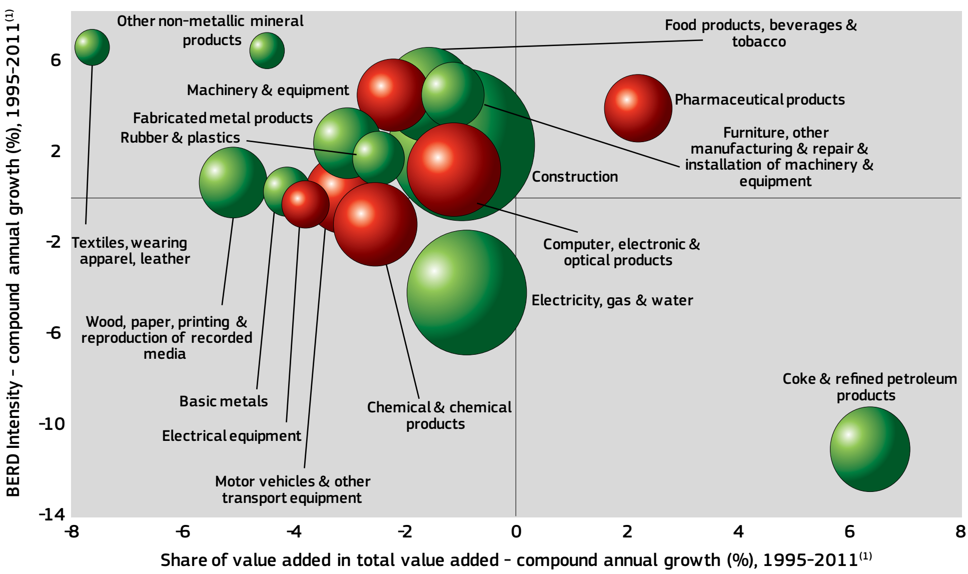
Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies

Data: Eurostat, OECD

Notes: [1]High-tech and medium-high-tech sectors (NACE Rev. 2 - 2 digit level) are shown in red. [2]EU: Croatia is not included. [3]Elements of estimation were involved in the compilation of the data.

In the US, between 1995 and 2011, only pharmaceutical products demonstrate increases in value added, as well as in BERD (see Figure I-5-11) [31]. Machinery and equipment and computers, electronics and optical products demonstrate increases in BERD. For the time period from 2008-2011, pharmaceuticals, motor vehicles, computers, and electronic and optical products demonstrate increases in their shares, but have not been able to increase BERD intensity at the same time (see Figure I-5-12). Electrical equipment and machinery and equipment show increases in BERD and decreases or stagnation in value added.

Figure I-5-11 Evolution of R&D intensity and industrial structure[1] in the United States, 1995-2011

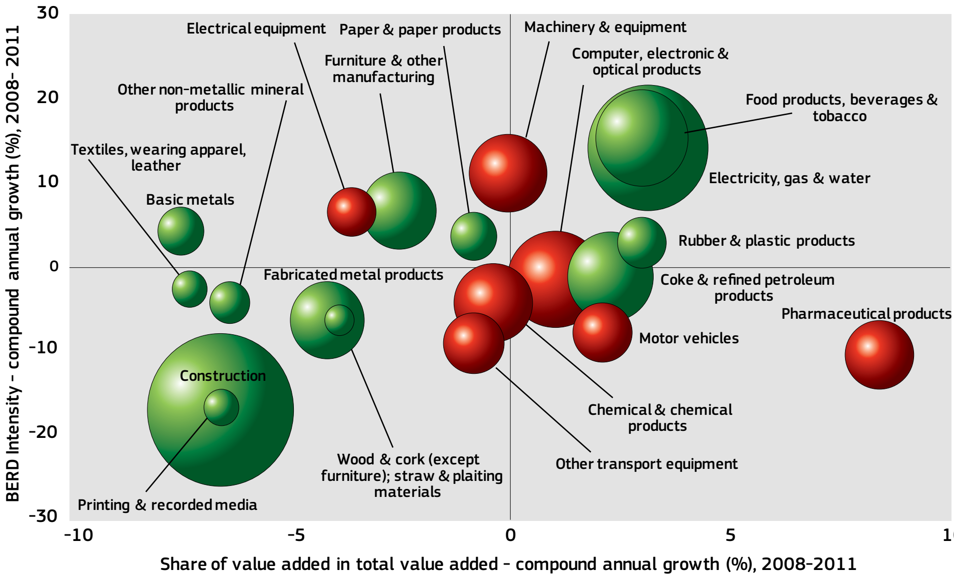


Science, Research and Innovation performance of the EU 2016

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: OECD
Notes: [1]'Chemicals and chemical products', 'Pharmaceutical products': 1995-2009; 'Construction': 1996-2011. [2]High-tech and medium-high-tech sectors(NACE Rev. 2 - 2 digit level) are shown in red. [3]Elements of estimation were involved in the compilation of the data.

[31] The size of the bubble for each sector is determined by the weight of the sector in the total value added (2011) of all of the sectors on the graph.

Figure I-5-12 **Evolution of R&D intensity and industrial structure[1] in the United States, 2008-2011**



Science, Research and Innovation performance of the EU 2016

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

Data: OECD

Notes: [1]High-tech and medium-high-tech sectors (NACE Rev. 2 - 2 digit level) are shown in red. [2]Elements of estimation were involved in the compilation of the data.

Value added in Knowledge-Intensive Services (KIS) as percentage of total value added in the EU is lower than in the US. In the time period from 1995-2013, it has grown at the same pace as in the US. However, in more recent years (2007-2013) it has been growing at a lower rate.

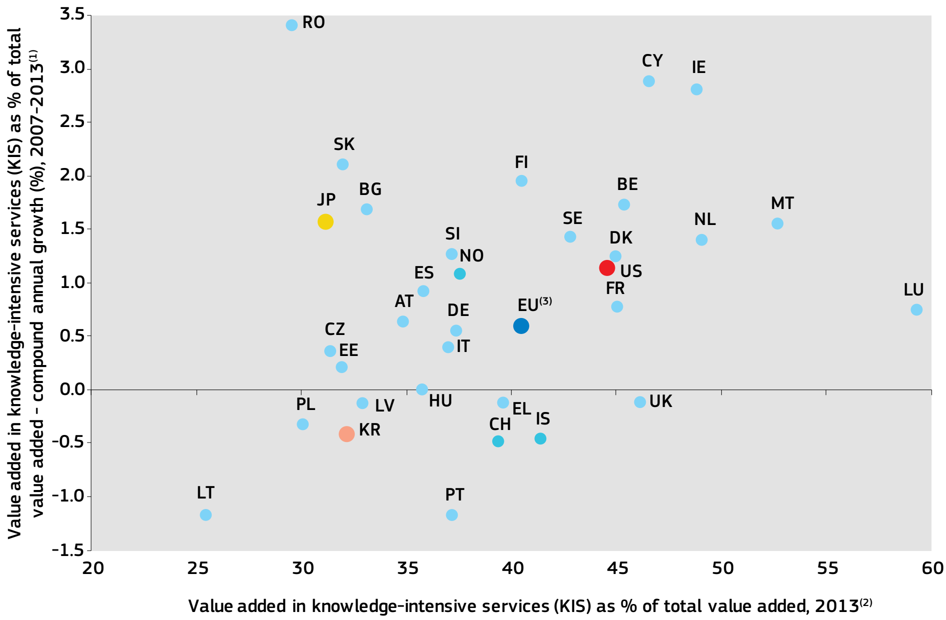
Overall, value added in KIS in the EU increased between 2007 and 2013. It is the highest in Luxembourg, Malta, the Netherlands and Ireland. The strongest growth rates can be seen in Malta and Romania (1995-2013) and Cyprus and Ireland (2007-2013), (see Figures I-5-13 and I-5-14).

Figure I-5-13 **Value added in knowledge-intensive services (KIS) as % of total value added, 2013 and compound annual growth, 1995-2013**

Science, Research and Innovation performance of the EU 2016

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat, OECD
Notes: [1]US, KR: 1995-2011; BE, DE, ES, IT, SE: 1995-2012; CZ, MT, NL, AT, FI, NO: 1995-2014; JP: 1996-2009; CH: 1997-2011; UK, EU: 1997-2012; IS: 1997-2013; LV: 2000-2012; BG, EE, LU: 2000-2013; PL: 2003-2012; LT: 2005-2013. [2]JP: 2009; CH, US, KR: 2011; DE, ES, LV, PL, SE, UK, EU: 2012; CZ, MT, NL, AT, FI, NO: 2014. [3]EU: BG, EE, HR, LV, LT, LU, PL are not included.
[4]Elements of estimation were involved in the compilation of the data.

Figure I-5-14 **Value added in knowledge-intensive services (KIS) as % of total value added, 2013 and compound annual growth, 2007-2013**



Science, Research and Innovation performance of the EU 2016

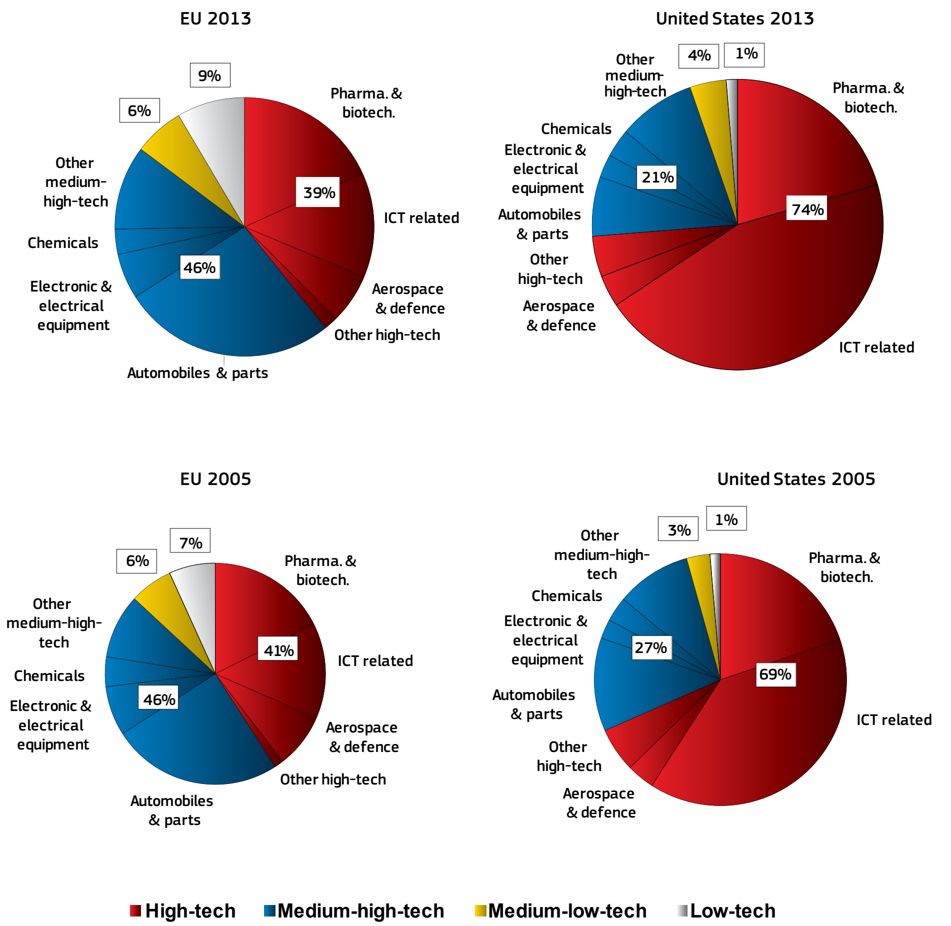
Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat, OECD
Notes: [1]JP: 2007-2009; CH, US, KR: 2007-2011; BE, DE, ES, IT, LV, PL, SE, UK, EU: 2007- 2012; CZ, MT, NL, AT, FI, NO: 2007-2014.
[2]JP: 2009; CH, US, KR: 2011; BE, DE, ES, IT, LV, PL, SE, UK, EU: 2012; CZ, MT, NL, AT, FI, NO: 2014. [3]EU: Croatia is not included.
[4]Elements of estimation were involved in the compilation of the data.

The EU is lagging far behind the US in HT sectors such as ICT but also lags in pharmaceuticals and biotech, while being strongly specialised in MHT sectors such as automobiles and parts.

The sectoral composition of R&D-intensive enterprises based on data from the EU Industrial R&D Scoreboard confirms the finding that R&D-intensive enterprises in the EU are more specialised in MHT sectors, while R&D-intensive enterprises in the US are more specialised in HT sectors. This specialisation has been reinforced between 2005 and 2013. R&D investments in the HT sectors in the EU have decreased from 41% to 39% between 2005 and 2013 while the same share has increased from 69% to 74% in the US (see Figure I-5-15). The EU is lagging far behind the US in ICT-related sectors, but also in pharmaceuticals and biotech, while the share of aerospace and defence is higher in the EU than in the US.

The share of R&D investments in MHT sectors in the EU remained stable at 46% between 2005 and 2013 while it decreased from 27% to 21% in the US. The EU shows a strong specialisation in automobiles and parts, and its share has increased slightly, while in the US the share of automobiles and parts decreased. To a lesser degree, the EU also shows some specialisation in electronics and electrical equipment, compared to the US.

Figure I-5-15 Sectoral composition of R&D intensive enterprises in the EU and the United States, 2005 and 2013



Science, Research and Innovation performance of the EU 2016

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

Data: EU Industrial R&D Scoreboard, 2014

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Part II

In-depth analysis of key R&I policy issues

TABLE OF CONTENTS

II. IN-DEPTH ANALYSIS OF KEY R&I POLICY ISSUES

1. The role of public research in economic development

Slavo Radosevic
University College London

There is considerable variation in the level of technological development across the EU's Member States, which in turn means that the role of research and development (R&D) in furthering their development differs significantly depending on the country's position in relation to the technology frontier. This calls for a differentiated understanding of the drivers of technological upgrading and, thus, for a differentiated understanding of the role of R&D in this process. In this context, we explore in more detail the role of public R&D, a topic that has not been subject to systematic review.

We start with a review of the literature on the effects of public R&D on productivity and growth. We summarise the main stylised facts and show that our understanding of the benefits of public R&D is limited, and that a broader approach is needed which takes account of a wider range of benefits from public R&D. Specifically, we explore these issues in the context of Central and Eastern Europe (CEE) and Southern Europe as two EU 'catching-up' regions. We show that the links between science and industry in these regions are stronger than is commonly assumed, but that we need a better understanding of the nature of these links and their intensity.

1.1 Introduction

Research and technological development, both public and private, are important long-term drivers of growth and economic development. Historical evidence shows that public research, in interaction with firms, constitutes one of the main drivers of catch-up processes (Mazzoleni and Nelson, 2007) and that technology development and innovation are the outcomes of intensive interaction between market actors and public sources of knowledge (Mazzucato, 2011).

However, the relationship between public and private R&D changes in the course of economic development. As national income increases, the share of R&D conducted and funded by the business sector also increases. During this process, the role of public R&D changes. From initially facilitating the absorptive capacity of domestic industry and other sectors (agriculture, health, defence and education), public R&D increasingly contributes to a further technology upgrading of the Business Enterprise Sector (BES).

The benefits of public R&D are not always obvious to all policy actors. As the level of public R&D is the outcome of a political process with arguments centring on the benefits of public R&D, which includes both measurable economic benefits to the business sector and difficult-to-measure benefits such as quality of life, health, security, etc., these benefits need to be well known and well understood.

In this chapter, we explore the role of public R&D from a long-term growth perspective, with special reference to the less developed EU countries and regions. For countries that operate close to, or at, the technology frontier and where growth is based on R&D and innovation, the role of public R&D in reducing technological uncertainties and building a body of knowledge to support future growth seems obvious. However, in the case of economies that are behind the technology frontier and where business sector demand for public R&D is weaker, the role of public R&D is not always obvious or well understood. This is a particularly important policy issue for the CEE and Southern EU economies, which are major recipients of EU Structural Funds directed mostly towards supporting R&D and innovation activities.

The special focus on the less developed EU countries is justified by the fact that these countries need to address specific challenges in their catch up processes. Their business sectors are typically of low R&D intensity, and

Foreign Direct Investment (FDI) and technology imports play an important Part In their technology upgrading, which calls for a different role for public R&D.

In Section 2, we provide a brief review of the literature on the effects and benefits of public R&D. We summarise the major stylised facts that emerge from this research and discuss its policy relevance. Section 3 discusses the role of public R&D in the EU with special reference to the CEE and South EU economies. We highlight similarities and differences in public and private R&D across three EU 'mega regions': EU South (Greece, Cyprus, Malta, Portugal, Spain and Italy), EU CEE ('new' Member States from CEE), and the 'EU North' (the remaining EU12 developed economies).

1.2 Public R&D: Role, effects and benefits

Historical evidence shows that catching-up, to a large extent, depends on an effective public research and higher education system (Mazzoleni and Nelson, 2007). The effects of R&D have been explored in depth by measuring its benefits based on rates of return or output elasticities with respect to R&D as inputs. We provide a brief review of this literature, focusing in particular on the benefits derived from public R&D.

1.2.1 Challenges related to measuring the returns from R&D investments and the specificity of public R&D

Measuring the returns to public R&D investment poses a number of particular challenges. First, R&D activities lead to intangible knowledge and ideas, which are known to be non-rivalrous and non-excludable. For private actors, patent protection is aimed at delaying free use or imitation, thus enabling innovators to capture a fair share of the rents from their inventions. Publicly funded research, on the other hand, is aimed at stimulating the generation of knowledge which becomes a public good that is shared widely.

Second, public R&D investments in health, quality of life, environment, social protection, defence, etc., are aimed at broader socioeconomic impacts that do not increase GDP directly. This means that such R&D investments should be treated in a different way even though they do contribute to providing a basis for a range of private activities in these areas (Sveikauskas 2007).

Third, the benefits from R&D are not limited to the original investors, but also accrue for competitors, other firms, suppliers, customers and to society at large. For example, private returns to the firms that initiated research may be negative, but other firms can build on these results which might lead to R&D with high social returns.

A conventional argument for public investment in R&D and, especially, public support for private R&D, is based on the assumption of poor appropriability from private investment in R&D. It is assumed that the difficulty for firms to appropriate all the benefits of their R&D activities is the main cause of private underinvestment in R&D, which, in turn, justifies public R&D or public support for private R&D.

Measuring the rates of return from R&D is based on a production function logic which treats R&D as an input along with capital and labour. This approach has the advantage that it can be used to generate quantitative estimates of how much R&D contributes to growth. Research on measuring the private returns to R&D has received impetus with the availability of large datasets and panel data econometrics which address the issues of simultaneity and unobservable factors that are inherent in such data. The most recent comprehensive survey was carried out by Hall et al. (2010).

In a nutshell, while it is clear that public R&D plays an important role in economic growth and convergence, its effects on growth are not easy to demonstrate. Estimates of the effects of public R&D are rather scarce, and much less reliable than those related to private R&D.

1.2.2 Private and social returns to R&D

Hall et al. (2010) conclude that, due to the stochastic nature of R&D outcomes, there is no single private 'rate of return'. Nevertheless, there is agreement that estimates of the private and social rates of return to privately funded R&D are large and positive for many countries, falling mostly in the range of (10%) 20% to (30%) 50% (Hall et al., 2010; Nadiri, 1993).

The social returns to R&D are large and exceed the private returns by a substantial margin (Griliches, 1995): 50% to 100%. Sveikauskas (2007) provides a review of the evidence on rates of return and suggests that the private return to R&D is around 25%, while the social return is 65%. The social returns are almost always substantially greater than the private returns and frequently are unequal among trading partners and industries. This is confirmed by a recent meta-survey by Kokko et al. (2015).

At the macro level, an OECD (2004) study shows that there is a clear positive link between private sector R&D intensity and growth of per capita gross domestic product (GDP) in the OECD economies. However, there is no clear-cut relationship between public R&D activities and growth, at least in the short term (OECD, 2004). The authors explain these results, pointing to the specificity of public R&D, i.e., important interactions between public and private R&D as well as difficult-to-measure benefits from public R&D (e.g., defence, energy, health and university research) (OECD, 2004).

Bouis, Duval and Murtin (2011) provide an update to this work based on a large sample of 40 countries over a more recent period. The results of their growth regressions show that expenditure on R&D has a positive effect on output per capita, as suggested by previous studies based on a smaller sample of countries. However, the estimated coefficient is significantly lower than in previous studies (0.06 compared to 0.15 in the 1980s and 1990s).

At the country level, Kokko et al. (2015) review the literature on the growth effects of R&D investment with special reference to the EU. They conduct a meta-analysis and conclude that the growth effects of R&D do not differ between the US and the EU, which includes high and low R&D spending countries. However, they show that the relationship is less significant in all specifications. They suggest that better utilisation of R&D investments in the US compared to the EU is due to lower private sector investment and weaker public-private sector linkages.

1.2.3 Explaining the lower rates of return to public R&D

A stylised fact in econometric research on spillovers is that the rates of return to public R&D are lower or less significant than in the case of private R&D [32] (see Griliches, 1986; Levy and Terleckyj, 1989; Lichtenberg and Siegel, 1991; Mansfield, 1980; Nadiri and Mamuneas, 1994 and references cited in Hall et al. 2010; Sveikauskas, 2007; and Kokko et al., 2015). However, we should bear in mind that this stylised fact holds if public R&D investments are considered to be identical in nature to private investments, which is a somewhat dubious assumption.

Apart from this important caveat, the explanations for the lower rates of public R&D differ. First, the conventional explanation is that private firms may be less efficient if their R&D is based on public funding or if this funding is used to support 'far from the market' research. Second, government R&D may be in areas that are far from the market (defence) or operate in a mixed mode such as in the case of health. Third, the aim of public R&D is rather to generate indirect and not direct benefits, by establishing a basis for R&D activities by firms and public organisations (universities, hospitals, etc.). Fourth, it is often claimed that public R&D is directed towards more risky areas with reduced rates of return. However, when the research is successful, the returns to basic

(32) There is a dearth of evidence on rates of return or elasticities of public R&D with respect to growth and productivity, for countries behind the technology frontier. See the survey by Hall et al. (2010) and the literature review in this chapter.

R&D can be higher than the returns to applied or developmental research (Griliches, 1986; Link, 1981; Mansfield, 1980). Fifth, there may be government overinvestment, which can lead to 'overcrowding' and lower returns. The EU's smart specialisation policy is aimed at avoiding exactly this kind of problem.

1.2.4 Types of benefits of public R&D: Beyond econometric approaches

Although econometrics dominates assessments of the effects of R&D, including public R&D, the complexity of the relationship between public R&D and growth demands alternative approaches. Econometric approaches are based on a simple production function model of the R&D system. They assume that R&D inputs and outputs can be reduced to information. However, the evidence shows that the links between publicly funded R&D and industry are more complex and, to a large extent, indirect. On this basis, Martin et al. (1996) and Salter and Martin (2001) (see also Martin and Tang, 2006) develop a classification of the benefits of public research, which demonstrates the variety and complexity of its impacts. Salter and Martin (2001: 520) distinguish the following types of benefits:

1. **Increasing the stock of useful knowledge;**

   Public R&D increases the stocks of knowledge available to firms. Publications represent important sources of learning for firms in sectors such as pharma, but it is knowledge, not just information, that is of most value to firms. Since public research is far from the market it stimulates and enables firms to focus on near-to-the-market research, acting as a complement rather than a substitute. This requires familiarity with the most recent published work, and informal contacts, joint R&D and networking (Arundel et al., 1995).

2. **Training skilled graduates;**

   Skilled graduates in many industries are seen as the primary benefit flowing to firms. They bring complex problem solving skills, new methodologies and the capacity to perform R&D. This transfer varies across areas and is dependent on where key competencies in specific technology areas reside.

3. **Creating new scientific instrumentation and methodologies;**

   Instrumentation drives scientific progress (De Sola Price and Bedini, 1967). The development of new instrumentation and methodologies is an important outcome of public R&D, and is especially significant in some sectors.

4. **Forming networks and stimulating social interaction;**

   Industries are social communities, and effective technology networking in industry includes academic networks. Links with academia are important for industries that are directly dependent on science. Also, in industries where graduates are an important source of new knowledge, networking may be more informal based on alumni networks. In some sectors, networks are maintained largely through attendance at exhibitions and conferences. Martin and Salter (2001) review the literature on the localised nature of R&D collaborations, which are reflections of geographical, cultural or institutional proximity.

5. **Increasing the capacity for scientific and technological problem-solving;**

   The problem solving capabilities in the public R&D sector complement its role of provider of general scientific knowledge. This expertise is embodied in individual contracts and collaborations between universities, public research organisations (PROs) and individual firms, and is frequent in applied R&D areas.

6. **Creating new firms.**

   The creation of new firms through spinoffs is generally seen as one of the major and desirable benefits of public R&D. However, despite the policy hype it would seem to be a less important benefit of public R&D (Brown and Mason, 2014).

In this section, we have discussed the difficulty of demonstrating, in an unambiguous quantitative manner, the benefits of public R&D. This difficulty is related to the methodological assumptions in the econometric approaches commonly used, which are unable to capture the specific features of R&D, and especially public R&D.

However, the available literature clearly shows that there is a market failure justifying public support for R&D. Work on the effects of R&D shows that the social rates of return on R&D are much higher than the rates of private R&D investment, which suggests substantial under-investment in R&D by the private sector. If we take the differences in the private and social rates of return to R&D at face value, then as Griffith (2000: 11) points out 'we should optimally be spending on R&D a share of GDP two to four times larger than we are currently'. The significant gap between the private and social rates of return on R&D is in line with the market failure model which considers the reluctance of entrepreneurs to invest in new knowledge for fear that knowledge will 'leak out' and, thus, not be fully appropriated, to be a major problem.

1.3 Public R&D in the context of the EU28

In this section, we explore the trends in and the role of public R&D and interaction between public and private R&D in the context of the EU28. The EU is one the world's most developed regions. However, this ignores the substantial differences in R&D and innovation capacities across the EU28 countries. For the purposes of this chapter, three EU28 'mega-regions' will be defined:

- North: Sweden, Finland, Austria, Germany, Denmark, Belgium, Luxemburg, France, the Netherlands, Ireland, UK
- South: Italy, Spain, Portugal, Malta, Greece, Cyprus
- CEEC: Slovenia, Czech Republic, Estonia, Hungary, Lithuania, Slovakia, Poland, Croatia, Latvia, Bulgaria, Romania

The differences in capacities between these mega-regions are illustrated in Figure II-1-1, which shows the differences between the three EU regions in terms of GERD per capita, transnational patents and S&T papers, in 2013.

Figure II-1-1 **Gross domestic expenditure on R&D (GERD), transnational patents and S&T articles per inhabitant in the three EU 'mega-regions'**

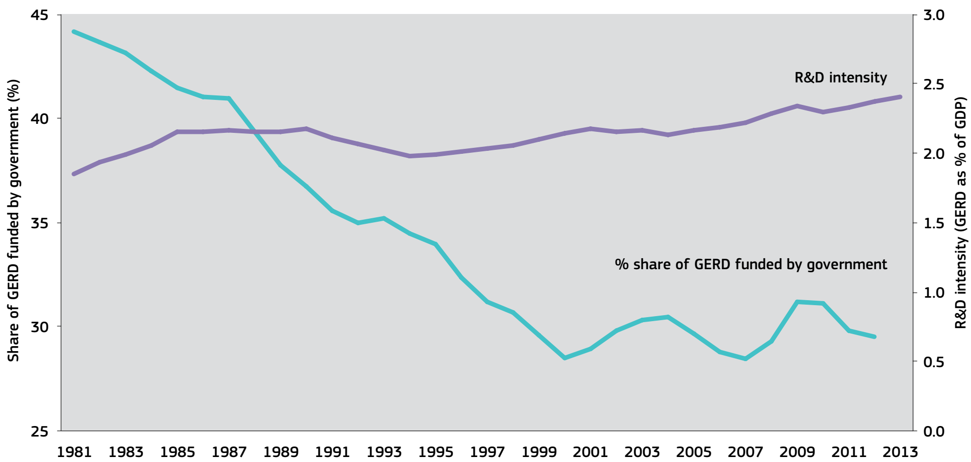
	GERD per inhabitant PPS€ 2013	Transnational Patents per million population 2012	S&T articles per million population 2013
EU - North	723	228	727
EU - South	203	36	356
EU - CEE	197	13	249

Science, Research and Innovation performance of the EU 2016
Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat, WIPO, World Bank

1.3.1 Trends in public and private R&D

The share of GERD funded by national governments has been continuously declining across the OECD since the beginning of the 1980s. This is usually ascribed to the ending of the Cold War and strained budgetary conditions, but it seems that this trend has a deeper structural basis. The decline started before 1989 and seems to be unrelated to budgetary conditions and economic growth. The decline in the share of government funding started in the 1980s, while at the same time the overall GERD/GDP share has been rising in most countries. This is due largely to increased R&D in the business sector, which accounts for the majority of expenditure in the OECD countries. However, the decline in the share of government funded GERD halted at the turn of century and now appears to have stabilised.

Figure II-1-2 **R&D intensity and share of GERD funded by government (%) in OECD countries, 1981-2013**

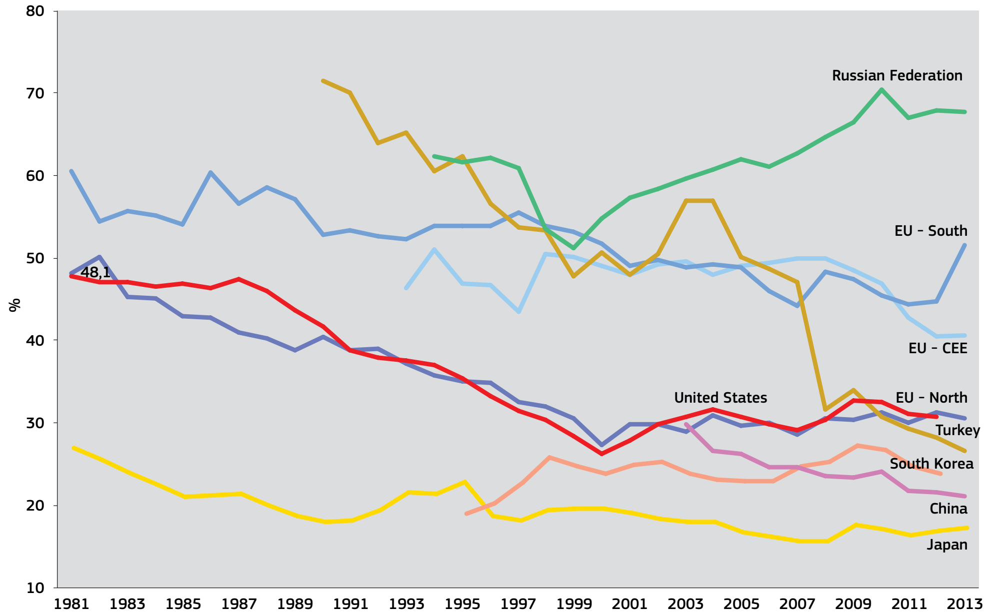


Science, Research and Innovation performance of the EU 2016

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

Figure II-1-3 shows this overall trend for the OECD countries disaggregated across different countries and the three EU regions defined above. In the EU North and US, the decline in government funded R&D has halted and its share is gradually increasing again. The trend is similar in Korea and, after 2008, in Japan. China shows a continuously declining share of government funded R&D, but an increasing overall GERD. In Russia, the role of government funding increased after 1999. EU CEE and EU South show higher shares of government funding compared to EU North, differences that we explore in greater detail later.

Figure II-1-3 **Share of GERD funded by government (%), 1981-2013**



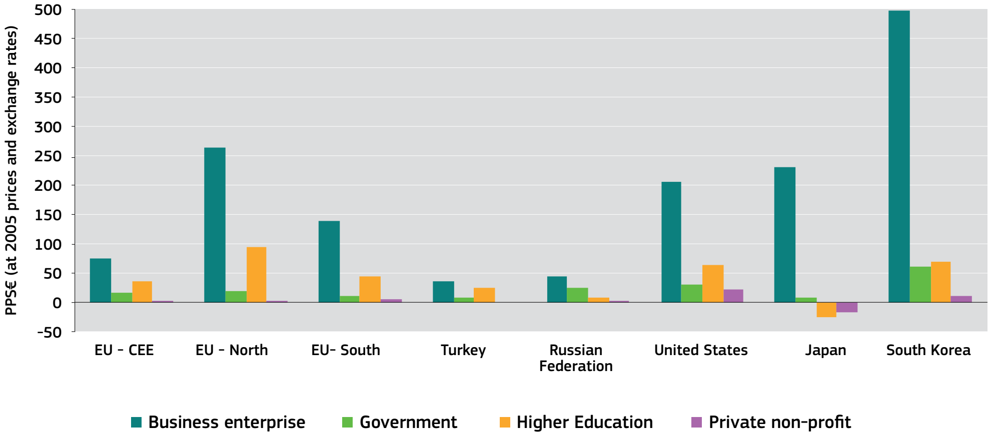
Science, Research and Innovation performance of the EU 2016

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

Data: Eurostat, OECD

Next, we look at changes in relative funding of GERD across the four institutional sectors. The biggest increases in R&D funding can be observed in the Business Enterprise Sector in the EU and other countries. The biggest increases in higher education funding can be found in North EU. South EU and CEE EU have invested more in the higher education than in the government sector and so the government sector share continues to be in decline. Korea has increased its investment per capita in both the government and higher education sector quite considerably.

Figure II-1-4 **GERD by sector per head of population in PPS€ at 2005 prices and exchange rates - difference between 2011 and 1991 in absolute values**



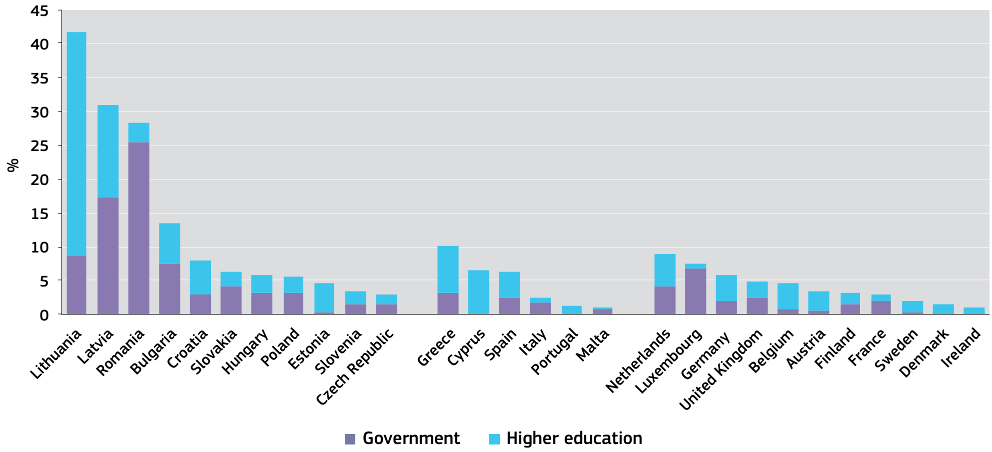
	EU - CEE	EU - North	EU - South	Turkey	Russian Federa-tion	United States	Japan	South Korea
Business enterprise	75.8	263.1	139.0	36.0	44.2	205.7	231.5	496.6
Government	16.0	18.9	10.6	9.1	25.8	31.0	8.0	59.6
Higher Education	36.4	94.5	43.0	26.0	9.2	62.6	-24.2	70.1
Private non-profit	0.5	0.7	6.3	:	0.2	21.3	-17.3	11.9

Science, Research and Innovation performance of the EU 2016
Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat

1.3.2 Business funding of public R&D

The funding of public R&D by the business sector is one way to measure the intensity of public-private interactions. The share of business funding used to support public R&D points to the importance of external R&D in an R&I system and the role of PROs and higher education institutions in company's innovation activities. Figures II-1-5 and II-1-6 show that the share of business sector funding going to public R&D is slightly higher in EU South and much higher in EU CEE compared to EU North. This may be due to weaker business R&D which relies more on public R&D to compensate for its own low R&D capabilities.

Figure II-1-5 **Share of business enterprise funding of R&D going to public (government and higher education) sector R&D, 2012**



Science, Research and Innovation performance of the EU 2016
Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat

There are quite substantial differences in reliance on public R&D between the EU CEE and the EU North. This is largely due to the strong reliance of two Baltic States (Lithuania and partly Latvia) on university R&D and the reliance on PROs in Romania. However, when looking at median values, EU CEE is still more reliant on public R&D than the EU North while the EU South lies somewhere in between (Figure II-1-6).

Figure II-1-6 **Share of business enterprise funding of R&D going to public sector R&D, 2012**

	Government	Higher education	Total
		Average	
EU - CEE	6.9%	6.9%	13.8%
EU - South	2.2%	3.6%	5.8%
EU - North	2.5%	2.1%	4.7%
		Median	
EU - CEE	3.1%	3.0%	6.3%
EU - South	1.3%	2.5%	4.4%
EU - North	1.4%	1.8%	3.3%

Science, Research and Innovation performance of the EU 2016
Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat

A higher share of business funding going to public R&D would be expected in economies with a high share of large firms with more linkages to public R&D. In addition, external R&D-industry links are more developed in more science-intensive sectors such as semiconductors, computers, communications equipment, drugs, organic chemicals, plastics, petroleum refining, pulp and paper (Klevorick et al., 1995; Cohen et al., 2002). However, these are all areas where EU CEE and EU South tend not to have comparative advantages (see Radosevic and Yoruk, 2014). Their economies are dominated by medium and small sized enterprises and comparatively smaller shares of large enterprises. So, the higher relative intensity of public R&D-enterprise sector links in the EU CEE noted above suggests that the nature of these links may be different. Demand from firms for the services of public R&D organisations is not less intensive in less developed EU economies, but it is probably different in nature.

1.4 Role of public research in technology upgrading

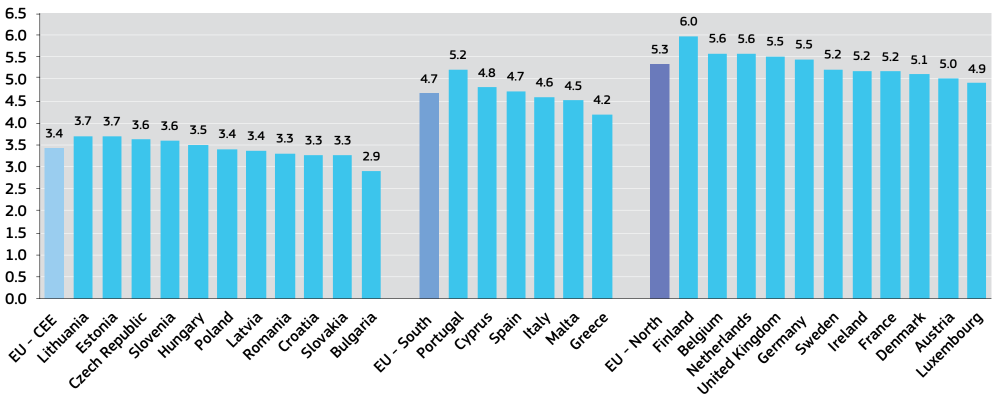
The latest research on public R&D, in countries that are catching up, shows that the role of public R&D can be understood only in relation to firms' changing capabilities (Albuquerque et al., 2015). So, in order to fully understand the role of public R&D, we need to take account of the evolution of the capabilities of both local public R&D (Eun et al., 2006; Liefner and Schiller, 2008) and of local firms.

In the early stages of catch up what matters is not only firms and their links to FDI but also their links with universities and PROs, which are important for linking the national innovation system to international flows of science and technology. For example, Ribeiro et al. (2015, Table 8.6) show that more than half (64%) of the institutional citations in US firms' patents are to domestic organisations. Domestic sources account for 39% of institutional citations in Europe, and 26% in Japan. The pattern is different for countries that are catching up, e.g., in the case of China only 6% of citations were from domestic sources.

This illustrates the importance of foreign sources of knowledge for development, and the greater shift towards domestic sources as countries upgrade technologically and the importance of local sources of knowledge increases. Thus, it is important to assess the quality of the R&D and innovation infrastructure, which should adjust over time to the technological upgrading of firms.

Figure II-1-7 presents a subjective assessment of the quality of R&D and innovation infrastructure in the EU, which shows big differences among the three EU regions.

Figure II-1-7 **Quality of R&D and innovation infrastructure[1] in the EU, 2014-15**



Science, Research and Innovation performance of the EU 2016

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: World Economic Report, Global Competiveness Report Database
Note: [1]Based on a subjective assessment of the business community and calculated as average quality of education, availability of scientists and engineers, availability of research and training services, and quality of scientific research institutions.

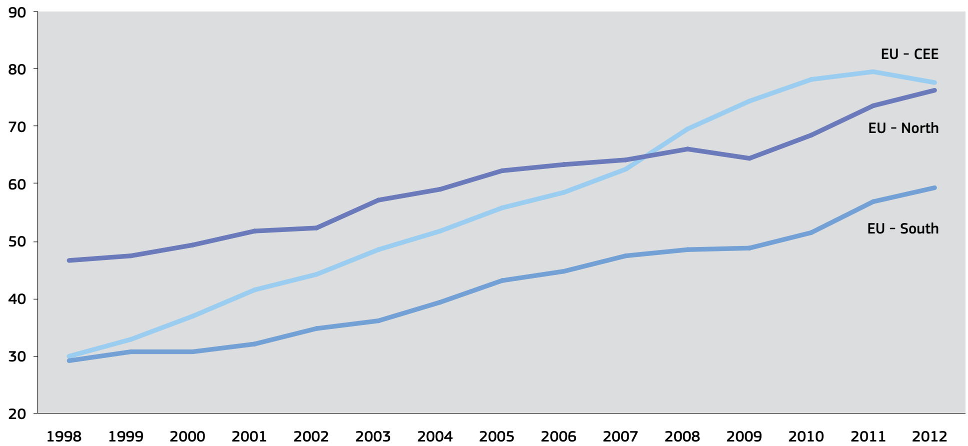
Figure II-1-7 shows that, particularly in EU CEE, firm upgrading is constrained not only by factors internal to the firm, but also by the poor quality of the R&D and innovation infrastructure. These indices suggest that in EU CEE the public R&D infrastructure is not yet adjusted to firms' technology upgrading needs. The infrastructure quality in EU South appears to be better.

Historical experience shows that in order for public R&D to contribute to catch-up, its research was oriented towards 'an actual or potential user-community' and R&D programmes were geared 'to help solve problems, and advance technology, relevant to a particular economic sector' (Mazzoleni and Nelson, 2007: 1525). Also, research conducted outside universities, in dedicated application-oriented laboratories, typically played an important role in this process (Mazzoleni and Nelson, 2007: 1526). In view of this experience it is important to note that PROs seem to be losing their position in public R&D systems in the EU and especially in EU CEE and EU South (Figure II-1-4). This evolution may be worrying given the increasing need for mission oriented R&D related to 'grand challenges' for which universities are not necessarily the best equipped.

Figure II-1-8 shows that there has been a quite intensive process of expansion of higher education in EU CEE. The annual rate of increase in the number of graduates per 1000 population aged 20-29 was 7.1% in EU CEE, 5.2% in EU South and 3.6% in EU North in the period from 1998-2012. This has led to a situation where, on average, EU CEE now has more graduates per 1000 population aged 20-29, than EU North.

This may have effects on the capacity of universities to facilitate technology upgrading of the economy. In EU CEE, the large increases in the number of university students are putting a strain on universities' knowledge generation and knowledge utilisation functions (Radosevic and Kriuacione, 2007). Coupled with limited budgets, this has endangered the balance between the three university missions of teaching, research and knowledge exchange. It would seem that, despite individual success stories, universities are not the key promoters of linkages in the national innovation systems of CEECs.

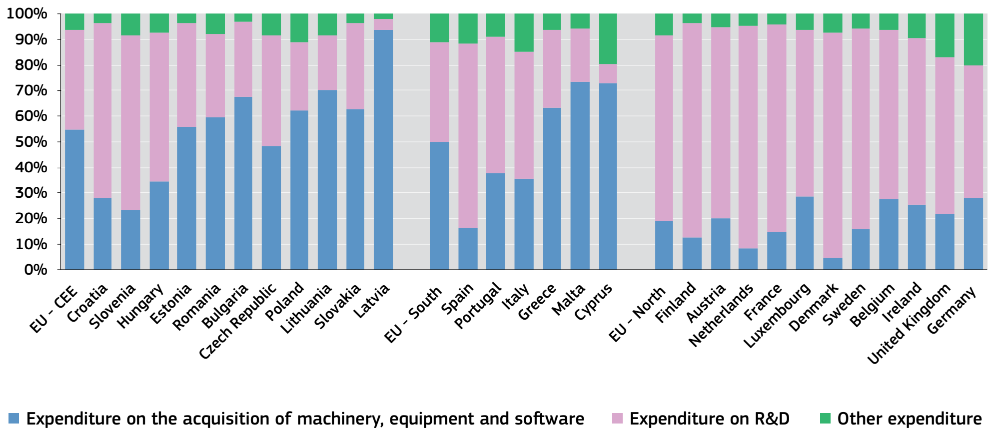
Figure II-1-8 **Total graduates (ISCED 5-6) per thousand population aged 20-29, 1998-2012**



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

The structure of innovation expenditures across the EU shows significant differences across the three EU regions (Figure II-1-9). Innovation in EU CEE and EU South consists more of acquisition of new machinery, equipment and software, and relatively little of R&D activities. This would be expected given the lower share of continuously active R&D firms in EU CEE and EU South. It also suggests that demand for external R&D and, thus, for public R&D is relatively less intensive in the EU periphery compared to EU North.

Figure II-1-9 Structure of innovation expenditure, 2010-2012



Science, Research and Innovation performance of the EU 2016
Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat

Figure II-1-10 decomposes expenditures on R&D into in-house R&D and external R&D. We are interested in whether the share of external R&D is significantly different across the three regions. In terms of averages, the differences are small (17% to 22%). In terms of the median share of external R&D, the more developed the region the higher the share (13% CEE, 18% South and 22% North). However, there seem to be no significant regional differences in the balance between enterprises' internal vs. external R&D activities, which suggests that, despite a lower share of R&D active enterprises in less developed EU regions, the proportion of R&D expenditures on external R&D is similar.

Figure II-1-10 Distribution (%) of R&D expenditure between in-house R&D and external R&D, 2012

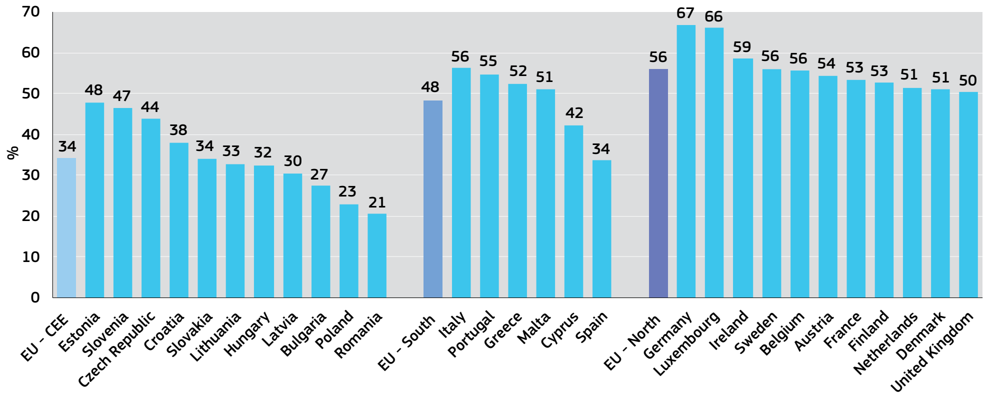
Science, Research and Innovation performance of the EU 2016
Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat

1.5 Industry — Public R&D links in the EU

Innovation surveys are important for understanding the role of public R&D and the nature of industry-public R&D links in the EU. Public R&D is an information input for innovation activity. A better understanding of the innovation process in the EU gives some idea of the relationships between firms and public R&D across the EU.

Innovation frequency differs significantly across the three EU regions (see Figure II-1-11 and Figure II-1-12). Innovation frequency is higher in EU North compared to EU CEE although there is less difference with EU South. Presumably, the higher share of inventors is representative of a potentially higher demand for public R&D.

Figure II-1-11 **Share of innovative firms[(1)] in total firms (%), 2010-2012**



Science, Research and Innovation performance of the EU 2016

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat
Note: [(1)]Data on innovation refer to core innovation activities which exclude Sectors: A (Agriculture, forestry and fishing) and N (Administrative and support service activities).

Figure II-1-12 **Descriptive statistics based on shares of innovative enterprises, 2010-2012**

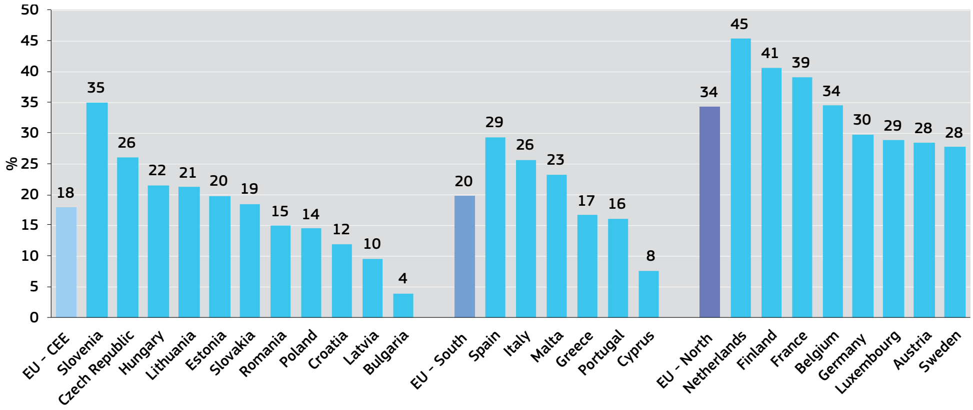
	EU - North	EU - South	EU - CEE
Max	67%	56%	48%
Min	50%	34%	21%
Range (max-min)	17%	22%	27%
Median	54%	52%	33%
Average	56%	48%	34%

Science, Research and Innovation performance of the EU 2016

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

An important feature of the innovation processes in the EU periphery compared to the developed EU12, is the share of enterprises which engage in continuous in-house R&D activity. Figure II-1-13 shows the average shares of such enterprises based on three innovation surveys (2008, 2010 and 2012), in terms of regional averages. It can be seen that it is not only the higher shares of innovators, but also higher shares of firms continuously engaged in R&D that differentiate the three EU regions.

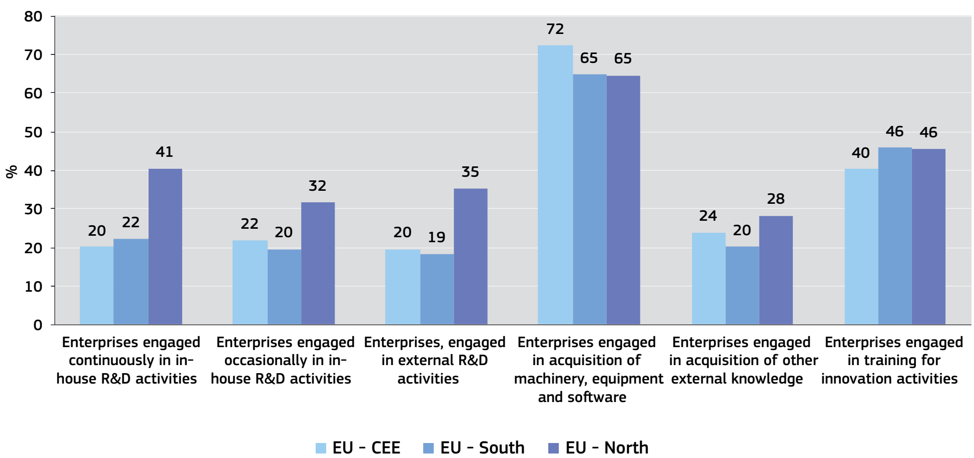
Figure II-1-13 **Share (%) of enterprises engaged continuously in in-house R&D activities – average 2008-2012**



Science, Research and Innovation performance of the EU 2016
Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat

In 2012, the share of firms with continuous R&D activity was twice as high in the EU North as compared to the EU periphery (see Figure II-1-14). Also, the share of enterprises that engage in external R&D is significantly higher in EU North compared to EU South and EU CEE. Differences in other types of innovation activity are less pronounced. The biggest difference is in the frequency of R&D active firms and the extent to which they are engaged in external R&D activities. EU North has more continuously R&D active firms and more frequent engagement in external R&D activities, a significant part of which consists of agreements with public R&D organisations.

Figure II-1-14 **Share (%) of enterprises involved in different types of innovation activity, 2012**



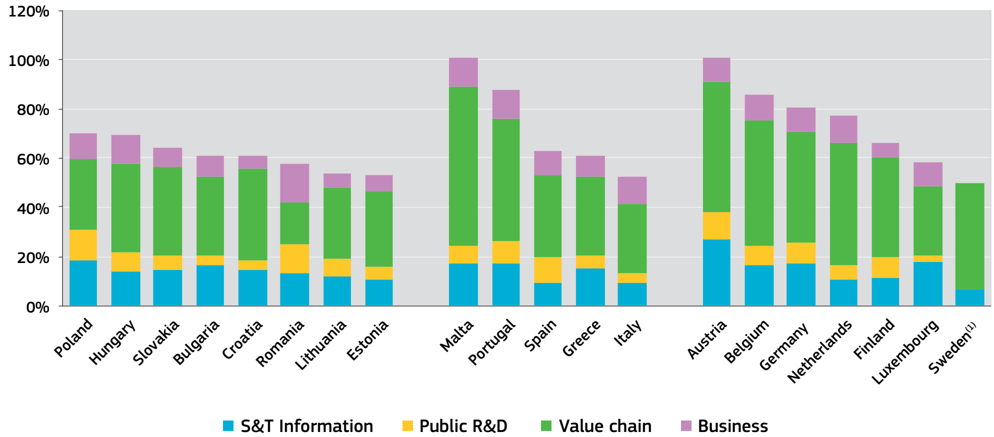
Science, Research and Innovation performance of the EU 2016
Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat

A simple correlation analysis suggests that the correlation between enterprises with continuous in-house R&D activities and those engaged in external R&D activities is 0.76, which suggests that these two activities are complementary.

The different sources of information for innovation can be categorised as: S&T information (conferences, trade fairs and exhibitions; scientific journals and trade/technical publications), public science organisations (universities and government, public or private research institutes), value chains (clients and customers; suppliers of equipment and materials) and business sources (professional and industry associations; consultants and commercials labs).

Figure II-1-15 depicts the percentages of firms that consider specific sources of information as highly important across different groups. It shows that, on average, the importance of external sources of information is slightly higher in the EU North compared to EU South, and considerably higher than in EU CEE. Also, value chains are the most frequent source of information followed by conferences, exhibitions and journals (Figure II-1-16). Public R&D and business sources are less important sources of information. However, the indirect importance of public R&D as an important generator of R&D knowledge through journals and other publications, and participation in conferences and professional associations should be noted. If this indirect or 'spillover role' of public R&D is included, the importance of public R&D for innovation processes in the enterprise sector is much higher**.** Finally, the importance of different sources of information is very similar across countries and across regions.

Figure II-1-15 **Share (%) of enterprises that consider information from different external sources as highly important for innovation, 2012**



Science, Research and Innovation performance of the EU 2016

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

Data: Eurostat

Note: (1)SE: Information on public scientific organisations is not available.

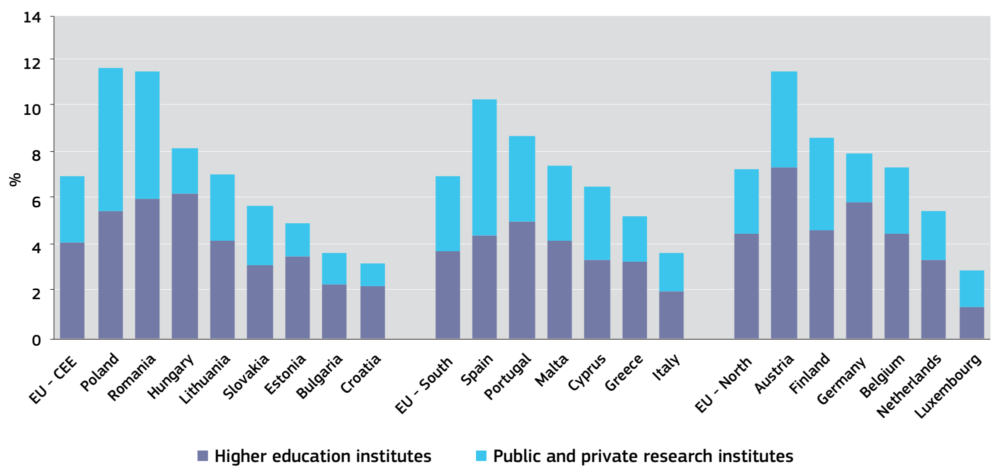
Figure II-1-16 **Percentage of enterprises considering information from different external sources as highly important for innovation, 2012 (median)**

	S&T information	Public R&D	Value chain	Business	Total
EU - CEE	14.9%	7.1%	32.1%	8.3%	62.4%
EU - South	16.2%	7.1%	41.7%	11.2%	76.2%
EU - North	16.7%	7.5%	45.5%	9.5%	79.2%

Science, Research and Innovation performance of the EU 2016
Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat

Finally, we examine firms' assessments of whether they regard public R&D (universities and PROs) as highly important sources of innovation. Data from innovation surveys shows that there are no major differences in that respect across the three EU regions, and that those differences that do exist are largely intra-regional. The overall importance of public R&D is surprisingly similar across the three mega regions in terms of both PROs and universities (Figure II-1-17). So, similar to the proportions of R&D expenditure on external R&D across countries and regions, we do not observe a lower frequency of importance of external sources of information including public R&D organisations across the different regions. This picture of the importance of public R&D seems to be a permanent feature since there are no significant changes across the most recent three innovation surveys.

Figure II-1-17 **Share (%) of firms that consider public and private research institutes and higher education institutes as important sources of information for innovation, 2012**



Science, Research and Innovation performance of the EU 2016
Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat

In summary, innovation surveys show that the frequency of innovators is higher in the developed part of the EU compared to EU CEE and South. The share of continuous R&D innovators is also much higher in EU North and, accordingly, a higher proportion of them engage in external R&D. The share of R&D expenditure is also much higher in EU North compared to EU CEE and EU South. In the latter regions, much innovation expenditure is for acquisition of equipment, machinery and software.

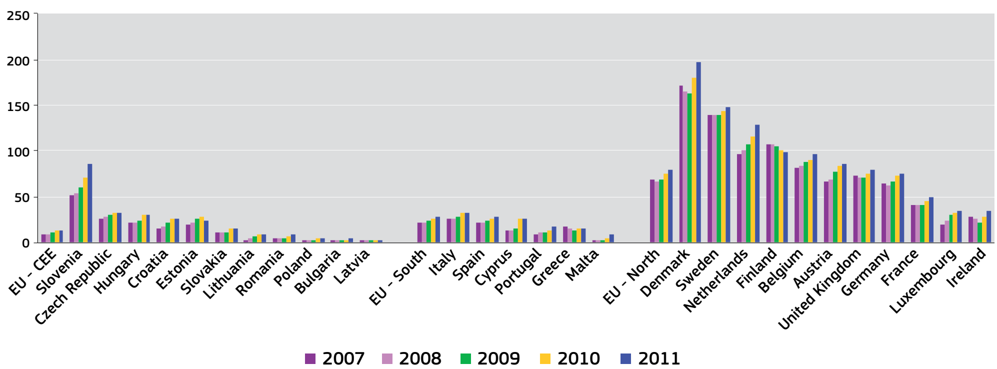
However, differences with respect to the share of external R&D expenditure and the frequency of importance of PRO and universities as sources of information for innovation, are much smaller and are not significant across the three regions. So, despite lower R&D intensity of innovation activities and lower intensity of demand for external R&D, the less developed EU regions have similar expenditure shares for external R&D. Also, information or knowledge from external R&D providers such as PROs and higher education institutions is equally important for EU CEE, EU South and EU North.

The above suggests that the usual argument that science-industry links in less developed regions of the EU are less intensive does not bear close scrutiny. It is usually assumed that science-industry links are quite undeveloped in catching up contexts. However, Albuquerque et al. (2015) and evidence from the EU would tend to disprove this assumption. Evidence from innovation surveys in catching up economies shows that innovative firms regard universities as highly important sources of information, to a similar or even higher extent than in developed countries. For example, in the 2008 Brazilian innovation survey, 6.8% of innovative firms regarded universities as highly important sources of information (Albuquerque et al., 2015), which is very close to the median value of 7% for the three EU regions. Also, there is no significant difference between developed and developing countries in the ranking by firms of the importance of sources of innovation [33].

Such evidence questions the notion that in catching up countries public-business R&D links are missing or weak. In our view, this assumption arises because the relation between public R&D and the business sector has been reduced to the mere commercialisation of R&D. This report provides evidence to support the view that science-industry links in less developed parts of the EU are not less intensive, but they are different.

In the EU context, the difference in the nature of the science-industry links between EU North, EU CEE and EU South is sufficient to merit further attention. There seem to be fewer upstream and research cooperation links, and more downstream S&T and innovation services links. Figure II-1-18 shows that the intensity of upstream cooperation in the form of joint publications between PROs/universities and the business sector are a much less developed form of cooperation in the EU CEE and EU South compared to the EU North. However, there is a process of convergence underway: the number of co-publications per million population increased in 2007-2014 by 54% in CEE EU, 42% in EU South and 16% in EU North.

Figure II-1-18 **Public-private co-publications per million population, 2007-2011**



Science, Research and Innovation performance of the EU 2016
Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Innovation Union Scoreboard

(33) E.g., correlation of the importance of sources of information for innovation between the US and India is 0.886 (Al Albuquerque et al., 2015, Table 5.6).

1.6 Conclusions: How to harness the potential of public R&D to support economic development

Our review of the literature on the role of public R&D in development shows that it is difficult to demonstrate its benefits in an unambiguous, quantitative manner. We reviewed various benefits of public R&D, and the differentiated role of public R&D in development in the context of the EU, which includes a diversity of R&D and innovation activities. Scattered, unsystematic evidence allows only tentative conclusions about the benefits of public R&D which differ across different groups of countries according to their technological development and distance from the technology frontier. The benefits of public R&D have a somewhat different ordering in catching up countries when compared to technology frontier economies.

Although we do not have systematic evidence of these benefits, training of skilled graduates is probably the most important benefit from public R&D in the less developed EU. The quality of higher education is especially important for 'knowledge-based industrialisation' and has been rather overlooked in the process of 'massification' of higher education that occurred in the first decade of 2000 (Dakowska and Harmsen, 2015). Also, increasing scientific and technological problem solving capacity should be high on the policy agenda. At the same time, we observe a gradual, but increasing pressure towards the achievement of scientific excellence, which is not always locally relevant. Funding criteria tend to be based on academic output, which does not contribute to improved local relevance. The challenge for policy is how to prioritise locally relevant but internationally excellent R&D (see Radosevic and Lepori, 2009).

The evidence in this chapter casts doubt on the commonly held view that relationships between PROs and universities and industry are less important for firms in less developed EU regions. This is in line with new evidence on science-industry links (Albuquerque, 2015; Schiller and Lee, 2015). Science-industry links are important at all stages of economic development, but similarly intensive links should not be mixed up with similarities or differences in their nature.

The first policy message from our analysis is that there is a need to redress the balance in the importance of channels of interaction and the benefits of public R&D in the less developed EU. Commercialisation and the aim of creation of new firms through public R&D has been over-estimated as a growth enhancing factor in the less developed EU economies, compared to other channels (Brown and Mason, 2014). Similar to other emerging economies (Albuquerque et al, 2015), the policy focus on commercialisation is too narrow in the context of CEE and South EU. The establishment of technology transfer offices to promote the commercialisation of existing inventions in a linear way should not be the major policy focus in this area. Such programmes, which are modelled on different contexts, ignore the needs of local firms and the capabilities of local public R&D organisations, which are much more focused on S&T problem solving.

The second important policy issue is whether countries will be able to develop specific roles for PROs as opposed to universities. As countries upgrade technologically, it might seem that the role of universities increases and the role of PROs decreases. However, new challenges related to climate change and energy transition may require a much greater role for more narrowly focused PROs (Mazzucato, 2015). It will be important for EU CEE and EU South to identify technology and mission-specific roles for their PROs. More advanced technology upgrading will require good support for small- and medium-sized, technology-intensive enterprises and firms. Some countries have plans to try to replicate the Fraunhofer model in response to this need.

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2. Public research and innovation policies and investment and their evolutions since the crisis

Claire Nauwelaers

2.1 Background

This chapter analyses the evolution of public investments and policies for research and innovation in the European Union over the crisis period. The key question is whether the crisis — started in 2008, but with long-lasting effects — is associated with shifts in intensity and direction of public investments in R&I. It also looks at how the situation differs between EU Member States.

Economic and policy context

The Union as a whole, and European Member States individually, face important development challenges, exacerbated by the crisis. Decreasing consumption and investment trends, coupled with high uncertainty, result in weak economic growth and meagre jobs creation; the priority placed on fiscal consolidation restricts the scope for policy interventions in reaction to the crisis; and mounting societal challenges — in particular an ageing population and environmental pressures — place new constraints on public budgets (due to rising expenditures for health and pensions, the need for enhanced investments and incentives to address environmental threats, etc.). The increasingly open competition on globalising markets, and the growing role, in international value chains, of new actors from emerging economies reinforce the pressure on economic actors on the 'old continent'. In particular, the crisis has a deep — though uneven — impact on firms' innovation investments; since that impact is stronger in countries with less developed R&I systems, there is a danger that the catching-up process that started before the recession in these countries may be slowed down or even stopped (Filippetti and Archibugi 2010). Thus, while the EU economy as a whole has started its journey on a recovery path in the years following 2008, most Members States are still struggling with slow growth, incomplete economic recovery, and possible structural bottlenecks to growth (e.g., due to brain drain).

The importance of research and innovation as an engine for maintaining and reinforcing the competitiveness of Europe on the global scene is undisputed. With Europe 2020, the European Union has set an ambitious strategy to support growth and jobs creation in all parts of its territory, in a difficult and globally open environment. Within this strategy, research and innovation take a prominent role: 'Building an Innovation Union' is one of its flagship initiatives. The 2014 Commission Communication 'Research and innovation as sources of renewed growth' [34] acknowledges this role in past periods, and points towards a reinforced role for post-crisis recovery. The European Union authorities have diffused the message that 'growth-friendly consolidation', namely budgetary consolidation that places a premium on maintaining — and even increasing — those public expenditures that contribute to an environment conducive to growth and employment, is the way forward. R&D and innovation is only one of those growth-friendly domains, but it has a crucial role to support European competitiveness in a medium-term perspective. Further boosting the assets of European economies — world-class innovative companies, development of cutting-edge key technologies and excellent research capacity — lies at the top of European Union policy agenda.

Such a priority is also visible in the European Union Cohesion Policy. In the 2014-2020 programming period, the Community Guidelines foresee a concentration of investments on four priorities: Research and innovation, ICT, competitiveness of SMEs, and low carbon economy. One third of the total EU budget is dedicated to Cohesion policy with a strong drive towards its contribution to the Europe 2020 goals, making it 'the first EU investment for growth and jobs'. Member States and Regions are incentivised to develop new approaches — in the form of smart specialisation strategies — to shift their regional development policies towards the promotion of innovation concentrated in knowledge-based, future-oriented activity domains.

[34] COM (2014) 339 final.

The Commission's policy agenda acknowledges that a full economic recovery fuelled by research and innovation is the responsibility of both the Members States and the European authorities. The 'European Semester' process and the National Reform programmes in each Member State are the main manifestations of this interaction between European-level and national-level authorities, in view of raising the contribution of research and innovation to economic growth. In this dialogue, 'improving the quality of research and innovation strategy development and the policy-making process' is one of three reform axes identified by the Commission for completing the European Research Area. With the economic crisis and the financial consolidation process, there is a pressing need for governments to get more benefits from each euro invested in R&I; therefore, the orientation and mix of policies targeting the R&I system is becoming a crucial issue for governments, in addition to the quantity of public funds invested in this field.

The quantitative and qualitative aspects of public R&I investments

The initial focus of EU policy on a R&D input indicator — the 3% Barcelona target for GERD/GDP — has been progressively complemented by an increasing attention to the outputs of R&D and the contribution of the latter to economic development of the Union through innovation. A new innovation output indicator was developed at the EU level for this purpose and the Innovation Union Scoreboard covers innovation enablers, activities and outputs.

Hence, this shared agenda between the EU and Member States, targeting investments in research and innovation as a way out of the crisis, has two dimensions:

1. **A quantitative dimension**

   The European Union, as a whole, and Member States individually, are committed to raise their investments in R&D to specific values (3% of the GDP by 2020 for the EU, and specific values for each Member State, defined according to their individual situation). While most of these investments should be realised by the private sector, the role of public sector investment is also important to reach such targets, both directly and indirectly through stimulation of private R&D investment. Maintaining, and even increasing, such public investments in times of fierce budgetary constraints is the challenge.

   The quantitative dimension of public investments in research and innovation is monitored regularly by the European Commission and the OECD, and in individual Member States by Ministries and Statistical offices using methods and indicators aligned with OECD and EU frameworks. The adoption of 3% Barcelona target has generated analyses of budget trajectories and scenarios to reach this investment target, both at EU and Member State levels. In parallel, studies have empirically investigated the size of private rates of return of R&D, the social rate of return, and the contribution of R&D to total factor productivity: such studies provide the justification for the importance of R&D and of associated public investments for economic growth (Griliches 1979, Grossman and Helpman 1991), and for the estimation of 'optimal' R&D/GDP ratios.

2. **A qualitative dimension**

   Different types of public investments have different impacts and provide different contributions to the evolution towards a more knowledge-intensive European economy. Depending on target groups, objectives of the R&I activities, mode of distribution for the funds, etc. different parts of national research and innovation systems will be affected, and the nature of the impact of these public investments on national R&I performance will vary. An increased attention to innovation in addition to R&D has also broadened the scope of relevant policies. These differences in orientations and priorities are enshrined in R&I policies which receive in-depth attention in all Member States as growth-enhancing strategies.

The qualitative analysis of public R&I investments has a long tradition in science policy research. An evolution took place from 'market failures' approaches considering fundamental, disciplinary research, driven by researchers' curiosity, towards justifications for funding science that is, at the same time, of a fundamental nature and providing solutions to societal demands, i.e., research in 'Pasteur's quadrant' (Stokes 1997). Interest has also shifted from 'Mode 1' to a 'Mode 2' type of research, i.e., towards research taking place in a broader transdisciplinary, social and economic context (Gibbons et al. 1994). Such an evolution points towards an increasing orientation of science systems towards strategic goals and the production of knowledge with societal relevance. With the wider adoption of the 'innovation systems' conceptual framework, the public sector has an additional role as a facilitator of system interactions, leading notably to the establishment of research-driven networks and clusters involving both the public and private actors in the system (relying on a 'systemic failure rationale'). Those justifications for public investments in R&I give rise to new trends and new organisations which take increasingly diverse configurations (Borras and Edquist 2014, Lepori et al. 2007). Current work underlines that there is no ideal model for such policies. Rather, policies have to address well-identified bottlenecks in research and innovation systems, and to capitalise on their specific assets. This places a high premium on the 'right configuration' of investments as well as on implementing adequate reforms of the R&I systems. These new orientations do not necessarily translate to changing money flows.

Work has also been carried out around the issue of complementarity between different types of policies in the broad R&D domain, generally concluding that there is a need to build policies carefully in order to take into account all elements of the R&I system (Mohnen and Röller 2005). A range of literature also covers issues in relation with a deepening and widening of the scope of policies relevant for innovation (Borras 2009). The introduction of the systemic perspective and of new public management techniques in innovation policy-making are viewed as responsible for this double phenomenon; the implementation of new and more sophisticated policy instruments (deepening) along with an expansion of the realm of action for innovation policy (widening).

Recently, interesting attempts have been made to characterise, in detail, the content of national 'policy mixes' for innovation (Izsak 2014), exploiting policy databases established by the European Commission, which depict new trends and enlighten similarities and differences between EU Member States' policy approaches. This work highlights: 1) the importance of differences in shape and performance of individual countries' research innovation systems for the direction of policies; 2) the persistence of policy profiles over time and 3) the lack of correspondence between the innovation levels of countries and the types of policy mixes.

Organisation of the chapter

This chapter examines the two aforementioned dimensions of public investments in R&I, analysing: a) how far the EU as a whole, its 28 Member States, and competitor countries, have used public investments in R&D as counter-cyclical strategy since the start of the crisis (Section 2); and b) what changes did occur in the nature of such investments and what reforms have been implemented in the research and innovation systems along with the evolution of public investments (Section 3). Section 4 draws policy-oriented conclusions from the analysis.

2.2 Evolution of public investments in R&I over the crisis period

As put in evidence in the first part of this report, two major phenomena have taken place since 2007 in Europe, with respect to public support for R&D. First, the use of fiscal incentives as a governmental instrument to support R&D investments has grown significantly, with more Member States using this instrument and considerable increases in volume of funds in several countries. Second, EU-level funding (Structural Funds and Framework programme funds) plays an increasingly important role in complementing domestic public funding sources for research and innovation. Those two trends have an important impact on the overall landscape of public funding for R&I and need to be taken into account to get a full picture of trends.

This section analyses first, the situation in terms of fiscal incentives for R&D in Europe; second, the role of Structural Funds and EU Research funds; and third, the evolution of domestic public investment in research.

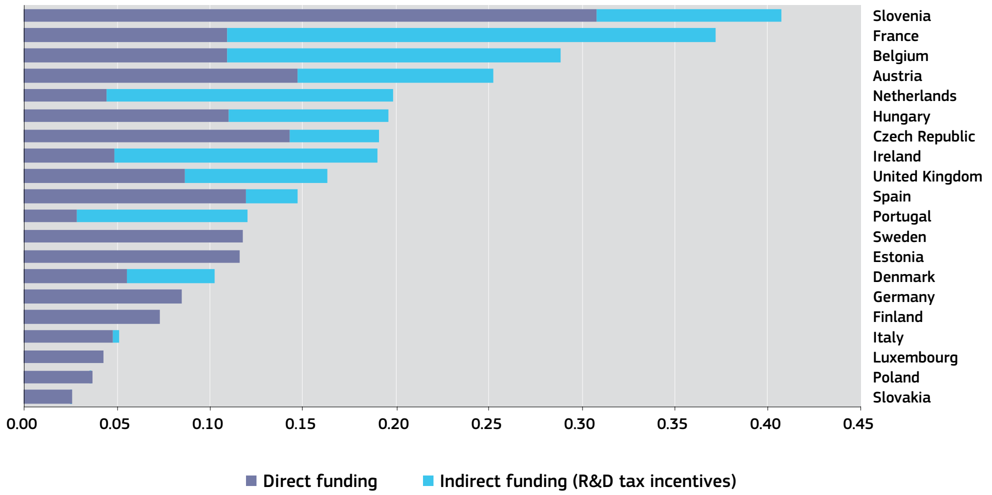
R&D tax incentives in EU Member States

As already indicated in Part 1, chapter 2 of this report, in a significant number of EU Member States, R&D tax incentives are used in addition to direct funding schemes to support business R&D. Nine European countries have introduced R&D tax incentives since 2008, and these add up to those countries that traditionally make use of such an instrument.

These amounts of foregone State revenues are not included in Government Budget Appropriations or Outlays on Research and Development (GBAORD), and hence, for these countries, the latter indicator provides a downward biased picture of public investments in R&D. This is especially true for the Netherlands, Portugal, Ireland, France, Belgium, and the United Kingdom, where foregone tax revenues due to R&D tax incentives equal or exceed the amounts of public money allocated to companies through direct funding in 2012. In a range of other countries, tax incentives also play an important role in supporting R&D, though the amounts disbursed through tax incentives are lower than direct government funding: Denmark, Austria, Hungary, Slovenia, Czech Republic and Spain (Figure II-2-1). Thus, for 12 out of 28 Member States, R&D tax incentives play either an important or a dominant role in addition to direct funding of business R&D.

All 12 Member States except Spain are making an increased use of such tax incentives during the crisis years (Figure II-2-2). The increase in foregone tax revenues due to R&D incentives between 2006 and 2011 is even spectacular in France, Belgium, the Netherlands, Ireland, Portugal and Slovenia.

Figure II-2-1 **R&D tax incentives for business and government direct funding for business R&D, as % of GDP, 2012**

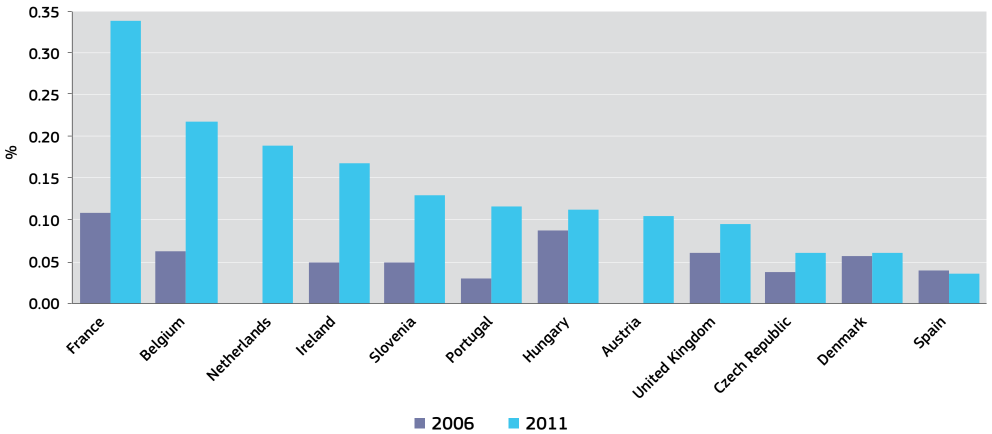


Science, Research and Innovation performance of the EU 2016

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

Data: OECD

Figure II-2-2 **R&D tax incentives as % of GDP, 2006 and 2011**



Science, Research and Innovation performance of the EU 2016

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

Data: OECD

However, there are no reliable time-series on the use of R&D tax incentives that would document possible substitution effects between direct and indirect support to R&D in Member States. In Belgium, such a substitution effect is not likely to be present as R&D tax incentives fall under the realm of federal policy, while direct support to R&D is mostly in the hands of the Regions and Communities, which take decisions on independence from the federal state. Therefore, in this country, complementarity between the two modes of funding for R&D is likely to be present. The reverse is likely to be true for a centralised country such as the Netherlands, where an explicit choice has been made to primarily support R&D through tax incentives rather than through direct funding. The case of France is interesting in that the spectacular increase in use of R&D tax incentives since 2008 has been accompanied by an increase in absolute amounts of GBAORD in 2008 and 2009, followed by a decline in GBAORD since 2011, while tax credit money continued to increase. This suggests at least a partial substitutive effect in the 'austerity' period. One main argument in favour of the use R&D tax incentives is its simplicity, neutrality and stability (compared to direct funding modes which tend to change over time as they follow new strategies and direct funds towards specific sectors, agents or goals, and often involve more cumbersome procedures to access funds). This acts as a disincentive to use tax credits for R&D to adjust for changing economic cycles.

In a growing number of EU Member States, R&D tax incentives provide additional governmental support to R&D, and the use of these incentives tends to increase over the crisis period, either complementing or substituting direct public support to R&D.

European Funds for R&D as a complement to national public funding

In addition to direct and indirect public funding to R&D, EU Member States receive resources from the EU level for their investments. Two main sources are available, with very different modalities, to complement national funding for R&D:

1. EU **Framework Programme** money distributed under the EU Research and Innovation policy, flowing directly to research performers in EU countries, based on a highly selective process relying on research excellence criteria, favouring actors and countries with high research capacities and endowments;

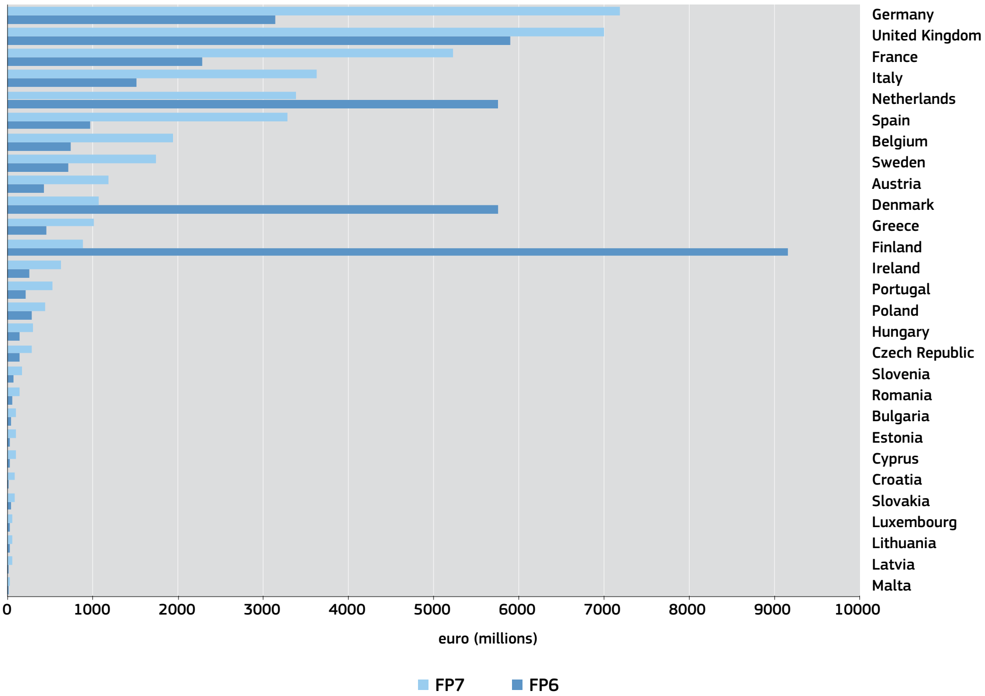
2. EU **Structural Funds** under the EU Cohesion policy, flowing to Member States and regions, based on partnership agreements between Member States and the European Commission, and calculated on the basis of economic development indicators favouring lagging regions.

With respect to **EU Framework Programmes**, total funding has increased between FP6 (2000-2006) and FP7 (2007-2013). The absolute amounts of allocated funding differ significantly between countries, the main beneficiaries being all old Member States: the UK, Netherlands, Germany, France, Denmark and Italy, as well as Spain and Sweden to a lesser extent (Figure II-2-3).

The overall contribution of these EU funds to public R&D spending in EU countries is significant in some countries (Figure II-2-4). The seven Member States for which FP7 funds are the largest contributors in comparison with GBAORD include new Member States and countries with weak public R&D intensity as depicted in Part 1, chapter 2: Malta (where FP7 money exceeds 20% of GBAORD), Greece, Cyprus, Latvia, Slovenia, and Bulgaria; an exception is Estonia, which has a high R&D intensity compared to all other countries. Three countries with more advanced research and innovation systems, namely Ireland, Belgium and the Netherlands, also see their GBAORD complemented with substantial amounts of research funds from EU origin.

EU funds from Research Programmes flow mainly to large old Member States with high R&D capacity, but the contribution of these funds to public funding for R&D is substantial in several small new Member States with low public R&D intensity.

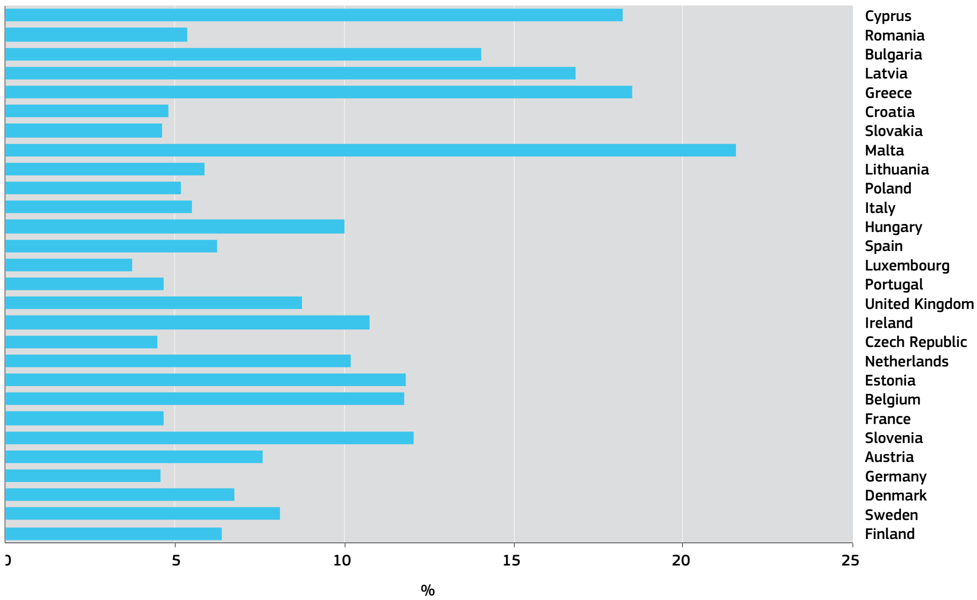
Figure II-2-3 **Contribution of the EU Framework Programmes for R&D to the Member States, FP6 (2000-2006) and FP7 (2007-2011)**



Science, Research and Innovation performance of the EU 2016

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

Figure II-2-4 **Contribution of the FP7 (2007-2013) EU Framework Programme for R&D to the Member States[(1)] as % of total GBAORD, 2007-2013**



Science, Research and Innovation performance of the EU 2016

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: DG Research and Innovation, Eurostat
Note: [(1)]The Member States are ranked in terms of increasing R&D intensity.

Concerning **European Structural Funds** for RDTI, an important shift towards higher priority in R&D and innovation has taken place between the programming periods 2000-2006 and 2007-2013, making them an important additional budgetary source available to Member States to support R&D.

Categories of Structural Funds expenditures differ between the two programming periods, making data not strictly comparable from one period to another. Different definitions of Research and Innovation in Structural Funds exist in various documents, evaluations and analyses, often resulting in a much broader coverage than activities considered under GBAORD. Keeping this limitation in data in mind, Structural Funds data have been analysed using the codes identified in Figure II-2-5, to compare figures between the two periods. The growth in importance of Structural Funds between 2000-2006 and 2007-2013 for public funding for RDTI is very significant. The share of funds allocated to R&D and innovation trebled, shifting from 4.8% in the first period to 14.6% in the second period. This growth provides important complementary resources to Member States' domestic budgetary spending on R&D.

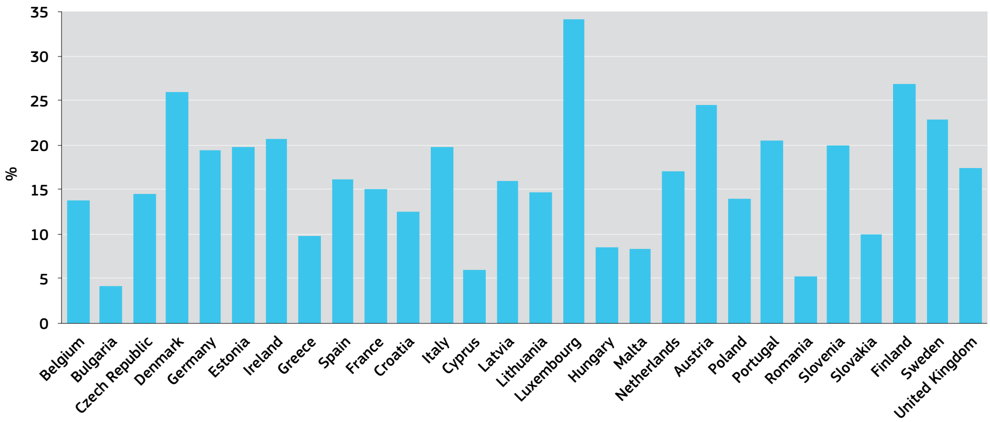
Figure II-2-5 **Codes used in Structural Funds policy for R&D and innovation**

Topic	2000-2006	2007-2013
Public research	181: Research projects based in universities and research institutes	01: R&TD activities in research centres
Research infrastructure	183: RTDI Infrastructure	02: R&TD infrastructure and centres of competence in a specific technology
Innovation eco-system (business innovation and technology transfer)	182: Innovation and technology transfers, establishment of networks and partnerships between businesses and/or research institutes	03: Technology transfer and improvement of cooperation networks 04: Assistance to R&TD, particularly in SMEs (including access to R&TD services in research centres)
	18: Research, technological development and innovation (RTDI)	07: Investment in firms directly linked to research and innovation
		09: Other measures to stimulate research and innovation and entrepreneurship in SMEs
Training and human potential	184: Training for researchers	74: Developing human potential in the field of research and innovation, in particular through post-graduate studies

However, the priority placed by Member States on RDTI within their Structural Funds' operational programmes varies a lot, from less than 5% in Bulgaria to close to 35% in Luxembourg from 2007-2013 (Figure II-2-6). This proportion correlates well, but not perfectly, with their position in the Innovation Union Scoreboard. With the exception of Luxembourg, it is innovation leaders who place the highest priority on RDTI, while modest and moderate innovators (with the exception of Portugal, Italy and Spain) display low priority rates. Despite those lower priority rates, the bulk of Structural Funds devoted to RDTI (in absolute terms) still go to modest and moderate innovators (Figure II-2-7), and those countries are also the ones for which Structural Funds constitute a sizeable contribution to public R&D funding, as compared to domestic efforts captured in GBAORD (Figure II-2-8).

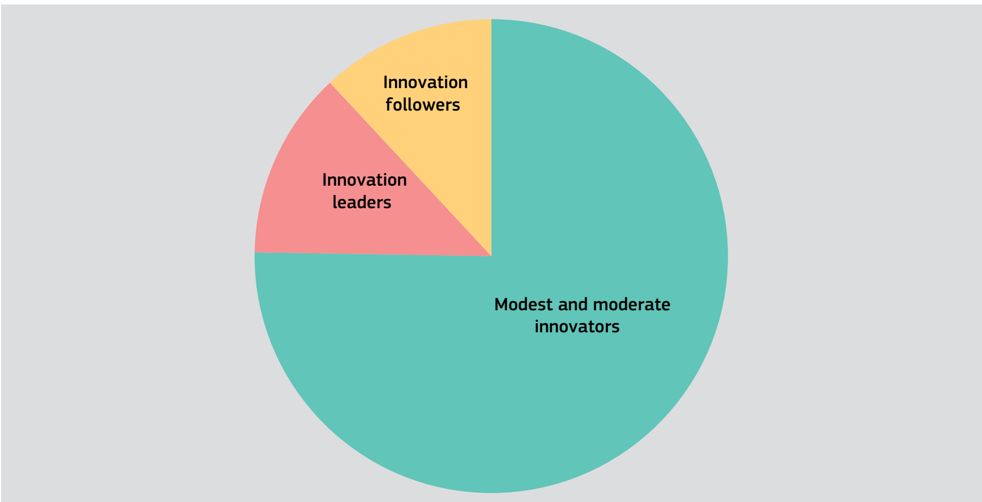
The orientation towards RDTI in Structural Funds is likely to be even stronger in all Member States in the period from 2014-2020, thanks to the pressure from European Authorities to develop strategies oriented towards knowledge-based development, a focus on RDTI priority, and a drive towards smart specialisation strategies exploiting knowledge and innovation assets in regions to fuel growth and jobs creation in new activities. For those less developed regions, which will again receive the lion's share of Structural Funds, the potential leverage effect of these funds is therefore substantial, in view of their relative size compared to GBAORD.

Figure II-2-6 **Share (%) of Structural Funds allocated to RTDI, 2007-2013**



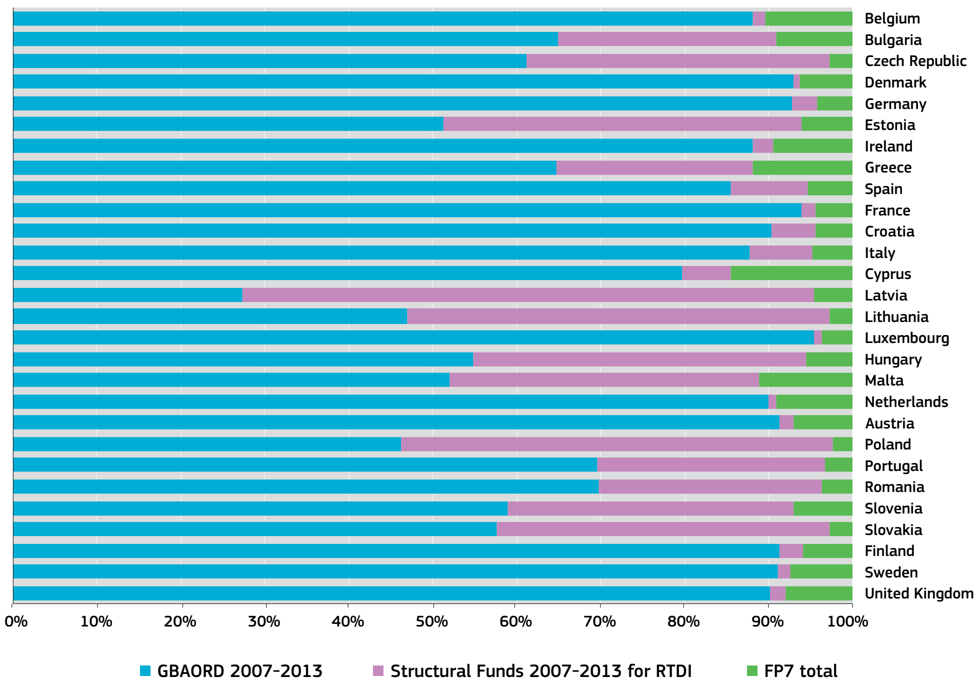
Science, Research and Innovation performance of the EU 2016
Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: DG Regional and Urban Policy

Figure II-2-7 **Structural Funds allocated to RTDI in the EU broken down by category in the Innovation Union Scoreboard, 2007-2013**



Science, Research and Innovation performance of the EU 2016
Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: DG Regional and Urban Policy

Figure II-2-8 **Shares (%) of GBAORD, Structural Funds allocated to RTDI, and FP7 funds[1], 2007-2013**

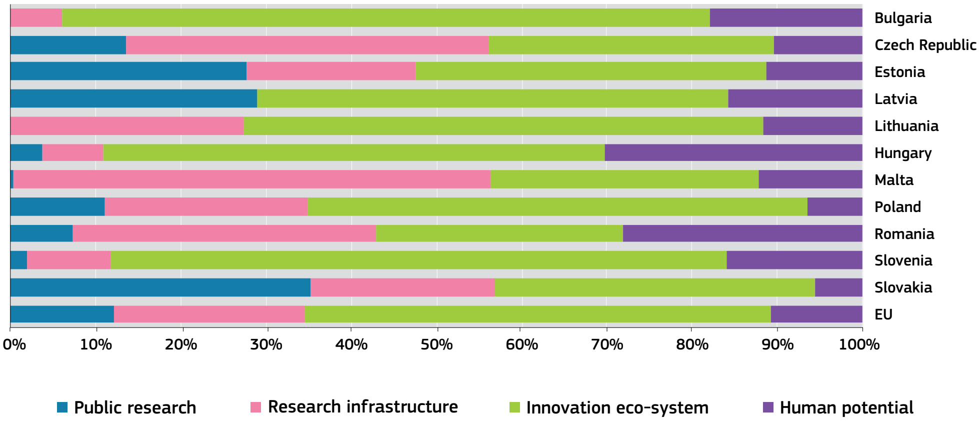


Science, Research and Innovation performance of the EU 2016

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: DG Research and Innovation, DG Regional and Urban Policy, Eurostat
Note: [1]The coverage of R&D differs between GBAORD and Structural Funds for RTDI.

An analysis of the composition of Structural Funds devoted to RDTI in 2007-2013 identifies a growing differentiation of strategies between EU regions, and an increasing diversification of measures implemented (European Commission 2011). While these Funds tended originally to fund classical RTD infrastructure and projects in public research centres, the range of activities targeted by the Funds has become more diverse, also including support for the innovation ecosystem and business innovation. Overall, investments in public research and in research infrastructure only represented one-third of Structural Funds allocations to R&D for the EU28 from 2007-2013 (Figure II-2-9).

Figure II-2-9 **Composition of Structural Funds allocated to RTDI, 2007-2013**



Science, Research and Innovation performance of the EU 2016
Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: DG Regional and Urban Policy

EU Structural Funds constitute a growing source of public Funds for RDTI, especially in those countries that are the largest recipients of these funds. Modest and moderate innovators still have an opportunity to grasp the concept of placing more strategic priority on RDTI in the use of the funds as a recovery device from the crisis.

Domestic public funding to R&D

This section analyses the evolution of GBAORD for the EU as a whole. The analysis distinguishes between pre-crisis period (2005-2008); a 'stimulus' period located just after the peak of the financial crisis, during which many countries were implementing recovery packages (2009-2010); and a so-called 'austerity' period (2011-2013).

Figure II-2-10 displays the evolution of GBAORD [35] aggregated for all Member States of the European Union. This is the main proxy traditionally used to capture efforts devoted by national governments to supporting research and innovation. However, important caveats should be placed with respect to GBAORD as an indicator of public investment to support research and innovation:

1. As discussed above, two other types of public expenditures also support R&D. First, tax credits for R&D provide indirect support to R&D and, therefore, a decrease in GBAORD may not indicate a decrease in government support for R&D for those countries making significant use of this indirect form of support, e.g., the increase in (foregone revenues due to) R&D tax incentives between 2009 and 2013 for France alone is of a similar size as the difference between the top level GBAORD in 2009 and the 2013 GBAORD for the whole EU. Second, EU funds (Structural Funds and Research Funds) also contribute — sometimes heavily, as shown in the previous figures — to supporting R&I in Member States;

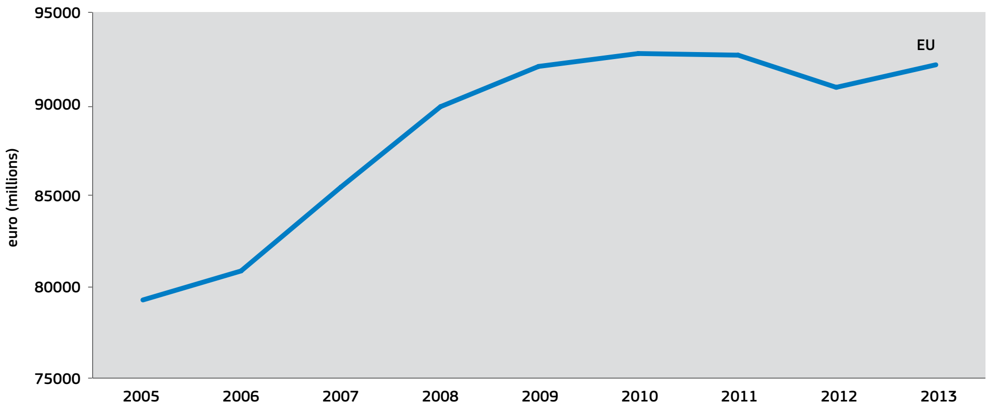
2. The GBAORD indicator captures research and innovation in a narrow sense, as it does not cover support to non-technological or organisational innovation;

[35] GBAORD is used rather than a government-funded part of GERD. Even if the latter captures actual expenditures rather than budgetary allocations which might not correspond to real expenditures, GBAORD illustrates policy intentions, and more recent data are available.

3. Another caveat to be borne in mind when looking at GBAORD figures is the one mentioned in Section 1; measuring the quantity of public expenditures is only one side of the coin. Quality, direction and effectiveness of those expenditures are crucial to reach the intended goal of ensuring growth and employment thanks to enhanced R&I;

4. Significant differences exist between Member States in terms of the evolution of their GBAORD.

Figure II-2-10 **Total government budget appropriations or outlays for R&D (GBAORD) - EU, 2005-2013**



Science, Research and Innovation performance of the EU 2016
Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat

Data on public R&D expenditures and on public support to business R&D presented in Part 1/ chapter 2 already showed clearly that total public efforts for R&D in the EU in 2012/2013 were much higher than in 2007. This is confirmed by the GBAORD-based approach, as EU28 GBAORD is higher in 2013 than in 2007. On top of this, there is a massive increase in tax incentives and in funding from the EU budget as shown in the two previous sections, which adds up to the GBAORD data in the latter part of the period.

However, this overall development at an aggregate level takes place in different phases: after strong growth in the years before the crisis, governments of the EU Member States have maintained a positive growth trend in their GBAORD between 2008 and 2010, during the 'stimulus' period. After stabilisation in 2011, these expenditures dropped in 2012 in line with increased pressures for fiscal consolidation (the so-called 'austerity' period), and started to grow again in 2013; however, they did not regain the high level seen from 2010-2011. EU Member States, taken as a whole, face difficulties in prioritising investments in R&D as an exit to crisis strategy.

However, those fluctuations take place in a quite narrow margin, compared to the amounts that have been discussed when the other data sets were analysed above.

The EU28 GBAORD is higher in 2013 than in 2007. This evolution took place in different phases; first, continuation (after the outbreak of the financial crisis) of the trend to increase public efforts for R&D (and thus despite the crisis), then slowdown and more recently a kind of breathlessness; for the EU as a whole, seen from a GBAORD perspective only, the so-called 'smart fiscal consolidation' process seems to vanish. Public support for R&D is, however, present in a number of Member States through tax incentives and EU-level funds, which may compensate for these worrying trends.

The situation in terms of evolution of GBAORD in the EU differs from that of the main competitor countries (Figures II-2-11 and II-2-12):

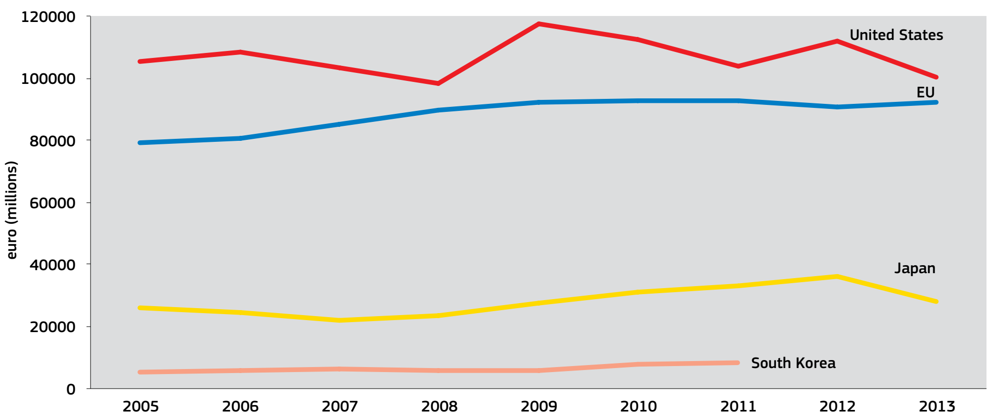
- The United States appears as a country that did not use public investments in R&D as a counter-cyclical strategy. The drop in GBAORD after 2009 is severe, as is the drop in priority placed on R&D in governmental budget. The latter share shifted from 2.65% in 2009 to 2.21% in 2012, i.e., a decrease of 16% over the period while, for the EU28, that decrease was limited to 3%. It should, however, be noted that the priority on R&D in US budgets was more than double that of the EU in 2005 (respectively, 2.75% and 1.20%) and is still much higher in the US than in the EU in 2012 (respectively, 2.21% and 1.22%).

- Japan has maintained a priority on R&D within its public investments in R&D after an initial drop in 2009. The priority placed on R&D in the Japanese governmental budget was on a downward trend since 2005 and dropped by 4% between 2008 and 2009; however, it has slightly increased since then. Japan, too, is characterised by a higher share of R&D expenses within governmental expenditures than in the EU (respectively, 1.85% and 1.22% in 2012).

- South Korea is the most striking case of a country that has (at least until 2011, the year for which the latest data are available) seen its public efforts to invest in R&D positively affected by the crisis. Both absolute values of GBAORD and their share in public budgets have increased steadily since 2008. The latter share has even reached 3.5% in 2011, a much higher ratio compared to EU28, the US and Japan, and a high 17% increase from 2008, quite the opposite trend as in the US.

Amongst the competitors, the US, Japan and South Korea, the latter is the only country that clearly placed a higher priority on R&D in governmental budgets in the wake of the crisis. The drop was most severe in the US but all three countries still place a higher priority on R&D than is the case for the EU (when GBAORD is taken as the sole indicator).

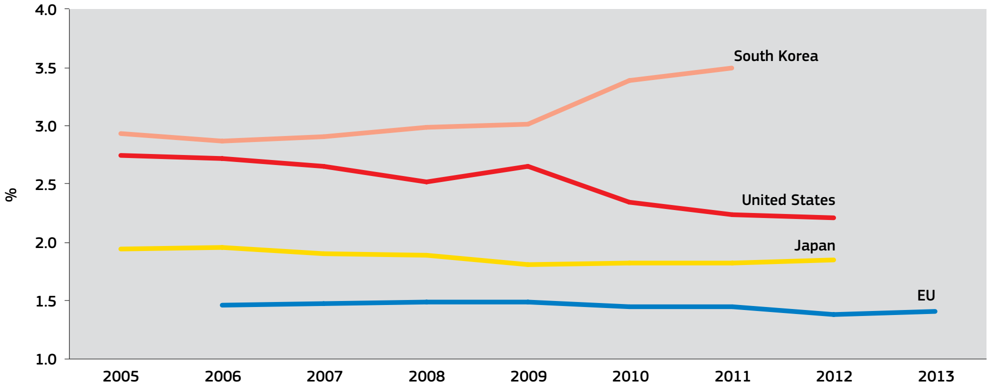
Figure II-2-11 **Total GBAORD - EU, United States, Japan and South Korea, 2005-2013**



Science, Research and Innovation performance of the EU 2016

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

Figure II-2-12 **Total GBAORD as % of general government expenditure - EU, United States, Japan and South Korea, 2005-2013**



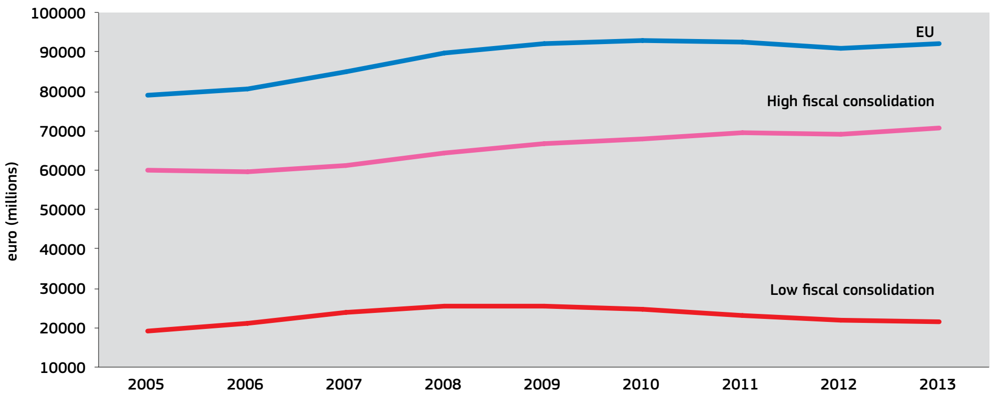
Science, Research and Innovation performance of the EU 2016
Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat

The above aggregated figures for EU28's public investments in R&D, seen from the angle of GBAORD, hide a large variation across EU Member States:

- The 15 Member States subject to high fiscal consolidation pressure [36] have experienced an important (16%) drop in their total GBAORD between 2008 and 2013, while the other countries have maintained an increase in absolute value (+ 10% over the same period, with a stable situation over 2010-2012) (Figure II-2-13). The difference between the two groups of countries is even more obvious when looking at the evolution of the share of GBAORD in their public budgets in comparison with the EU28 average (Figure II-2-14). While a process of convergence in the degree of priority placed on R&D in public budgets was at play until 2008, strong diverging trends took place between 2008 and 2010. Since 2011, a reverse trend has started, but the gap in priority on R&D between the two types of countries is still wide. It should, once more, be emphasised that these trends only concern GBAORD data; since there is a large overlap between the list of countries with high fiscal consolidation pressure and the list of countries which are large recipients of EU Structural Funds, a substitution effect may exist between the two types of public investments in some countries.

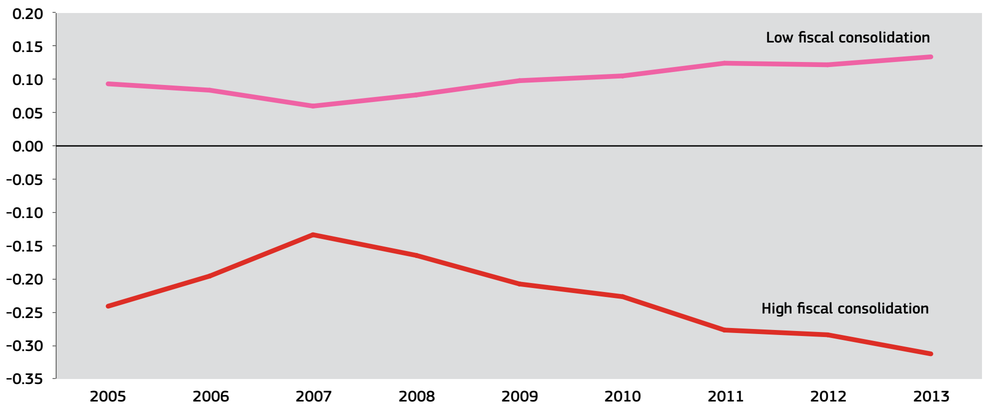
[36] Those are: LV, RO, CY, IE, HU, GR, PT, ES, BU, CZ, EE, IT, LT, PL, SK. This is based on Veugelers (2014), who defines countries with high (low) fiscal consolidation pressure as those countries with an above (below)-median cumulative change in their structural primary balance since the year in which consolidation started (the year with the lowest negative structural primary balance in the period from 2008-2010).

Figure II-2-13 **Total GBAORD for EU Member States subject to high and low fiscal consolidation pressures, 2005-2013**



Science, Research and Innovation performance of the EU 2016
Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat

Figure II-2-14 **Total GBAORD as % of general government expenditure for EU Member States subject to high and low fiscal consolidation pressures - difference with EU average, 2005-2013**



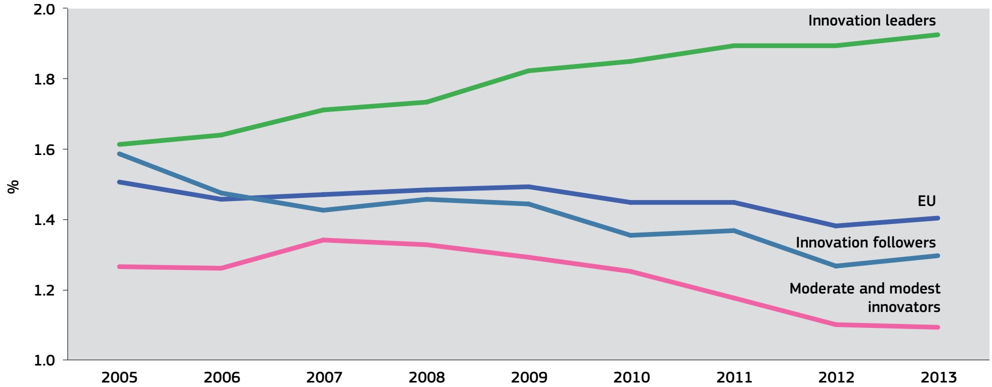
Science, Research and Innovation performance of the EU 2016
Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat

- Aggregating Member States under categories as defined by the Innovation Union Scoreboard [37], we see that the Innovation Leaders category is the only category maintaining and even increasing its priority on R&D in public expenditures over the crisis period; an improvement is taking place for Innovation Followers since 2013, the year when the priority placed on R&D in public budgets in these countries started to rise again; while the priority placed by Modest and Moderate Innovators started to stabilise between 2012 and 2013 (Figure II-2-15). A rising trend would however be needed if Modest and Moderate Innovators have to close the gap with countries with better performing research and innovation systems: data do not allow to state whether the strong increase in Structural Funds devoted to R&D is sufficient to meet this challenge.

[37] Innovation leaders: SE, DK, FI, DE. Innovation followers : SI, FR, UK, EE, CY, IE, AT, BE, NL, LU. Moderate innovators: PL, LT, HR, MT, SK, HU, GR, PT, ES, CZ, IT. Modest innovators: LV, RO, BG.

- While aggregating Member States under categories as defined by the Innovation Union Scoreboard provides a handy way to summarise trends, caution should be taken in drawing conclusions from these figures; there is also an important diversity of situations within each of those categories, as shown in Part 1, chapter 2 'Investments in R&D', with e.g., Malta and the Czech Republic, despite being 'moderate innovators' investing strongly in R&D (notably thanks to the use of Structural Funds) while others do not (such as Bulgaria and Romania); or some leaders continuing to considerably strengthen their public R&D even in recent years (e.g., Germany, Denmark), while others do not (e.g., Finland).

Figure II-2-15 **Total GBAORD as % of general government expenditure - EU Member States according to their position in the Innovation Union Scoreboard, 2005-2013**



Science, Research and Innovation performance of the EU 2016
Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat

The crisis has a larger impact on GBAORD in those countries that already invested less in R&D and had weaker innovation systems before the crisis. It is not clear whether the support from Structural Funds is sufficient to compensate for weak GBAORD investments. There is a large amount of diversity in national developments and, in fact, huge divergences inside each of the various Innovation Union Scoreboard groups of countries.

2.3 New orientations for R&D policies and structural reforms of R&I systems in the wake of the crisis

Composition of RDTI policy mixes

As mentioned at the start of the chapter, the evolution in amounts of public funding for R&D (though GBAORD, tax incentives or EU funds) is insufficient to appreciate the quality of those expenditures and their effectiveness in contributing to knowledge-based competitiveness. In this section, recent trends in R&D policies are analysed to capture changing orientations for R&D policies and structural reforms of R&I systems over the crisis period. The aim is understand trends that are not necessarily visible in, but lie behind existing indicators and data. The analysis exploits qualitative studies of policy developments, based mainly on (OECD 2014) and (European Commission 2014a). These sources rely on:

1. Surveys and questionnaires used both by OECD (the biennial STI Outlook questionnaires) and by the European Union (ERAWATCH), addressed to policy-makers for the former and to national experts for the latter;

2. Country-specific analyses, based on database of policies (in the case of the European Union, the Trendchart/ Erawatch database, and the OECD Innovation Policy Platform) and on policy assessments (European Semester and Country Specific Recommendations in the European Commission, OECD peer reviews and country analyses).

EU Member States have all incorporated R&D and innovation into their National Reform Plans, and introduced measures and policies aiming at raising effectiveness of public spending on R&D. The analysis of trends in research and innovation policies in European countries indicates that these policies are characterised by five main strategic axes, all aiming to address bottlenecks and reinforce performance of research and innovation systems, and get better results from money invested in this policy domain (Figure II-2-16).

Figure II-2-16 **Main trends in priorities for research and innovation policies in European countries**

1. Improving excellence and quality of public research and higher education
• Raising the share of performance-based funding allocations to PROs and universities and/or introducing new assessments and funding criteria reflecting research performance
• Reforming the public research base through reorganisation, mergers, etc. in view of fostering inter-disciplinary research and higher critical masses
• Reinforcing the autonomy of research institutions
• Increasing incentives for research conducted in international cooperation
• Providing better conditions and incentives for attracting international research talent
• Improving quality and relevance of higher education
2. Raising relevance and contribution of public research for society
• Focusing investments in public research on specific priorities, i.e., areas of societal relevance
• Increasing the share of cooperative research (between public and private research actors)
• Establishing and reinforcing bridging mechanisms between public and private research
3. Shift towards demand- and user-driven innovation policies
• Supporting the establishment of joint poles and clusters bringing together innovation actors in knowledge-based domains of competitive advantage (or smart specialisation)
• Public procurement for innovation
• Supporting absorptive capacities in the business sector, and particularly for SMEs
• Supporting knowledge-based start-ups and high growth enterprises
4. Improving framework conditions for innovation
• Improving finance for innovation (loans, guarantees, venture capital) and establishing close-to-market innovation funding mechanisms
• Establishing or modifying tax incentive schemes for R&D
• Improving innovation culture
5. Improving governance and strategic policy intelligence for research and innovation
• Developing practices and tools, adjusting policy cycles towards evidence-based policies
• New institutions and governance mechanisms for RDTI policy.

Science, Research and Innovation performance of the EU 2016

Source: Claire Nauwelaers

EU Member States have introduced measures and policies aiming at raising effectiveness of public spending to R&D focusing on improving excellence in public research and higher education; raising the contribution of public research for society; supporting demand- and user-driven innovation; improving framework conditions for innovation and improving governance and strategic policy intelligence for research and innovation.

All EU Member States, across all types, tend to cover all the elements of the menu for contemporary policies depicted in Figure II-2-16. However, the priority between the strategic axes and their components varies. It is not possible to measure objectively, based on budgetary data, the relative importance placed on priorities or their components: first, because some of them (e.g., those involving regulatory changes, reorganisations, changes from generic to thematic research, or changes in implementation modalities) do not translate in budgetary figures; and second, because the budgetary weights of the various elements differ due to the nature of public intervention (e.g., expenses for scientific infrastructure, where the public sector acts as the investor, are more costly than policies with a stimulus character such as cluster policies, where the role of public intervention is that of facilitator).

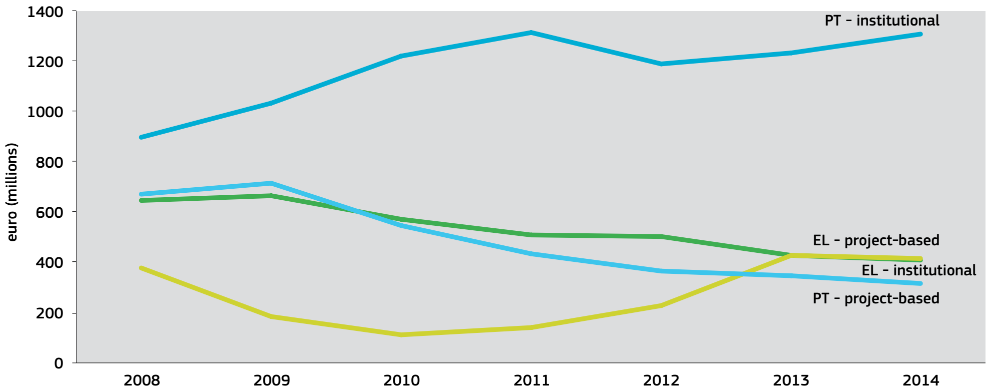
The conclusions of this overview are in line with those reached by (Izsak et al. 2014), based on an exploitation of data included in the European Inventory of Research and Innovation Policy measures. In that study, the relative presence of six types of instruments [38] has been compared across Member States, leading to the definition of five types of policy mixes. The policy mixes represent different combinations of policy orientations towards business R&D, Science or commercialisation of R&D; improvement in framework conditions; and importance of Structural funds. There is, however, no clear correspondence between the various types of policy mixes and the level of innovation performance of countries; countries at very different performance levels are classified into the same policy mix groups. The same conclusion can be drawn with respect to the severity of fiscal consolidation pressures; countries under high pressure are dispersed across all policy mix types. Also, the policy mixes display a high level of stability between the pre- and post-crisis-periods 2004-2008 and 2009-2012. A hypothesis that those Member States which are at the lower end of the innovation performance spectrum have seen their policies moving towards policies favouring absorption and diffusion of knowledge, while Members States at the higher end of the innovation spectrum would place a higher priority on knowledge creation, is not supported by this analysis either.

Institutional versus project-based funding

For a few EU countries, GBAORD data are available by funding mode, i.e., institutional funding or project-based funding. The later mode of funding is typically allocated in a competitive way. Figure II-2-17 displays the situation for two countries which are moderate innovators with high fiscal consolidation pressure. Portugal shifts towards a higher priority on institutional funding at the expense of project funding, while the reverse situation holds for Greece. Amongst countries in a more favourable situation (innovation leaders or followers with low fiscal consolidation pressure), Germany and France have a much larger part of GBAORD allocated to institutional rather than project funding, and France displays a particularly low share of project-based GBAORD (Figure II-2-18). In the Netherlands, the situation is stable, with a relatively high share of project funding compared to the two other countries. There are countries which display an unusual situation of using project-based funding more intensively than institutional funding, such as Ireland and the Czech Republic (Figure II-2-19). While as such, these differences cannot be directly interpreted in terms of effectiveness of the research funding system, they show that there is a large amount of diversity in choices made to support public and private R&D in Member States, partly reflecting the size of the public research system.

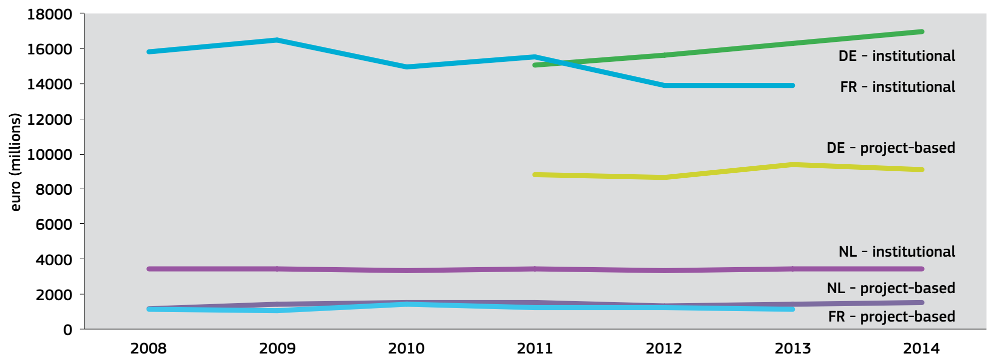
[38] The following typology of policy instruments is used in the analysis by (Izsak et al. 2014): (1) public R&D, including competitive research and centres of excellence; (2) industry-science collaboration, including collaborative research, cluster policies and competence centres where both the industry and academic sector are involved; (3) knowledge and technology transfer, including technology transfer and spin-off measures; (4) business-RDI, including direct support to business R&D and business innovation; (5) tax incentives; and (6) venture capital funds (state-backed).

Figure II-2-17 **GBAORD by funding mode (institutional or project-based) - Greece and Portugal, 2008-2014**



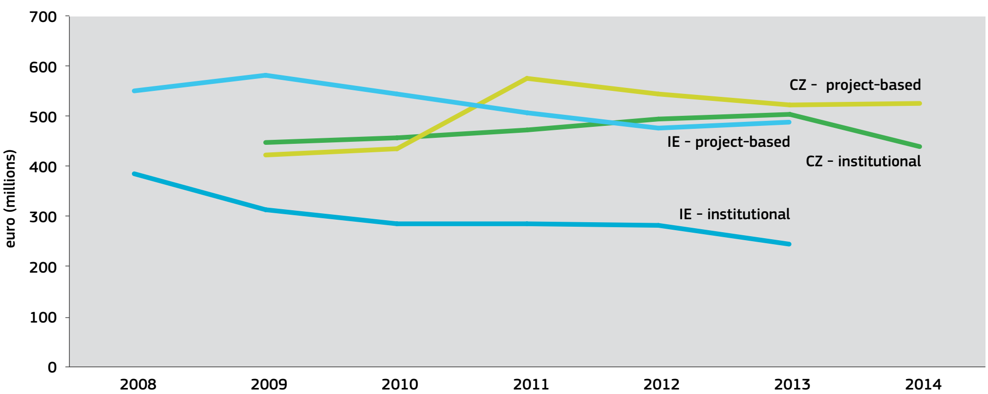
Science, Research and Innovation performance of the EU 2016
Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat

Figure II-2-18 **GBAORD by funding mode (institutional or project-based) - Germany, France and the Netherlands, 2008-2014**



Science, Research and Innovation performance of the EU 2016
Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat

Figure II-2-19 **GBAORD by funding mode (institutional or project-based) - Czech Republic and Ireland, 2008-2014**



Science, Research and Innovation performance of the EU 2016
Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat

A more detailed analysis at the country level is needed to identify the real weight of some policy trends which are present in the policy mixes (e.g., supporting absorptive capacities in SMEs can be done through anecdotal policy instruments or be included more pervasively in a range of policies), their precise configuration (similar instruments such as clusters cover very different realities in different environments), and most importantly, their effectiveness in addressing the particular bottlenecks, or boosting the best potential in research and innovation systems.

EU Member States of different types (in terms of innovation performance and severity of fiscal consolidation pressure) tend to display similarity in overall policy mixes. The devil lies in the details of concrete features as regards the relevance and effectiveness of policy mixes for improving individual research and innovation systems.

2.4 Conclusion

As a whole, the EU Members States' governments have increased their domestic expenditures on R&D (measured through the GBAORD) between 2007 and 2013. But this overall trend hides different phenomena. First, a contrasted evolution over the crisis period with an increase of such expenditures during and just after the height of the crisis, then a stabilisation, and finally an apparent difficulty for such investments to regain strength and truly act as growth-enhancing devices. Second, a huge diversity across Member States; their individual situation does not correlate well with the status of their innovation system.

But the most important argument in this paper is that, beyond those trends in domestic public funding for R&D, two important changes are taking place in this landscape, which are the increased and more widespread use of tax incentives to complement (or replace) direct support to R&D in some Member States, and an important shift in the use of Structural Funds for this purpose, which is especially important for less developed regions. Those two combined trends blur the picture given by GBAORD data only, and change the situation in many Member States that are either complementing their domestic direct funds with indirect R&D support, or making intensive use of Structural Funds for R&D, or both.

Structural Funds represent an untapped opportunity for those countries that are the largest beneficiaries of such Funds, to redress the balance in public spending in favour of RDTI. The development of smart specialisation strategies, if taken seriously, is a new opportunity to further counteract some worrying trends in public policies, especially in less advanced regions. But this would require addressing existing barriers in terms of 'strategic absorption capacity' in these Member States. This is notably the case for more complex measures (beyond bricks and mortar), which are progressively dominating the policy scene, as evidenced by the policy trends analysis in this paper.

EU funds for research also partly compensate for low public investments in R&D in a number of Member States, especially those countries which have low public expenditures on R&D. But the big amounts from the EU Research Framework programme continue to be channelled into large, old, research-intensive Member States.

Public funding for R&D, covering all the variety of forms, is necessary and important, but not sufficient. New types of policy measures which are going beyond the mere funding of research activities and capacities in a linear mode, encompass a large variety of types of interventions that are taken up by all Member States. This calls for tailor-made policy mixes. Faced with an enlarged EU menu of policies for RDTI, each Member State needs to develop its own mix, adapted to its own strengths and opportunities, and addressing its specific bottlenecks and deficiencies. Thus, the effectiveness in the use made of this public money is as important as the quantity of funds made available through direct and indirect government funding, including EU funds.

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3. Publishing and perishing — bibliometric output profiles of individual authors worldwide

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3.1 Introduction

Policymakers analyse and compare the performance of national research systems on the basis of input indicators such as total R&D expenditure, percentage of GDP spent on R&D and number of researchers, and output indicators such as the number of patents and the number of scientific publications and citations. However, without a good understanding of the relationship between these inputs and outputs policymakers are likely to make incorrect or simplistic policy choices.

Therefore, this chapter looks at the productivity of individual 'authors' in different countries using bibliometric data. The analysis confirms, on a much larger scale, previous findings which have suggested that a small proportion of scientists are responsible for producing the great majority of scientific output. For example, just 10% of authors were associated with 82% of all the publications recorded in the Scopus database from 2000-2010. An even smaller proportion of authors are associated with the great majority of highly cited publications. For example, during the same period, less than 3% of authors were associated with 82% of all the top 10% publications produced and less than 1% were associated with 74% of all the top 1% publications produced. Furthermore, the chapter provides a breakdown of the location of these authors by region and country.

Finally, the chapter examines if this output data can be linked to the data on the number of 'researchers' in different countries which are commonly used in comparative international statistics.

Policymakers need to be aware of and understand the reasons for the 'fat-tailed' distribution that we see in terms of the output and citation impact of individual researchers both between and within countries if they wish to understand and potentially improve the performance of national research systems.

3.2 Overall output and citation impact of individual authors

Many previous studies going back to the 1920s [40] have looked at the productivity of scientists. A typical finding is that less than 6% of publishing scientists produce about 50% of all papers [41]. However, many of the classic studies on this question are now rather dated and most existing studies have used small data sets of scientists from specific countries or institutions, publishing in specific fields or journals. Many previous studies have also focussed on trying to identify 'top performing scientists'.

This chapter attempts to see if these earlier results still hold using a much larger, modern data set and looks at productivity across all quantiles and not just the top. It also looks at productivity differences between authors working in different regions and countries. The aim is to help policymakers improve their understanding of research systems in order to be able to make better policies.

The average output of individual authors in terms of publications is very low but this masks a remarkable variability. The top 10% most productive authors were associated with 82% of all the publications produced during the period while 50% of authors were associated with just a single publication.

For the years 2000-2010 worldwide there

(39) Currently at Barcelona Institute of Economics

(40) The Frequency Distribution of Scientific Productivity, Lotka 1926.
(41) Little Science, Big Science. Price, 1963.

are 12.8 million distinct scientific publications recorded in the Scopus database with 9.47 million associated distinct authors [42].

Of these authors, the top 1% most productive authors (97 000 authors with 58 publications or more each) were associated with over 5 million publications or 40% of all the publications produced during the period. The top 10% most productive authors (1.07 million authors with 11 or more publications each) were associated with over 10 million publications or 82% of all the publications produced during the period. Only 2% of authors (197 000) published at least one publication in each year of the period.

In the same period, 50% of authors were associated with just a single publication, while 80% of authors (7.23 million) were associated with four or fewer publications in this period. See Figure II-3-1 below.

Figure II-3-1 **Global output of world authors**

Percentile	Number of authors	Number of publications per author	Total cumulative number of publications
99	96 876	58 and over	5 092 574
95	410 488	21 to 57	9 054 620
90	563 514	11 to 20	10 560 087
80	1 171 276	5 to 10	11 623 288
64	2 507 865	2 to 4	12 344 194
50	4 721 641	1	
Total	9 471 660		12 801 440

Science, Research and Innovation performance of the EU 2016
Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Scopus database

A relatively high proportion of authors were associated with highly cited publications. 24% of authors were associated with at least one publication in the top 10% of the most highly cited publications in the world. However, most of these authors were associated with just one such publication, while 10% of these authors were associated with 82% of all the top 10% publications produced during the period.

The expert judgment of scientists in the field is necessary to properly assess the scientific importance of a particular publication, and even then the real significance of papers may not become apparent for many years. However, the number of times a publication is cited by other publications is widely considered to be useful proxy for assessing the potential significance or impact of a particular publication or body of publications [43].

For the years 2000-2010, of the over nine million distinct authors recorded in the Scopus database worldwide, 24% (2.23 million authors) were associated with at least one publication in the top 10% of the most highly cited publications in the world (1.52 million publications). However, most of these authors were associated with just one such publication, while 10% of these authors (261 000) were associated with 82% of all the top 10% of publications produced during the period. See Figure II-3-2 below.

(42) The Scopus Author ID is known not to be perfectly accurate in terms of individual identification but is considered reliable enough to be used as a tool for bibliometrics. *Accuracy evaluation of Scopus Author ID* based on the largest funding database in Japan. Kawashima and Tomizawa, 2015.

(43) Unless otherwise stated, the analysis of citations in this chapter is based on looking at the number of citations to each publication by Scopus class in the year of publication and the three subsequent years (taking into account citations up to 2013 for 2010 publications).

Figure II-3-2 **Output of authors associated with the top 10% of highly cited publications**

Percentile	Number of authors	Number of top 10% publications per author	Total cumulative number of publications
99	22 664	33 and over	531 008
95	101 278	12 to 32	1 045 440
90	137 200	7 to 11	1 241 008
70	805 281	2 to 6	1 466 680
52	1 167 416	1	
Total	2 233 839		1 515 226

Science, Research and Innovation performance of the EU 2016
Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Scopus database

Similarly, for the years 2000-2010, while 5% of authors (476 000) were associated with at least one publication in the top 1% of most highly cited publications in the world (161 000 publications) most were associated with just one, while 10% of them (63 000) were associated with 74% of all the top 1% publications produced during the period. See Figure II-3-3 below.

Figure II-3-3 **Output of authors associated with the top 1% of highly cited publications**

Percentile	Number of authors	Number of top 1% publications per author	Total cumulative number of publications
99	4 833	18 and over	38 660
95	21 079	7 to 17	90 292
90	37 253	4 to 6	119 504
80	109 094	2 to 3	146 422
64	303 635	1	
Total	475 894		160 981

Science, Research and Innovation performance of the EU 2016
Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Scopus database

A very significant proportion of authors were associated with publications which received no citations during either the three year citation window after publication or for the whole period analysed. Almost half of all authors produced at least one publication which was not cited in the relevant citation window. 18% of authors were associated with publications which received no citations in the whole period from 2000-2013.

In contrast, around 22% of authors (2 million authors with 3.5 million associated publications) received no citations for any of their publications in the year of publication or the three subsequent years. Indeed, none of the publications of 18% of authors (1.75 million authors with 2.47 million associated publications) received any citations in the whole period from 2000-2013. Besides, almost half of all authors produced at least one publication which was not cited in the relevant citation window. See Figure II-3-4 below.

Figure II-3-4 **Authors associated with uncited publications**

Number of authors with at least one paper not cited in window	Percentage of authors with at least one paper not cited in window	Number of authors with no paper cited in window	Percentage of authors with no paper cited in window	Number of authors with no paper cited 2000-2013	Percentage of authors with no paper cited 2000-2013
4 583 920	48.40%	2 090 040	22.10%	1 745 862	18.40%

Science, Research and Innovation performance of the EU 2016
Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Scopus database

It is possible that some of these publications will go on to be cited in the future. Some papers, so called 'sleeping beauties', can lie dormant for years before experiencing a sudden spike in citations as they are discovered and recognised as important. However, this happens rarely and the rate at which papers acquire citations generally declines after an initial period of growth [44].

There is a strong correspondence between the most productive authors and the most highly cited authors.

In theory it is possible that the productivity and quality of production of individual authors is independent. It is true that some authors associated with a small number of publications or even a single publication can nonetheless be associated with highly cited or very highly cited papers. For example, around 40 000 authors were associated with a single publication and that publication was one of the top 1% most highly cited publications.

At the opposite end of the spectrum, it is also true that some of the most productive authors are not associated with any of the most highly cited publications. 23% of the top 10% most productive authors are not associated with any publications in the top 10% most highly cited.

However, in practice there is a strong, if not linear, relationship between quantity and quality of production. For example, 4 585 of the 4 833 authors (95%) in the top 1% for most highly cited publications are also in the top 1% for general productivity. Similarly, 255 918 of the 261 142 authors (98%) in the top 10% most productive in terms of top 10% most highly cited publications are also in the top 10% for general productivity.

Conversely, 92% of authors with only one publication do not have any publications in the top 10% most highly cited publications, and 83% of the authors with 10 or fewer publications have no publications in the top 10% of those most highly cited. See Figure II-3-5 below.

Figure II-3-5 **Authors by overall output and output by percentile rank class**

Number of publications by author	% of authors with number of publications in selected quantiles								
	18 and over top 1% pub	7 to 17 top 1% pub	2 to 6 top 1% pub	1 top 1% pub	at least 1 pub in top 1%	at least 1 pub in top 10% but none in top 1%	at least 1 pub in top 50% but none in top 10%	no pub in top 50%	Total
58 and over	4 585	12 925	28 504	15 775	64%	34%	3%	0.05%	96 876
21 to 57	248	7 179	57 589	63 908	31%	54%	14%	0.3%	410 488
11 to 20		902	30 834	57 685	16%	51%	32%	1%	563 514
5 to 10		73	21 550	67 946	8%	37%	49%	7%	1 171 276
2 to 4			7 870	57 690	3%	18%	53%	26%	2 507 865
1				40 631	1%	7%	36%	56%	4 721 641
Total	4 833	21 079	146 347	303 635	475 894	1 757 945	3 855 160	3 382 661	9 471 660

Science, Research and Innovation performance of the EU 2016
Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Scopus database

(44) 'Sleeping beauty' papers slumber for decades — Nature, May 2015.

In summary, at the global level there appears to be a core group of around one million 'productive authors' that were responsible for around 82% of the publications during the period from 2000-2010. Furthermore, within this group there are progressive tiers of authors with increasingly higher levels of productivity in terms of both quantity and 'quality'.

Ultimately, we find that just 97 000 authors were associated with 40% of the world's publication output. In terms of quality, just 261 000 authors were associated with 82% of all the top 10% publications and just 63 000 authors were associated with 74% of all the top 1% publications produced during the period. At the other end of the scale, a very significant majority of authors were associated with very little output and much of this output was not only not highly cited but uncited.

The next section will look at the distribution of these authors by region and country.

3.3 Overall output and citation impact of individual authors by country

It is difficult to precisely replicate the analysis above in terms of the output of authors by country because many authors have institutional affiliations in more than one country associated with their publications. Furthermore, it is the most productive authors that are more likely to have institutional affiliations in multiple countries. For example, 79% of the most productive 1% of authors and 50% of the most productive 10% of authors have institutional affiliations in more than one country during the period analysed. In addition, around 9% of authors have no institutional affiliation in the database and, in some cases, an author can have institutional affiliations in more than one country on a single publication. See Figure II-3-6 below.

Figure II-3-6 **Number of affiliated countries by author output**

Number of publications by author	Number of countries in which the author has an institutional affiliation(1)						
	0	1	2	3	4	5	> 5
58 and over	*	21%	26%	21%	13%	8%	11%
21 to 57	0.2%	43%	33%	15%	6%	2%	1%
11 to 20	0.4%	59%	29%	9%	2%	0.5%	0.3%
5 to 10	1%	73%	21%	4%	1%	0.1%	*
2 to 4	2%	86%	11%	1%	0.1%	*	*
1	6%	93%	1%	*	*	*	*

Science, Research and Innovation performance of the EU 2016
Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Scopus database
Note: (1) * = less than 0.05%.

Nonetheless, the average 'productivity' (in terms of publications recorded in the major citation databases) of authors working in different countries is shown in Figure II-3-7 below.

We can see that there are some significant differences. For example, the percentage of authors in a country which is in the top 10% most productive authors worldwide (authors with at least 11 publications from 2000 — 2010) varies from 2% in Malta to 13.7% in Italy. However, this table needs to be treated with caution, because as explained above many of the most productive authors (those with institutional affiliations in multiple countries) do not appear on this table which explains why the world average is higher than that for most countries and why the EU average is higher than that for most of the EU Member States. It also explains why the publications per author do not vary that much from the world average of 1.35.

Figure II-3-7 **Output of authors by country**

Country	Pub total (whole)	Pub total (fractional)	Author total	Pubs per author	Author at least 58 pubs (1%)	Author at least 11 pubs (10%)	% authors at least 58 pubs	% authors at least 11 pubs
Belgium	159 733	105 253	92 275	1.73	1 169	9 424	1.27	10.2
Bulgaria	24 121	16 534	15 417	1.56	29	1 193	0.19	7.7
Czech Republic	91 431	65 674	56 941	1.61	371	5 952	0.65	10.5
Denmark	115 088	75 216	64 579	1.78	587	6 471	0.91	10.0
Germany	941 459	680 563	600 543	1.57	6 388	56 729	1.06	9.4
Estonia	10 632	7 065	6 720	1.58	18	587	0.27	8.7
Ireland	54 400	36 962	35 997	1.51	170	2 686	0.47	7.5
Greece	101 620	76 162	73 096	1.39	490	7 148	0.67	9.8
Spain	416 457	316 037	330 603	1.26	2 043	30 367	0.62	9.2
France	671 406	484 566	433 177	1.55	3 762	49 317	0.87	11.4
Croatia	32 614	25 836	24 721	1.32	42	2 247	0.17	9.1
Italy	491 797	365 673	338 747	1.45	3 817	46 515	1.13	13.7
Cyprus	4 716	2 593	2 742	1.72	4	144	0.15	5.3
Latvia	4 146	2 722	3 311	1.25	4	185	0.12	5.6
Lithuania	13 088	10 062	9 058	1.44	10	601	0.11	6.6
Luxembourg	2 558	1 213	1 867	1.37	2	80	0.11	4.3
Hungary	62 333	42 175	40 799	1.53	219	3 843	0.54	9.4
Malta	1 224	774	985	1.24	0	24	0.00	2.4
Netherlands	285 254	195 510	169 658	1.68	2 163	17 442	1.27	10.3
Austria	108 163	70 202	66 846	1.62	570	6 694	0.85	10.0
Poland	201 065	154 587	118 931	1.69	710	12 743	0.60	10.7
Portugal	68 889	48 243	46 035	1.50	301	4 224	0.65	9.2
Romania	42 790	31 050	32 015	1.34	74	2 081	0.23	6.5
Slovenia	28 353	21 082	15 227	1.86	92	1 542	0.60	10.1
Slovakia	31 460	21 902	20 928	1.50	59	1 809	0.28	8.6
Finland	103 038	73 367	57 626	1.79	692	6 832	1.20	11.9
Sweden	207 981	141 129	114 897	1.81	955	11 726	0.83	10.2
United Kingdom	997 902	726 413	599 488	1.66	4 668	53 331	0.78	8.9
EU	4 508 638	3 798 565	3 004 981	1.50	30 654	348 700	1.02	11.6
Iceland	6 030	3 205	4 097	1.47	12	291	0.29	7.1
Norway	86 612	57 782	50 001	1.73	284	4 707	0.57	9.4
Switzerland	211 534	130 073	127 678	1.66	1 215	11 475	0.95	9.0
Serbia	16 105	11 191	14 067	1.14	10	919	0.07	6.5
Turkey	195 452	169 034	131 002	1.49	595	16 951	0.45	12.9
Ukraine	56 297	42 158	38 228	1.47	85	2 518	0.22	6.6
Israel	128 978	95 506	76 946	1.68	547	8 055	0.71	10.5
Russian Federation	328 775	263 624	212 043	1.55	1 217	20 648	0.57	9.7
United States	3 630 971	2 964 479	2 391 800	1.52	21 195	238 114	0.89	10.0
Japan	943 241	798 440	782 358	1.21	8 928	82 389	1.14	10.5
China	1 384 493	1 244 334	1 090 507	1.27	10 576	94 789	0.97	8.7
South Korea	289 856	239 088	225 755	1.28	2 208	23 543	0.98	10.4
India	406 411	355 507	311 680	1.30	1 453	23 854	0.47	7.7
Brazil	280 904	225 390	306 366	0.92	1 067	17 829	0.35	5.8
World	12 801 440	12 801 440	9 471 660	1.35	96 876	1 070 878	1.02	11.3

Science, Research and Innovation performance of the EU 2016
Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Scopus database

However, it is possible to look at the overall citation impact of authors with institutional affiliations in different countries. This is shown in Figure II-3-8 and II-3-9 below.

We can see that there are significant differences. For example, the percentage of authors in a country which are associated with at least one publication in the top 10% most highly cited in the world varies from 6.5% in the Ukraine to 35% in the Netherlands compared to a world average of 23.6%. Many of the EU Member States and countries associated to the Framework Programme do well on this comparison and rank above the world average. The Netherlands, Switzerland and Denmark occupy the first three positions. The US is ranked fourth, above all the larger EU Member States (Germany, UK, France and Italy) which account for the bulk of EU publications (60%), and therefore ranks higher than the EU overall. On this measure, nearly all Southern and Eastern EU Member States (EU13 plus Spain, Portugal and Greece) as well as Luxembourg rank below the world average.

In the bottom quantiles, we see that the percentage of authors in a country that received no citations in the period from 2000 — 2013 for any of their publications produced during 2000 — 2010 varies from 35.7% in Ukraine to 7.6% in Israel compared to a world average of 18.4%. On this measure, Romania, Bulgaria, Malta, Latvia, Croatia, Slovakia, Hungary and Poland are the EU Member States that rank below the world average.

One way to show both output and citation impact together is to use the I3 indicator whereby publications are weighted according to their percentile rank class [45]. Figure II-3-11 shows the publications and the I3 indicator for each country (the percentiles were categorised in six rank classes). In addition, in order to normalise this data, each country's share of world I3 is divided by its share of world publications. On this ranking, it is again the smaller Northern European countries which perform best along with the US. The Netherlands, Switzerland, Denmark, Iceland and Sweden all rank above the US on this measure. Based again on I3, this time calculated for each author in the country, Figure II-3-10 shows a visualisation of the percentage of authors in the Netherlands, the US, the EU, Japan and China by the average percentile rank class of their publications.

Figure II-3-8 Quality of production of individual authors by country (top quantiles)

First part

Country	Pub total (whole)	Pub total (fractional)	Author total
Netherlands	285 254	195 510	169 658
Switzerland	211 534	130 073	127 678
Denmark	115 088	75 216	64 579
United States	3 630 971	2 964 479	2 391 800
Sweden	207 981	141 129	114 897
Finland	103 038	73 367	57 626
Belgium	159 733	105 253	92 275
United Kingdom	997 902	726 413	599 488
Iceland	6 030	3 205	4 097
France	671 406	484 566	433 177
Germany	941 459	680 563	600 543
Italy	491 797	365 673	338 747
Norway	86 612	57 782	50 001
EU	4 508 638	3 798 565	3 004 981
Austria	108 163	70 202	66 846
Israel	128 978	95 506	76 946
Ireland	54 400	36 962	35 997
World	12 801 440	12 801 440	9 471 660
Portugal	68 889	48 243	46 035
Luxembourg	2 558	1 213	1 867
Spain	416 457	316 037	330 603
Estonia	10 632	7 065	6 720
South Korea	289 856	239 088	225 755
Greece	101 620	76 162	73 096
Cyprus	4 716	2 593	2 742
Japan	943 241	798 440	782 358
Slovenia	28 353	21 082	15 227
Hungary	62 333	42 175	40 799
Czech Republic	91 431	65 674	56 941
Turkey	195 452	169 034	131 002
Poland	201 065	154 587	118 931
India	406 411	355 507	311 680
China	1 384 493	1 244 334	1 090 507
Romania	42 790	31 050	32 015
Lithuania	13 088	10 062	9 058
Brazil	280 904	225 390	306 366
Bulgaria	24 121	16 534	15 417
Slovakia	31 460	21 902	20 928
Malta	1 224	774	985
Latvia	4 146	2 722	3 311
Croatia	32 614	25 836	24 721
Serbia	16 105	11 191	14 067
Russian Federation	328 775	263 624	212 043
Ukraine	56 297	42 158	38 228

[45] How to analyse percentile impact data meaningfully in bibliometrics. Bornmann, 2013.

Figure II-3-8 **Quality of production of individual authors by country (top quantiles)**

Second part

Country	Pub 1% (w)	Author with pub 1%	Pub 10% (w)	Author with pub 10%	Pub 50% (w)	Author with pub 50%	% authors with top 1%	% authors with top 10%
Netherlands	7 539	14 274	58 762	59 465	201 468	130 620	8.4	35.0
Switzerland	6 427	11 527	44 395	43 481	144 364	95 196	9.0	34.1
Denmark	2 951	5 392	22 650	21 891	80 767	49 232	8.3	33.9
United States	88 092	203 384	669 721	797 542	2 424 311	1 798 369	8.5	33.3
Sweden	4 303	6 922	36 019	36 507	144 549	89 503	6.0	31.8
Finland	1 938	3 399	17 010	18 204	70 945	44 667	5.9	31.6
Belgium	3 453	6 175	28 224	28 378	105 294	67 254	6.7	30.8
United Kingdom	22 283	42 120	176 560	181 507	658 217	437 770	7.0	30.3
Iceland	183	371	1 078	1 174	4 088	3 017	9.1	28.7
France	11 395	24 447	99 122	123 774	406 152	305 380	5.6	28.6
Germany	18 271	38 420	148 363	171 508	575 132	419 640	6.4	28.6
Italy	8 162	19 874	71 165	96 604	303 086	241 657	5.9	28.5
Norway	1 585	2 410	13 961	14 060	58 559	37 221	4.8	28.1
EU	65 289	171 549	615 078	822 456	2 677 873	2 087 190	5.7	27.4
Austria	2 108	3 426	17 026	18 124	67 702	47 053	5.1	27.1
Israel	2 315	3 825	19 422	20 827	83 024	57 377	5.0	27.1
Ireland	1 078	1 625	8 734	9 157	35 385	25 848	4.5	25.4
World	160 981	475 894	1 515 226	2 233 839	6 998 609	6 088 999	5.0	23.6
Portugal	966	1 509	9 260	10 241	42 874	31 225	3.3	22.2
Luxembourg	35	61	383	398	1 591	1 231	3.3	21.3
Spain	5 733	12 061	54 784	69 639	245 699	203 615	3.6	21.1
Estonia	157	211	1 337	1 409	6 389	4 755	3.1	21.0
South Korea	2 931	6 826	31 250	46 306	165 577	150 345	3.0	20.5
Greece	1 125	1 821	11 985	14 505	60 105	49 091	2.5	19.8
Cyprus	65	60	692	529	3 005	1 854	2.2	19.3
Japan	9 034	23 741	94 955	150 228	506 580	492 084	3.0	19.2
Slovenia	294	468	2 700	2 762	15 087	9 638	3.1	18.1
Hungary	750	995	6 070	6 739	31 861	23 874	2.4	16.5
Czech Republic	822	1 332	7 793	8 970	42 883	32 730	2.3	15.8
Turkey	1 070	2 848	12 634	18 903	87 072	80 195	2.2	14.4
Poland	1 442	2 144	13 195	14 668	84 214	63 287	1.8	12.3
India	2 206	4 695	27 275	38 186	175 802	159 954	1.5	12.3
China	8 257	18 677	93 118	133 013	558 038	523 354	1.7	12.2
Romania	233	1 312	2 627	3 722	17 345	15 080	4.1	11.6
Lithuania	92	106	909	1 042	6 292	5 290	1.2	11.5
Brazil	1 747	4 459	19 334	33 918	131 932	165 804	1.5	11.1
Bulgaria	139	193	1 675	1 702	10 175	7 405	1.3	11.0
Slovakia	227	344	2 018	2 177	13 026	10 444	1.6	10.4
Malta	26	21	118	101	603	517	2.1	10.3
Latvia	36	37	311	337	1 948	1 762	1.1	10.2
Croatia	213	263	1 756	2 379	12 754	13 178	1.1	9.6
Serbia	81	130	952	1 275	6 750	7 153	0.9	9.1
Russian Federation	1 597	3 413	14 812	16 876	95 695	78 531	1.6	8.0
Ukraine	176	375	2 536	2 496	18 380	14 516	1.0	6.5

Science, Research and Innovation performance of the EU 2016
Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Scopus database

Figure II-3-9 **Quality of production of individual authors by country (bottom quantiles)**

First part

Country	Pub total (whole)	Pub total (fractional)	Author total	Pub non-cited in 3y window (w)	Author with at least one pub non-cited 3y	Author non-cited in 3y window	% authors non-cited 3y
Ukraine	56 297	42 158	38 228	28 903	28 213	17 790	46.5
Russian Federation	328 775	263 624	212 043	167 191	160 707	94 141	44.4
Romania	42 790	31 050	32 015	17 281	20 255	11 495	35.9
China	1 384 493	1 244 334	1 090 507	586 167	704 927	397 112	36.4
Bulgaria	24 121	16 534	15 417	8 934	10 072	5 321	34.5
Malta	1 224	774	985	423	509	333	33.8
Latvia	4 146	2 722	3 311	1 330	1 868	1 007	30.4
Croatia	32 614	25 836	24 721	13 357	15 520	7 754	31.4
Slovakia	31 460	21 902	20 928	10 807	12 111	6 141	29.3
Serbia	16 105	11 191	14 067	4 979	7 697	3 583	25.5
India	406 411	355 507	311 680	137 165	172 133	88 190	28.3
Hungary	62 333	42 175	40 799	17 322	20 857	10 501	25.7
Poland	201 065	154 587	118 931	68 836	69 733	31 779	26.7
World	12 801 440	12 801 440	9 471 660	3 525 024	4 583 920	2 090 040	22.1
Czech Republic	91 431	65 674	56 941	27 705	29 484	13 966	24.5
Slovenia	28 353	21 082	15 227	8 522	8 181	3 706	24.3
Luxembourg	2 558	1 213	1 867	540	686	423	22.7
Lithuania	13 088	10 062	9 058	4 246	4 951	2 224	24.6
Spain	416 457	316 037	330 603	95 028	152 946	75 045	22.7
Brazil	280 904	225 390	306 366	75 811	133 831	70 502	23.0
Japan	943 241	798 440	782 358	241 579	365 723	167 221	21.4
Turkey	195 452	169 034	131 002	61 083	71 230	27 528	21.0
Germany	941 459	680 563	600 543	210 483	235 512	115 217	19.2
EU	4 508 638	3 798 565	3 004 981	1 048 059	1 317 204	601 099	20.0
Austria	108 163	70 202	66 846	22 278	26 163	12 174	18.2
Cyprus	4 716	2 593	2 742	1 025	1 049	509	18.6
France	671 406	484 566	433 177	154 152	182 275	77 700	17.9
Portugal	68 889	48 243	46 035	13 598	19 228	8 297	18.0
Greece	101 620	76 162	73 096	22 678	31 452	12 871	17.6
Italy	491 797	365 673	338 747	99 206	149 385	54 154	16.0
South Korea	289 856	239 088	225 755	65 281	96 339	38 045	16.9
Belgium	159 733	105 253	92 275	29 597	34 008	14 783	16.0
Switzerland	211 534	130 073	127 678	35 785	41 361	18 963	14.9
United Kingdom	997 902	726 413	599 488	192 163	211 979	95 366	15.9
United States	3 630 971	2 964 479	2 391 800	666 444	799 501	351 234	14.7
Ireland	54 400	36 962	35 997	9 972	12 411	5 398	15.0
Norway	86 612	57 782	50 001	13 781	16 541	7 150	14.3
Estonia	10 632	7 065	6 720	2 025	2 678	948	14.1
Netherlands	285 254	195 510	169 658	43 285	54 427	22 198	13.1
Iceland	6 030	3 205	4 097	929	1 141	545	13.3
Finland	103 038	73 367	57 626	15 904	20 337	7 504	13.0
Denmark	115 088	75 216	64 579	16 117	19 731	8 053	12.5
Sweden	207 981	141 129	114 897	29 543	35 069	13 509	11.8
Israel	128 978	95 506	76 946	23 794	26 556	9 904	12.9

Science, Research and Innovation performance of the EU 2016

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

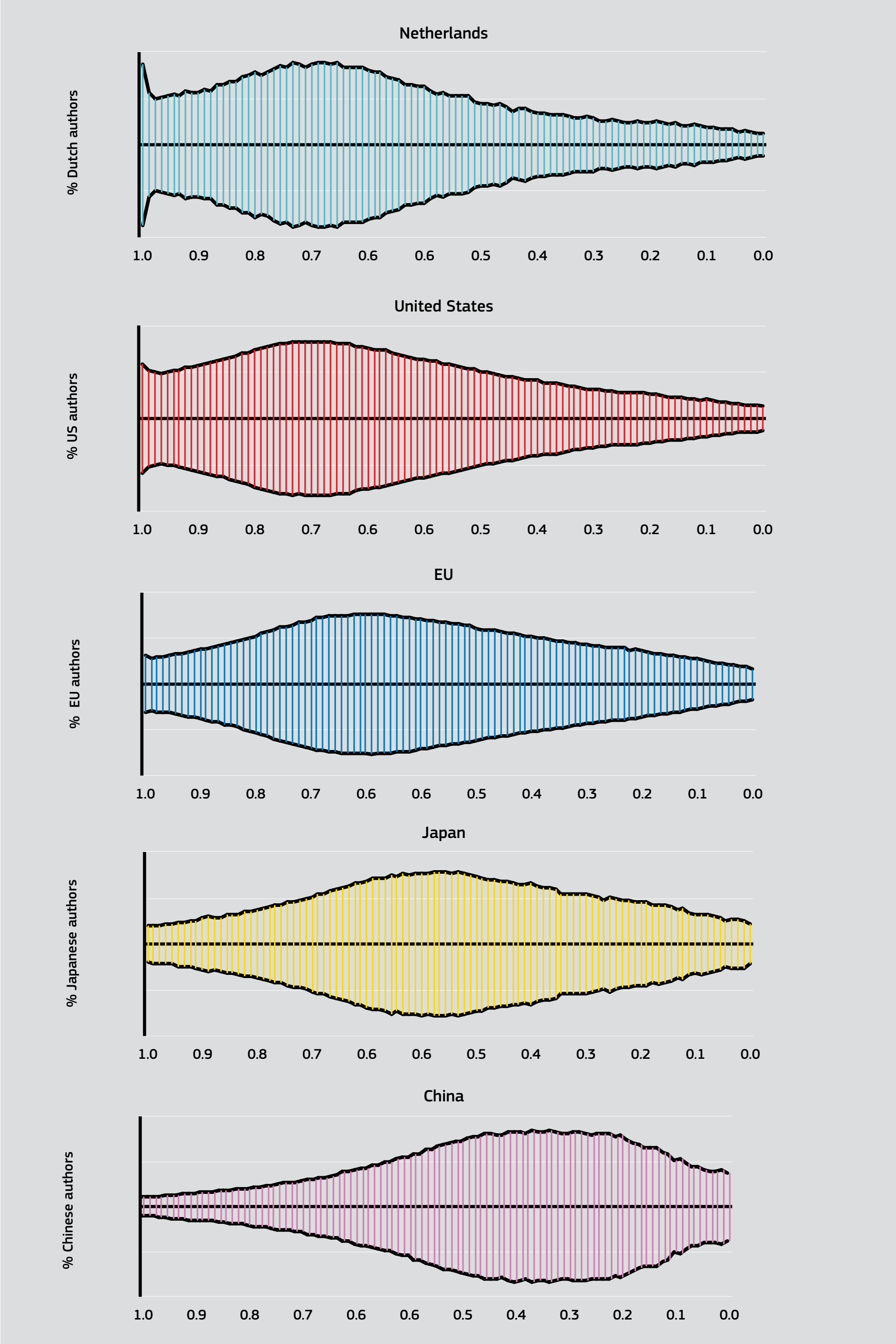
Data: Scopus database

Figure II-3-9 Quality of production of individual authors by country (bottom quantiles)

Second part

Country	Pub non-cited 2000-2013	Author non-cited 2000-2013	% authors non-cited 2000-2013
Ukraine	22 062	13 648	35.7
Russian Federation	124 427	70 796	33.4
Romania	13 764	9 583	29.9
China	451 016	317 617	29.1
Bulgaria	6 720	4 168	27.0
Malta	294	245	24.9
Latvia	977	817	24.7
Croatia	9 931	5 864	23.7
Slovakia	7 846	4 609	22.0
Serbia	3 645	2 866	20.4
India	92 819	62 084	19.9
Hungary	12 225	7 915	19.4
Poland	48 872	23 064	19.4
World	2 466 083	1 745 862	18.4
Czech Republic	20 124	10 373	18.2
Slovenia	5 995	2 751	18.1
Luxembourg	401	334	17.9
Lithuania	3 070	1 619	17.9
Spain	65 484	54 769	16.6
Brazil	47 027	46 056	15.0
Japan	167 002	117 322	15.0
Turkey	40 129	19 270	14.7
Germany	154 400	87 951	14.6
EU	724 775	433 024	14.4
Austria	15 678	8 885	13.3
Cyprus	661	359	13.1
France	107 303	55 380	12.8
Portugal	8 835	5 776	12.5
Greece	14 524	8 780	12.0
Italy	67 036	38 850	11.5
South Korea	42 329	25 623	11.3
Belgium	20 086	10 454	11.3
Switzerland	25 118	13 782	10.8
United Kingdom	122 716	63 316	10.6
United States	429 832	234 322	9.8
Ireland	6 227	3 502	9.7
Norway	8 448	4 699	9.4
Estonia	1 254	628	9.3
Netherlands	28 546	15 269	9.0
Iceland	609	358	8.7
Finland	9 783	5 028	8.7
Denmark	10 119	5 470	8.5
Sweden	18 061	8 743	7.6
Israel	13 682	5 835	7.6

Figure II-3-10 **Percentage of authors by average percentile rank class of publications**



Science, Research and Innovation performance of the EU 2016
Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Scopus database

Figure II-3-11 **Publication output of countries weighted by percentile rank class**

Country	Pub total (whole)	Pub total (fractional)	Ratio pub to World (whole)	I3 (PR6)	Ratio I3 (PR6) to World	Ratio I3 / Ratio pub
Netherlands	285 254	195 510	0.022	118 198	0.027	1.23
Switzerland	211 534	130 073	0.017	86 983	0.020	1.22
Denmark	115 088	75 216	0.009	47 075	0.011	1.21
Iceland	6 030	3 205	0.000	2 397	0.001	1.18
Sweden	207 981	141 129	0.016	82 377	0.019	1.17
United States	3 630 971	2 964 479	0.284	1 435 778	0.333	1.17
Finland	103 038	73 367	0.008	40 305	0.009	1.16
Belgium	159 733	105 253	0.012	62 329	0.014	1.16
United Kingdom	997 902	726 413	0.078	389 352	0.090	1.16
Norway	86 612	57 782	0.007	33 471	0.008	1.15
Ireland	54 400	36 962	0.004	20 658	0.005	1.13
Israel	128 978	95 506	0.010	48 222	0.011	1.11
Austria	108 163	70 202	0.008	40 336	0.009	1.11
Luxembourg	2 558	1 213	0.000	949	0.000	1.10
Germany	941 459	680 563	0.074	348 372	0.081	1.10
Cyprus	4 716	2 593	0.000	1 743	0.000	1.10
Italy	491 797	365 673	0.038	179 675	0.042	1.08
France	671 406	484 566	0.052	244 525	0.057	1.08
Portugal	68 889	48 243	0.005	24 913	0.006	1.07
EU	4 508 638	3 798 565	0.352	1 606 099	0.372	1.06
Spain	416 457	316 037	0.033	146 994	0.034	1.05
Estonia	10 632	7 065	0.001	3 747	0.001	1.05
Greece	101 620	76 162	0.008	35 229	0.008	1.03
South Korea	289 856	239 088	0.023	97 759	0.023	1.00
Japan	943 241	798 440	0.074	307 743	0.071	0.97
Slovenia	28 353	21 082	0.002	9 170	0.002	0.96
Hungary	62 333	42 175	0.005	19 950	0.005	0.95
Malta	1 224	774	0.000	389	0.000	0.94
Czech Republic	91 431	65 674	0.007	27 850	0.006	0.90
Lithuania	13 088	10 062	0.001	3 923	0.001	0.89
Latvia	4 146	2 722	0.000	1 242	0.000	0.89
Brazil	280 904	225 390	0.022	83 124	0.019	0.88
Turkey	195 452	169 034	0.015	56 413	0.013	0.86
India	406 411	355 507	0.032	116 904	0.027	0.85
Bulgaria	24 121	16 534	0.002	6 933	0.002	0.85
Poland	201 065	154 587	0.016	57 136	0.013	0.84
Slovakia	31 460	21 902	0.002	8 891	0.002	0.84
China	1 384 493	1 244 334	0.108	389 245	0.090	0.83
Serbia	16 105	11 191	0.001	4 502	0.001	0.83
Romania	42 790	31 050	0.003	11 684	0.003	0.82
Croatia	32 614	25 836	0.003	8 881	0.002	0.81
Ukraine	56 297	42 158	0.004	14 342	0.003	0.76
Russian Federation	328 775	263 624	0.026	81 355	0.019	0.73

Science, Research and Innovation performance of the EU 2016
Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Scopus database

3.4 What is the overlap between authors and researchers counted in international statistics?

The analysis in this chapter has been based on the 'authors' recorded in Scopus. However, international comparative statistics are usually based on the number of full time equivalent (FTE) 'researchers' based in a country. One might expect that these two groups would overlap significantly. This is, after all, the assumption behind using scientific publications and citations as an output of a country's researchers. However, as we will see below, there is likely to be little overlap between 'authors' and 'researchers'.

Based on the definitions used by the major international statistical bodies, there are considered to be over seven million full time equivalent researchers in the world [46]. What is their relationship with the 9.47 million distinct authors recorded worldwide in the Scopus database from 2000 — 2010?

The term 'researcher' covers many different roles and activities.

The term 'researcher' covers many different roles and activities. From university academics and scientists engaged in long-term basic research at large research infrastructures to more mission-orientated researchers at government labs, from corporate employees carrying out market-orientated development work to the staff of high-tech SMEs pursuing technology transfer or product and process innovation.

In order to understand the scientific production of countries it is necessary to try to identify a core group of researchers that might be expected to produce scientific publications.

Firstly, we know that overall most researchers are in the private sector and that scientific publications are typically produced by public sector researchers.

For the OECD countries as a whole, 60% of researchers were in the business enterprise sector in 2011, although the percentage does vary considerably by country [47].

In 2012 in the US, 14% of all publications were produced by industry and the private non-profit sector while 76% were produced by the academic sector. The rest were produced by the federal government, Federally Funded Research and Development Centers, and state and local governments [48].

In 2005, midway through the period under consideration, there were 733 000 public sector researchers FTE in the EU [49]. In the same year, there were 320 600 scientific publications recorded in the Scopus database (28% of the world total) with associated EU authors.

In the same year, there were 278 000 public sector researchers in the US and there were 268 800 scientific publications recorded in the Scopus database with associated US authors.

We can therefore see that even public sector researchers as a whole are not on average very prolific in terms of producing publications.

The public sector itself is very diverse.

However, the public sector itself is very diverse. Public research is, broadly speaking, performed in either Higher Education Institutions (HEIs) or Public Research-performing Organisations (PROs) and both of these sectors contain a very diverse range of institutions of different sizes, budgets and missions.

The main mission of HEIs is, of course, to teach, with some also carrying out research. In certain systems such as the US, the UK and Switzerland HEIs are differentiated between institutions that largely have a teaching role and those with a greater research focus, and most public research is performed at a relatively small number of research-intensive HEIs. For example, in the UK 15% of HEIs (the 24 Russell Group

(46) Researchers FTE in 2007. Unesco Science Report 2010.

(47) Main Science and Technology Indicators 2014, OECD.

(48) Science and Engineering Indicators 2014, NSF.

(49) IUCR 2013 Introduction, EC.

universities) receive 74% of UK universities' research grant and contract income and award 60% of doctorates (50). In other systems HEIs are relatively undifferentiated and a higher proportion of public research is performed in dedicated PROs.

Europe has around 3 000 HEIs, of which 1 400 are research-active (47%), and 171 in 21 countries are highly research-intensive (6%) in terms of scientific production (51). In 2012, around 40% of EU researchers were in the Higher Education sector (52). By contrast, out of around 3 300 degree-awarding bodies in the US (which comprise a broader range of institutions than the European universities), only about 215 award postgraduate degrees. There are also fewer than 100 recognised research intensive universities in the US (53). The bulk of R&D expenditures in the United States are concentrated among this small number of research-intensive institutions, and the extent of this concentration has remained very consistent over the last two decades, even as the identity of the institutions in the top groups has changed. In Financial Year 2012, the top 10 institutions in terms of R&D performance accounted for 18.0% (18.8% in FY 1989), the top 20 for 30.6% (32.5%), and the top 100 for 78.8% (82.0%) (54).

PROs can be classified as scientific research institutes, government laboratories, or Research and Technology Organisations (RTOs). The former are mainly associated with basic research while the latter mainly carry out applied research and technical development. Government laboratories engage in technical norms, standardisation or metrology, testing or other specific missions and duties.

There are around 150 large PROs in Europe with over 50 researchers or 100 affiliated staff members (55) such as the Max Planck Institutes in Germany, the CNRS in France, CNR in Italy and CSIC in Spain, as well as large parts of the Science Academies in Central and Eastern European countries. In 2012, around 12% of EU researchers were in the Government sector (56).

The proportion of public research performed in HEIs and PROs is an important differentiating feature of national research systems. For example, in 2011 around 36% of the public sector researchers in Germany were in the Government sector (54 000 compared to 94 000 in the Higher Education sector). 27% of public sector researchers in France were in the Government sector, 30% in Italy, 27% in Spain and 26% in Poland. In contrast, Switzerland had just 2% of public sector researchers in the Government sector and the UK had 5%. Equivalent figures are not available for the US but less than 5% of total US researchers were in the Government sector in 2000 (57).

Comprehensive data on the main activities and tasks of researchers working at PROs is not available. However, in 2007, 54% of the researchers working for PROs in the Government sector in Germany worked for institutions with basic research as one of their main activities and tasks (the Max Planck Institutes and the Helmholz and Leibniz Associations) (58). The other PROs in Germany, the Federal, regional and local research establishments and also the Fraunhofer Association did carry out some basic research but were more orientated towards applied research, technology transfer to enterprises, consultancy to public authorities and other roles.

The publishing practices in different scientific disciplines, especially in the social sciences and humanities, are also very different.

It is also well known that the publishing practices in different scientific disciplines are very different. In particular, the social sciences and humanities produce a greater proportion of scientific publications that are not journal articles, and have a greater tendency to publish in languages other than English and in journals with a national, rather than international, distribution. This means that the output of social sciences and humanities

(50) Russell Group Profile October 2014.
(51) IUCR 2011 Part II Chapter 1, EC.
(52) Main Science and Technology Indicators 2014, OECD.
(53) Developing a knowledge flagship: the European Institute of Technology, EC 2006.
(54) Science and Engineering Indicators 2014, NSF.
(55) IUCR 2011 Part II Chapter 1.
(56) Main Science and Technology Indicators 2014, OECD.
(57) Main Science and Technology Indicators 2014, OECD.
(58) IUCR 2011 Part II Chapter 1.

scholars will be highly underrepresented in the major citation databases.

The number of FTE researchers broken down by field of science is available for some countries. For example, in Germany in 2005 29% of researchers in the HE sector were classified as being in the field of social sciences or humanities [59]. For Italy, Spain, Poland, Romania, Sweden and Denmark the figures were, respectively, 35%, 40%, 34%, 11%, 23%, and 32%.

For the same year in Germany, 14% of researchers in the Government sector were classified as being in the field of social sciences or humanities [60]. For Italy, Spain, Poland, Romania, and Denmark the figures were, respectively, 14%, 9%, 10%, 34%, and 21%.

The core group of researchers that might be expected to produce scientific publications is likely to be around a quarter of the overall number of researchers.

Based on the considerations above, we should therefore expect that only a small proportion of the seven million total researchers in the world will be producing a large proportion of all the publications which are recorded in the major citation databases. The primary 'publication active' researchers will be those public sector researchers working at the research active HEIs and those PROs with basic research as a main task or activity. This proportion could be around 25% of the total number of researchers and this could help explain why a small proportion of authors is associated with the vast majority of the publications recorded in Scopus in the period from 2000 — 2010 (1.07 million authors with 11 or more publications over the period and another 1.17 million authors with five or more).

The first lesson from the discussion above is that policymakers should be careful when talking about 'research' and 'researchers' in general terms and they should not look at publications as the output of national research systems. The publications recorded in the major citation databases and the knowledge embedded in them are produced by a relatively small sub-set of researchers working at a specific sub-set of research institutions.

This is not to say that the many researchers who are not associated with many, or any, of these recorded publications are not productive. Rather they are engaged in different types of activity (including, for many of them, teaching) which need to be assessed in different ways and with different metrics.

3.5 Conclusions

This analysis confirms previous findings but uses a much larger, and up to date, set of data. The production of individual authors in terms of publications recorded in the major citation databases is extremely varied and that production also varies greatly in terms of its impact and significance as measured by citations.

This analysis confirms many previous findings. The output of individual authors in terms of publications recorded in the major citation databases is extremely varied. Indeed, the productivity of individual authors seems to follow something like an inverse square law. This analysis also confirms that production varies greatly in terms of its impact and significance as measured by citations. Previous studies have also shown that the proportion of the scientific workforce that maintains a continuous uninterrupted stream of publications each and every year over many years is very limited [61]. Furthermore, the citation impact of the publications produced by researchers in different countries has been shown to be highly variable [62].

At first glance, the very large differences that exist in output and citation impact between individuals, the low overall productivity of authors, and the very significant tail of uncited publications and authors may seem surprising or disappointing. Scientific publications report the findings of original experimental and theoretical work in appropriate scientific journals. Furthermore, the publication of the results of research is an

[59] Science, technology and innovation in Europe 2009, Eurostat.

[60] Science, technology and innovation in Europe 2009, Eurostat.

[61] 'Estimates of the Continuously Publishing Core in the Scientific Workforce' Ioannidis et al. 2014.

[62] 'The European Union, China, and the United States in the top-1% and top-10% layers of most-frequently cited publications: Competition and collaborations.' Bornman et al. 2014.

essential part of the scientific method and has been since the birth of modern science.

However, it is likely that many of the recorded authors were never involved in research as their main activity or were involved only for a brief period, and thus contributed only on an ad hoc basis to a single publication or a small number of publications. It is also the case that the number of authors per publication has been steadily increasing, going from 2.48 in 1981 to 5 in 2012 [(63)]. In particular, we know that 'the majority of people undertaking a PhD will end up in careers outside scientific research' in the long-term [(64)].

It is also the case that, by definition, researchers are looking to discover new facts about the phenomenon they choose to explore. There is no guarantee beforehand that they will be able to do this or, even if they do, that their results will be of significance or interest to other researchers. If two researchers of equal talent set out to explore two different areas it may be that one of those areas will turn out to be productive in terms of publishable results and the other might not.

One obvious way to explain the very large differences in output and citation impact between individuals would be to suggest that some researchers are naturally more productive than others because of their talent. This intuition could be said to be behind the policy of concentrating research funding on an elite group of the most productive (or 'excellent') researchers or institutions.

A further implication of this model is that the effect of simply increasing the amount of research funding and the number of researchers would not necessarily be positive. There may be a diminishing rate of return which sets in as more, less productive, researchers start to be funded.

Scientific research looking into the determinants of research productivity has not been abundant, but is gradually receiving more attention [(65)]. However, we can readily see that the very large differences in productivity and quality between researchers in different countries cannot be explained by the distribution of natural talent (even if we take into account that some systems are able to attract significant numbers of talented researchers from abroad) [(66)]. Therefore, the institutional frameworks in which researchers operate and, in particular, the levels of funding are likely to be highly significant in determining these differences.

Further criticism of the 'excellence' model comes from those who believe that scientific productivity is subject to accumulated advantage [(67)], or the 'Mathew effect' [(68)], whereby small initial differences between researchers in talent, networks or, indeed, luck can turn into very large differences in terms of funding, recognition, publications, citations, prizes and high profile roles received by researchers over the course of a career as 'the rich become richer' (some studies estimate that there might indeed be such an effect but that it is relatively small) [(69)].

This second view implies that opportunities to develop an independent research programme and research funding should be more evenly distributed (in particular to researchers in the early stages of their careers) and that more emphasis should be paid to qualitative over quantitative measures of research output.

In conclusion, countries and institutions that wish to improve their level of scientific production will need to ensure the right institutional framework and an adequate level of funding. However, given that the resources which any society is willing to devote to research will be limited, it is also clear that measures to select and attract the most productive researchers are likely to be a key part of any framework.

(63) Single-Author Papers. Science Watch 2013.
(64) The Scientific Century, Royal Society 2010.
(65) The Great Divide in Scientific Productivity. Why the Average Scientist Does Not Exist. Kelchtermans and Veugelers, 2008.

(66) In Switzerland and the UK, more than four out of ten doctoral students are international students. A number of other countries, including New Zealand, Australia, the United States, Ireland, Sweden, and Canada, have relatively high percentages (more than 20%) of doctoral students who are internationally mobile. Education at a Glance: 2012. OECD.
(67) The Economics of Science. Stephan, 1996.
(68) The Matthew Effect in Science. Merton 1968.
(69) Matthew: Effect or Fable? Azoulay et al. December 2012.

4. The role of well-designed framework conditions for business investment in R&I

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4.1 Introduction

As emphasised in the European Commission's Investment Plan for Europe [70], a key priority at the current economic juncture is to implement the necessary structural reforms that promote investment as an engine of productivity, growth, and a source of productive jobs.

In line with this, in addition to the creation of a new European Fund for Strategic Investment (EFSI) and the establishment of a pool of viable projects, the Investment Plan proposes an ambitious roadmap for removing regulatory barriers to investment [71]. Clearly, this involves taking actions to boost structural reforms both at EU and country level, with the aim to improve the functioning of labour and product markets and the framework conditions in which economic actors operate. The idea behind this is that providing greater regulatory predictability, removing barriers to investment across Europe and further reinforcing the Single Market, i.e., creating optimal framework conditions, will unlock the full potential of investments in Europe.

This also applies to business investments in R&D; taking measures to leverage private investment favouring supportive framework conditions may unlock their full potential. In fact, the efficacy of the wider innovation system often hinges upon the quality of framework conditions and the capacity to ensure an innovation-friendly environment in both more and less R&D intensive parts of the economy.

EU business R&D investment is still far away from the target set in the 2012 Barcelona council (2/3 of the EU2020 target of 3% should be represented by private investment in R&D), and lags significantly behind the US. In addition, since the crisis started, this EU-US gap in business R&D has increased; in 2008, EU business expenditures in R&D represented almost 80% of the US expenditures, but in 2012 (the latest year for which data on the US are available) this value is 69.4%. In terms of business R&D intensity, the EU-US gap in 2012 is 1.29% versus 1.96%.

Moreover, cross-country heterogeneity in BERD intensities among Member States is high and, although sectoral differences among them partly contribute to explain it, tends to persist even after controlling for MSs' sectoral specialisation. This means that there are Member States that, *ceteris paribus*, present a lower level of private investment in R&D than others (and *vice versa*) irrespective of their structural characteristics. What is more problematic, since the mid-1990s the rate of return-to-R&D of firms from European countries has been generally lower than that of their US counterparts (Hall et al., 2009). Both intensity of investment and its efficiency are thus lower.

Remaining cross-country heterogeneity in BERD intensities could be then explained by differences in business environments that, combined with different conditions to accessing finance, differences in human capital and skills availability, market potential and other demand-side bottlenecks, prevent private R&D investments in the EU from increasing and converging towards similar intensities and, more specifically, toward the target set during the aforementioned 2012 Barcelona council.

Therefore, in the following, the focus will be on the role and likely impact of (product and labour) market regulation, red tape barriers, judicial and insolvency frameworks and access to finance

[70] http://ec.europa.eu/priorities/jobs-growth-investment/plan/index_en.htm

[71] Among the priorities of the 2015 Work Programme, the European Commission is committed to lightening the regulatory load while keeping high levels of social, health and environmental protection and consumer choice, cutting unnecessary red tape or administrative burdens, while at the same time bringing the benefits that citizens expect. The EC proposes measures to further deepen the Single Market for goods and services, and to develop a truly connected Digital Single Market.

on business investments in R&D. The first four framework condition aspects, when investments in R&D are considered, tend to be less emphasised than those related to skills availability, IPR regimes and access to finance, which are more commonly discussed when considering the conditions for efficient R&D systems.

Clearly, this is not to say that emphasising the role of human resources and skills for innovation are not as important, but simply that this chapter focuses on a different narrative. It has been shown that skills availability and mismatch is still a key bottleneck in some MSs. In addition to generating new knowledge, higher skill levels raise economies' absorptive capacity and ability to perform incremental innovation (Toner, 2007). Human capital can also contribute indirectly to innovation through the *spillovers* generated by skilled workers, who diffuse their knowledge throughout their workplace and the wider environment and spur faster accumulation of human capital by other workers through their interactions. In this regard, what this chapter aims to do, for instance, is stress that in the presence of stringent employment protection legislation, this reallocation of resources may be less efficient, harming the most innovative and productive firms and sectors, which would need these resources to undertake their innovative projects and grow.

In a nutshell, the analysis shows that framework conditions for business R&D vary considerably across European countries and confirm the room for policy action; the need for the completion of the Single market, harmonisation, and further reform efforts appear rather obvious.

The rest of the chapter is organised as follows. Section 1 briefly explains why well designed framework policies may enhance business investment in R&D and innovation. Section 2 presents the available empirical evidence on business dynamics in the EU and highlights the main trends in (product and labour) market regulation, judicial and insolvency efficiency and access to finance. Section 3 uses the narrative developed in previous sections to interpret the well-known EU low adoption of ICT in services. Section 4 presents the conclusion.

4.2 Why do well designed framework policies allow productive and innovative firms to thrive?

Economic theory suggests that structural reforms and improvements in institutional quality can lead to better resource allocation and greater productive capacity, foster catch-up, and encourage entrepreneurship and innovation. In line with this, factors affecting the ease of entry to, and exit from, a market and growth such as the level of product and labour market regulation, bankruptcy laws and the efficiency of the judicial system and access to finance, all deeply affect firms' strategic behaviour, investment choices, productivity and growth prospects.

The removal of entry and other regulatory barriers favours the entry of new, young firms in protected sectors. This entails the reduction of excessive rents and provides incumbents with incentives to make their production processes more efficient (*see*, among others, Nicoletti and Scarpetta, 2003; Syverson, 2011; Christiansen, Schindler, and Tressel, 2013; OECD, 2013; Prati, Onorato, and Papageorgiou, 2013; Restuccia and Rogerson, 2013; EC, 2014). Gains from more efficient production and increases in firm-level productivity in the liberalised sectors would, in turn, spread throughout the economy, due to the role of these sectors in providing intermediate inputs to other sectors (OECD, 2015; Ciriaci et al., 2015; EC, 2014; Canton et al., 2014). Concurrently, bankruptcy legislation and judicial efficiency shape the exit margin, further facilitating the reallocation of resources towards the most efficient firms, which is further enhanced in the presence of efficient employment protection legislation.

In particular, the link between product market regulations (PMR) and innovation has to be found in the fact that reforms to PMR, especially those reducing entry barriers, can spur innovation via: i) more entry, as young firms have a comparative advantage in radical innovation and more entry may pressure incumbents to innovate [72]; ii) greater market discipline, which improves management performance and scope for technology adoption;

(72) The nature of this effect will vary with a firm's distance to the frontier (Aghion and Griffith, 2005).

and iii) easier and cheaper access to inputs, which, because of easier reallocation, raises the returns to investment in knowledge-based capital such as investment in R&D, innovation and technology development, training and education of workers, internal organisation structures, customer and institutional networks, marketing, and software and information technology. Therefore, reforms aiming at increasing business dynamics via the entry (but also the exit) channel may contribute to stronger market selection and post-entry growth, thereby enhancing the ability of firms to achieve sufficient scale to enter global markets. However, as suggested by Aghion et al. (2002), although competition may increase the incremental profit from innovating, it may also reduce innovation incentives for laggards. That is why, according to the authors, the relationship between product market competition and innovation has an inverted U-shape [73]. Competition may increase the incremental profits from innovating (thereby encouraging R&D investments aimed at 'escaping competition') and it will do so to a larger extent in industries in which oligopolistic firms face more similar production costs (in the so-called 'neck-and-neck' industries) [74].

In addition, for economies to thrive on innovation, labour needs to be reallocated within and across firms and sectors as labour may not be initially efficiently allocated and/or labour-saving technologies, that may generate temporary unemployment, may be introduced. In these cases, a stringent employment protection legislation (EPL) may hinder the redirection of resources towards their most productive uses and, hence, productivity growth and impede on a quicker match of labour supply and demand. According to the OECD, EPL reduces R&D expenditure, hampering firms engaging in innovations and needing skilled personnel and complementary resources to implement and commercialise them (Andrews and Criscuolo, 2013). Not surprisingly, the Global Competitiveness Report (World Economic Forum, 2014) ranks restrictive labour regulations (which include EPL) as not necessarily being the most problematic factor for engaging in business; 22.7% of respondents cite restrictive labour regulations and 18.6% cite an inadequately educated workforce; 12% cite an inefficient government bureaucracy (12.0%).

At the same time, bankruptcy regimes can foster experimentation with risky technologies if they do not sanction business failure too much. In this regard, while almost all Member States have formal in-court restructuring proceedings, the options of informal and/or hybrid restructuring are limited in many cases (Ciriaci et al., 2015). This scarce availability of less costly out-of-court procedures is a problem, particularly for smaller companies, given that the costs of legal proceedings are to some extent fixed and, in many cases, not affordable. This incomplete insolvency framework may push some solvent firms in (actual or foreseen) financial difficulties, into formal insolvency proceedings and, ultimately, premature liquidation. This leads in turn to the closure of potentially viable firms, creating financial and non-financial losses (including avoidable job destruction), borne by firms' creditors, shareholders, employees, and public authorities across the EU. In line with these arguments, the OECD (2015) stresses that lowering the cost to close a business increases the ability of economies to learn from new innovation at the technology frontier and the size of national frontier firms.

The incentive to invest in innovation will also be affected by the efficiency of the judicial system (EC, 2014; Lorenzani and Lucidi, 2014). A well-functioning civil justice system that guarantees legal certainty and proper contract enforcement is mostly relevant for innovative firms given the higher than average risk generally associated with investment in R&D and given the importance, in such a field, of copyright protection and intellectual property rights. Reforms such as rationalising the organisation of courts, fostering investment in in-court ICT, and introducing incentives to reduce excessive litigation rates (for instance by enhancing the use of alternative dispute resolution methods), are all found to positively affect the efficiency of

[73] The economic model developed by the authors also suggests that (i) the equilibrium degree of technological neck-and-neckness among firms should decrease with product market reforms, (ii) the higher the average degree of neck-and-neckness in an industry, the steeper the inverted-U relationship and that (iii) firms may innovate more if subject to higher debt-pressure, especially at lower levels of product market reforms.

[74] A firm with lower unit costs is referred to as the technological leader in the corresponding industry, and when both firms have the same unit costs they are referred to as neck-and-neck firms. See Aghion et al. (2002).

civil justice and, through it, to enhance entry rates and favour the exit of less successful firms, the resources of which can be then reallocated among surviving firms.

It is also worth noting that the World Economic Forum (2014) includes an indicator of perceived judicial independence among its competitiveness indicators. Well-functioning judiciaries could guarantee security of property rights and contract enforcement, in turn reinforcing economic agents' incentives to save and invest, as well as entrepreneurship in a broader sense, not least by dissuading opportunistic behaviour and reducing transaction costs. This is likely to promote competition, innovation, and growth (Lorenzani and Lucidi, 2014).

In addition, it is the existence of a competitive market that allows translating process innovation, mismatch lower unit labour costs of production, into lower output prices (Bogliacino and Vivarelli, 2012). This decrease in output prices, however, is not the end of the process. On the one hand, lower prices encourage additional demand for products, additional production and, henceforth, higher employment. However, given that this price effect is not immediate, in the period between the observed decrease in production costs and the resulting fall in prices, excess profits and excess income may be accumulated. Whereas excess profits may be invested, excess income may result in higher consumption, and hence higher employment, or the so-called income effect (Freeman et al., 1982; Freeman and Soete, 1987; Katsoulacos, 1986). On the other hand, as the effect of innovation might not always be job-friendly, competitive labour and product markets might favour a quicker reallocation of labour resources among firms and across sectors, reducing a possible negative impact of innovation on employment and/or favouring and helping to reduce the mismatch between labour demand and supply [75].

[75] This view is also supported, for instance, by the EC (2013) that emphasized that, among the factors discouraging firms from investing in R&D and other intangible assets, a 'difficult to understand' regulatory framework is one of the main bottlenecks, along with the high cost of the investment and the limited public financial support for them, and an unfavourable tax treatment. EC (2013), Flash Eurobarometer 369, Investing in Intangibles: Economic Assets and Innovation Drivers for Growth.

4.3 Business environment for R&I: anticompetitive market regulations and red tape barriers have pervasive effects

If we adapt the context of R&I investment to President Juncker's political guidelines — according to which jobs, growth and investment will only return to Europe if we create the right regulatory environment and promote a climate of entrepreneurship and job creation — this implies an environment where:

(i) competition increases the supply of new ideas and incentivises frontier firms to innovate and produce new technology and non-frontier firms to catch-up;

(ii) well-functioning markets diffuse and facilitate its wider adoption;

(iii) resources are rapidly reallocated from less efficient and failing firms to more efficient and growing ones;

(iv) there are financial incentives for entrepreneurs to undertake risky projects.

Unfortunately, only a very limited number of Member States have so far embraced a systemic approach to reviewing their R&I policies and identifying the bottlenecks that need to be overcome to create a business environment in which innovative firms are more likely to invest and grow [76]. Regulation within product, labour, and land markets limits possible business models, raises the cost of R&I investment, and slows down market forces that can incentivise firms to adopt more productive routines and practices.

In the following, we present and comment on the empirical evidence on business dynamics and highlight the main trend in (product and labour) market regulation, judicial and insolvency efficiency, and access to finance, with the aim of emphasising the high degree of heterogeneity existing in the EU and the extent to which these differences contribute to differences in the innovation-friendliness of the EU business environment.

[76] Europe 2020 targets: research and development. http://ec.europa.eu/europe2020/pdf/themes/15_research__development.pdf

4.3.1 Business dynamics: empirical evidence

As previously stressed, the creation of new businesses and the decline or market exit of less productive firms are often regarded as key to business dynamism and economic growth [77]. It could be argued, indeed, that entry into a market is one of the key elements of the transmission mechanism through which product market reforms ultimately affect productivity; the entry of new firms, or the threat of it, induces existing firms to become more efficient by setting their prices closer to marginal costs, reducing mark-ups through reallocation of resources within the firm, and investing in innovation. In addition, less productive firms are supposed to be pushed out of the market, while more efficient ones grow and gain market share, thus leading to further efficiency gains [78].

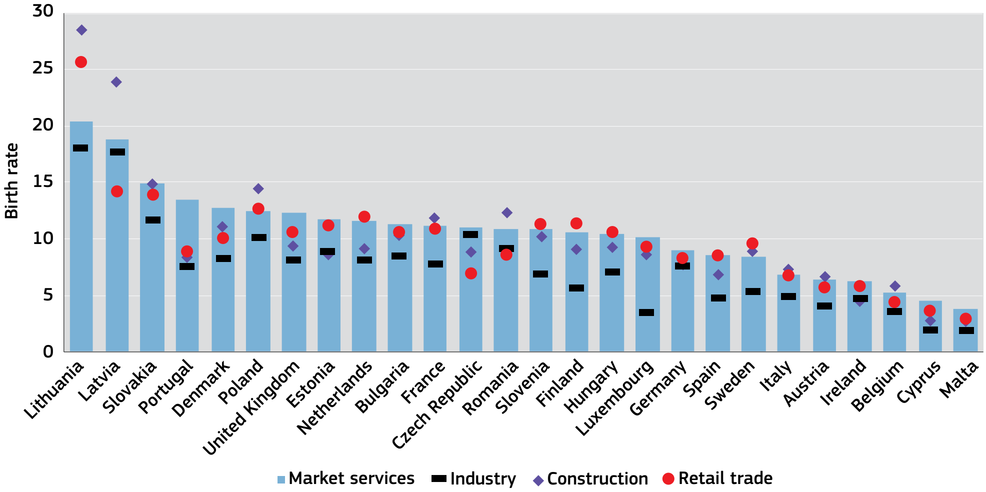
The theoretical reasons behind the aforementioned expectations on the relevance of firm entry and exit for innovation and productivity can be better grasped considering that their direct impacts on it can be decomposed into several effects. The first effect is due to a process of internal restructuring ('within effect'); the productivity of firms in the industry increases because of internal factors, such as organisational change, new technologies, or reallocation of inputs. The second effect regards, instead, the so-called external restructuring, which represents a reallocation of resources among firms via a process of creative destruction with the exit of the least efficient firms or via a shift in market shares towards most efficient firms. Related to these ideas are creative destruction models of economic growth (Aghion and Howitt, 1992), according to which new firms play a crucial role in developing innovations. Innovators replace old firms and earn monopoly profits until a new innovation comes along. Barnes, Haskell and Maliranta (2001) found substantial within effects for the OECD; Baily, Hulten and Campbell (1992) found similar results for the US manufacturing firms between 1972 and 1988; and so do Griliches and Regev (1995) for the Israeli industry over 1979-1988. There are also studies that decompose aggregate productivity growth into the contributions of entrants, incumbents, and those who exit, and show that the process of firm entry and exit plays a role in reallocating resources from low to higher productivity units (Scarpetta et al., 1992; Foster et al., 1998, Baldwin and Gu, 2003). At the same time, firm entry rates tend to be higher in industries with higher output and employment growth (Brandt, 2004), a result that might be related to the aforementioned positive impact of firm entry on productivity.

According to recent analysis, the EU's business research and development deficit in R&D intensity relative to the US can be virtually entirely accounted for by the EU having fewer young leading innovators (*yollies*). Even more importantly, EU *yollies* are less R&D intensive, a feature largely explained by their different sectoral composition and ability to take up technological opportunities that create radical changes (Cincera and Veugelers, 2013). This is also in line with the evidence presented in Bartelsman et al. (2009), according to which entry and exit dynamics as well as survival patterns seem to have a similar pattern in the EU and US, whereas there are remarkable differences regarding the growth performance of surviving firms.

(77) As a matter of fact, the existence of a positive link between the process of entry, reallocation of resources (within and between sectors) and macroeconomic growth is established in the economic theoretical and empirical literature. For instance, the entry of very high productive firms in a certain market may favour productivity-enhancing investment by incumbents interested in and trying to preserve their market power. Moreover, firms experiencing higher than average productivity growth are likely to gain market shares if the productivity gain goes along with upsizing, whereas they will lose market shares if their gain was driven by a process of restructuring associated, instead, with downsizing. Scarpetta et al., 2002.

(78) Ciriaci (2015).

Figure II-4-1 **Birth rate[(1)] of enterprises by sector, 2011[(2)]**



Science, Research and Innovation performance of the EU 2016

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat
Notes: [(1)]The number of enterprise births divided by the number of active enterprises in the reference period. [(2)]EE, IE, CY, LT: 2010.

Therefore, while in the case of the specialisation pattern the room for effective policy action in the short to medium term is limited (a change in EU yollies' R&D intensity would require a change in sectoral specialisation), the lower number of yollies could be a more feasible short-term policy target. This is likely due to different business conditions and a regulatory environment that is not friendly to young innovative firms [(79)]. More favourable conditions for younger and smaller firms/start-ups exist in the US, where, as a matter of fact, successful (unsuccessful) firms grow (shrink) faster than in the EU. In terms of innovation and competition, recent research (Bartelsman et al., 2013) also shows that the size of entering and exiting firms tends to be smaller in the US than in Europe. Also, successful young firms tend to expand relatively more quickly in the US than elsewhere [(80)]. In this regard, as emphasised by van Stel et al., (2007), when it comes to increasing the rates of new firm formation and subsequent wealth creation, policy-makers are faced with a central choice; they can either follow a low regulation route, as done, for instance, in the US, or follow a high "support" route, which in the past has been the traditional route in the EU. The low regulation route focuses on enabling the starting of a business to take place as quickly and cheaply as possible and on minimising the number, and severity, of regulations upon that business whilst it is trading. The alternative policy is for government to provide "support" to new and small firms in the form of information, advice, training, or finance to new firms or existing small firms.

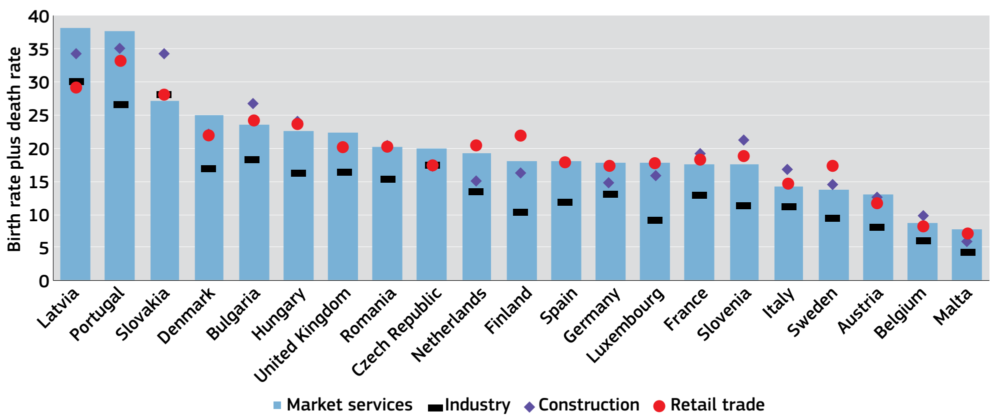
(79) See, among others, Klapper, L., Quesada Delgado J.M. (2009), The impact of the business environment on the business creation process, Policy Research Working Paper Series 4937, The World Bank; Nicodeme G., and Sauner-Leroy, J.B., (2004), Product market reforms and productivity: a review of the theoretical and empirical literature on the transmission channels, ECFIN Economic papers, n. 218.

(80) This has been identified as another cause of the innovation gap with the EU. Bartelsman, E.J., J. Haltiwanger and S. Scarpetta (2013), 'Cross-Country Differences in Productivity: The Role of Allocation and Selection', American Economic Review, vol. 103(1).

As shown in Figure II-4-1, birth rates (the ratio between the number of new firms that enter the s^{th} sector between *t* and *t+1* and the total number of firms (incumbent and entrant) in sector *s* at time *t*) across Member States vary significantly. These tend to be significantly lower than the average in industry sectors (also likely because of different sectoral firms' optimal scales), or those mainly investing in business R&D (the same applies to death rates). The range of variation among birth rates in industry is 1.91% (observed in Malta) — 18% (observed in Lithuania), with an EU median of 7.6%.

If we consider the sum of birth and death rates, the so-called churn rate, the range of variation across EU MSs decreased, but is still large (Figure II-4-2), with an EU median of 13%.

Figure II-4-2 **Churn rate (birth rate[1] plus death rate[2]) of enterprises by sector, 2011**

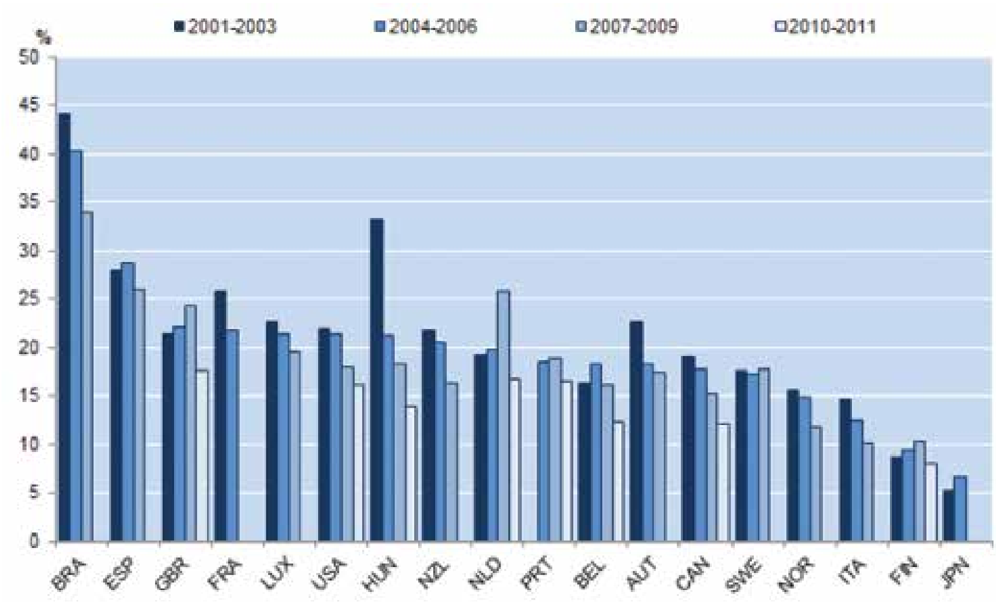


Science, Research and Innovation performance of the EU 2016

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat
Notes: [1]The number of enterprise births divided by the number of active enterprises in the reference period. [2]The number of enterprise deaths divided by the number of active enterprises in the reference period.

In a recent publication, the OECD has also shown that, in OECD countries, business dynamism is declining; the share of start-ups (defined as the fraction of firms which are from 0 to 2 years old among all firms) has declined sharply over the period from 2001-2010 (Criscuolo et al., 2014) in all 18 of the OECD countries analysed in the study (Figure II-4-3).

Figure II-4-3 **Share of start-ups in all firms in manufacturing, construction and non-financial business services sectors, averaged over three-year periods**



Science, Research and Innovation performance of the EU 2016

Source: Criscuolo et al., 2014

Recent efforts in the EU have been concerted on fostering the functioning of the Single Market (Single Market Acts I and II) and ensuring a pro-competitive environment in Europe, to complete the Banking Union and to streamline legislation and reduced regulatory burdens (for instance, with the REFIT Initiative) and the priority given to reducing red tape barriers and excessive regulation in the investment plan are all policy initiatives that will go in the direction of increasing entry rates.

4.3.2 Business environment for R&I: Regulation in product and labour markets and red tape barriers

Among the several factors affecting firms' decision regarding entry, product market regulations stand out as having a considerable influence (Cincera and Galgau, 2005). Scarpetta et al. (2002) found that the overall product market regulation level and, in particular, administrative barriers to start-ups, have a significant negative impact on firm entry. Accordingly, Ciriaci (2014) estimated the impact of changes in the administrative cost of starting a business on entry dynamics in 17 European member countries during the period from 2004-2011 and found a significant negative impact of the level of red tape barriers on entry dynamics at the sectoral level.

Notwithstanding the agreement on the key role of business dynamics for productivity and innovation, and despite recent reform efforts, some countries are still lagging behind in terms of product market regulation. The main data source of cross-country comparable information on the level of product market regulation is the OECD's Product Market Regulation (PMR) composite indicator [81], whose value spans from 0 to 6 (a

[81] The OECD's PMR translates policy action into a quantitative indicator. Though comprehensive and rich, its construction has some limitations. For instance, the indicator does not capture all the regulatory barriers in each sector covered, but a selection of them; therefore it provides a partial approximation of the regulatory framework in each country. Moreover, the information on regulatory structures and policies is collected through a questionnaire sent to governments and, therefore, does not reflect the opinion of the private sector. Finally, the PMR captures the 'de jure' policy settings while not reflecting, for instance, the way in which regulations are applied by authorities, even though enforcement can have a considerable impact on the level of competition. Even so, the PMR indicator provides a comparable picture of the regulatory framework across countries. For detailed information about the OECD indicators and their components see: http://www.oecd.org/eco/reform/indicatorsofproductmarketregulationhomepage.htm .

low value corresponds to light regulation) and that translates policy action into a quantitative indicator. Figure II-4-4 reports the value of the PMR index in 2013 (the cut-off date for reforms to be considered in the 2013 PMR index is December 2012), and of its components, for the EU MSs and EU's main competitors, and Figure II-4-4 shows the change in the level of regulation made by EU Member States since 2008, which might be considered a proxy of their reforms effort, relating the PMR value in 2008 with the difference between the 2008 and 2013 values.

Figure II-4-4 **PMR index and its components, 2013**[(1)]

	PMR	Barriers to entrepreneurship	Complexity of regulatory procedures	Licence and permits system	Communication and simplification of rules and procedures	Administrative burdens on start-ups	Administrative burdens for corporations	Administrative burdens for sole proprietor firms	Barriers in services sectors	Regulatory protection of incumbents	Legal barriers to entry	Antitrust exemptions	Barriers in network sectors
Belgium	1.39	1.78	1.47	2.00	0.94	2.53	2.20	1.00	4.40	1.34	1.50	0.00	2.52
Bulgaria	1.57	1.70	2.23	3.33	1.13	1.82	1.80	0.80	2.86	1.05	0.46	0.00	2.69
Czech Republic	1.39	1.82	2.49	4.00	0.97	2.11	1.80	0.80	3.72	0.86	0.20	0.00	2.39
Denmark	1.22	1.26	1.28	2.00	0.57	1.30	1.20	0.00	2.69	1.20	0.80	0.58	2.22
Germany	1.29	1.66	2.00	2.67	1.33	1.62	1.00	0.20	3.65	1.38	0.40	1.40	2.34
Estonia	1.29	1.56	2.06	4.00	0.11	1.83	1.60	0.60	3.28	0.79	0.21	0.00	2.17
Ireland	1.45	1.98	3.37	5.33	1.40	1.49	1.40	0.20	2.86	1.07	0.72	0.00	2.50
Greece	1.74	1.91	2.07	4.00	0.15	2.37	1.80	1.40	3.91	1.30	1.10	0.00	2.79
Spain	1.44	2.10	2.83	4.67	0.99	2.34	1.60	1.40	4.01	1.15	1.30	0.00	2.14
France	1.47	1.68	1.57	2.00	1.15	2.16	2.00	0.60	3.89	1.32	1.14	0.00	2.81
Croatia	2.08	1.99	2.00	4.00	0.00	2.98	2.60	2.75	3.60	0.97	0.67	0.00	2.25
Italy	1.26	1.22	0.52	0.67	0.38	2.14	1.60	0.20	4.62	1.01	0.48	0.00	2.56
Cyprus	1.65	2.09	2.90	4.67	1.13	2.05	1.40	1.40	3.36	1.32	0.50	0.89	2.57
Latvia	1.61	2.03	2.67	5.33	0.00	2.40	2.20	1.60	3.40	1.04	0.50	0.00	2.61
Lithuania	1.52	1.57	1.56	2.00	1.13	1.97	1.80	1.00	3.11	1.17	0.96	0.00	2.56
Luxembourg	1.46	1.71	1.41	2.67	0.15	2.40	1.40	1.20	4.60	1.33	0.67	0.00	3.33
Hungary	1.33	1.69	0.90	0.67	1.13	2.68	2.40	1.40	4.25	1.50	1.45	0.82	2.22
Malta	1.57	2.18	2.85	4.00	1.70	2.13	2.40	1.20	2.80	1.57	1.08	0.50	3.13
Netherlands	0.92	1.19	1.08	2.00	0.16	1.25	1.40	0.00	2.34	1.26	1.15	0.00	2.62
Austria	1.19	1.31	1.02	2.00	0.05	2.01	1.80	0.20	4.04	0.89	0.20	0.00	2.47
Poland	1.65	1.64	1.36	2.67	0.06	2.58	2.40	1.00	4.34	0.96	0.20	0.00	2.69
Portugal	1.29	1.35	0.41	0.00	0.82	2.48	1.80	2.00	3.63	1.16	1.57	0.00	1.92
Romania	1.69	2.06	2.00	4.00	0.00	2.91	2.60	2.20	3.92	1.28	0.64	1.14	2.07
Slovenia	1.70	1.81	2.33	4.67	0.00	1.97	2.20	0.40	3.31	1.13	0.90	0.00	2.48
Slovakia	1.29	1.15	0.46	0.00	0.91	2.09	1.60	0.80	3.86	0.90	0.40	0.00	2.31
Finland	1.29	1.55	1.63	2.67	0.59	1.74	1.20	1.20	2.83	1.26	0.90	0.00	2.89
Sweden	1.52	1.71	2.77	4.67	0.87	1.45	1.40	1.00	1.94	0.92	0.80	0.00	1.95
United Kingdom	1.08	1.49	2.46	4.67	0.25	1.36	0.80	0.20	3.07	0.64	0.60	0.35	0.97
EU	1.44	1.69	1.85	3.05	0.64	2.08	1.76	0.96	3.51	1.13	0.77	0.20	2.43
United States	.	.	.	.	.	.	.	.	.	.	.	.	.
Japan	1.41	1.67	1.83	2.67	1.00	1.54	1.20	0.00	3.41	1.65	1.07	0.53	3.34
China	2.86	3.13	3.65	4.67	2.63	4.11	4.20	4.60	3.53	1.63	0.93	0.00	3.94
South Korea	1.88	1.87	2.00	4.00	0.00	1.87	1.80	0.80	3.01	1.73	1.21	0.53	3.47

Science, Research and Innovation performance of the EU 2016

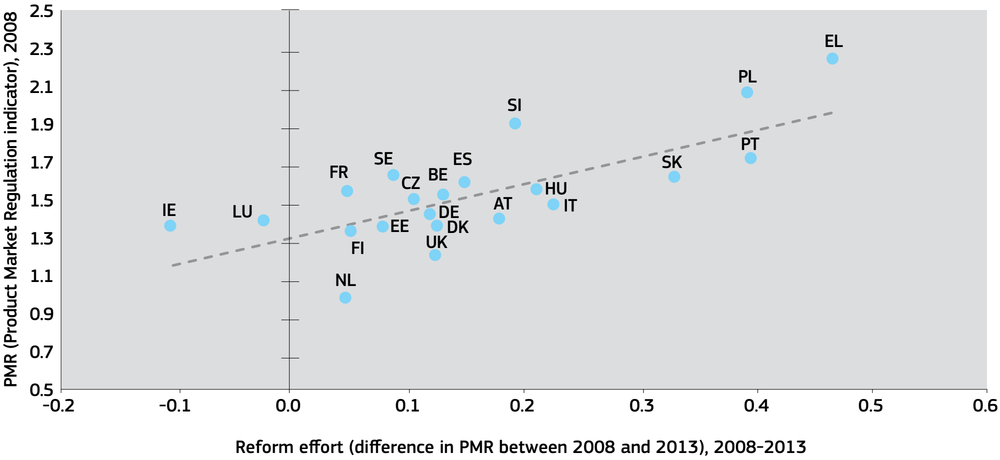
Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies

Data: OECD

Note: [(1)]IE: 2012.

The range of variation of the PMR index in 2013 is 0.92(Netherlands)-2.08(Croatia), and confirms that there is room for further effort; many Member States are far away from the best performers (the Netherlands and the UK). Overall, regulation appears particularly strict in the case of licences and permits and in services and network sectors. Barriers to entry are relatively higher than the EU average in 15 Member States, with Malta, Spain, Cyprus, Romania, Latvia and Croatia being among those with higher levels and also registering at higher than EU average levels of complexity with regard to regulatory procedures. Concurrently, the administrative burdens on start-ups are significantly higher than the EU average in Croatia, Hungary, Poland, Belgium and Portugal.

Figure II-4-5 **Reform efforts[1] in EU Member States during the crisis, 2008-2013**



Science, Research and Innovation performance of the EU 2016

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

Data: European Commission, OECD

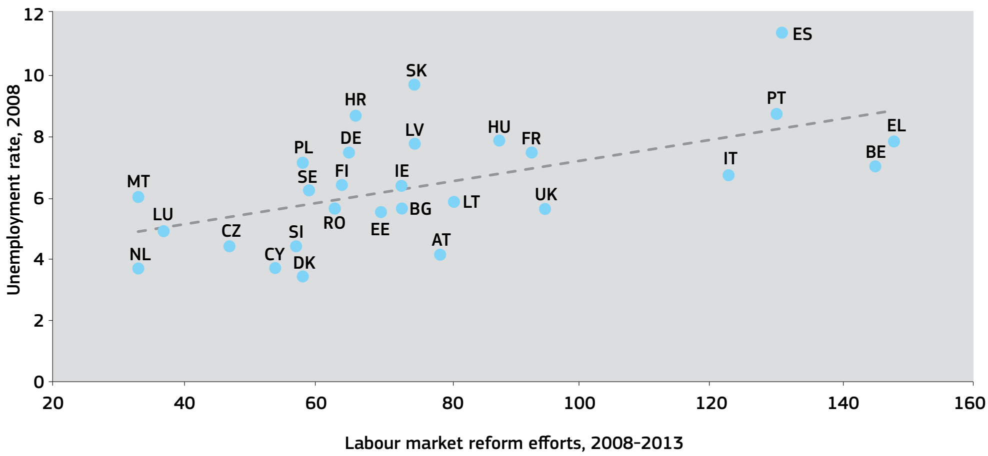
Note: [1]OECD's Product Market Regulation (PMR) indicator ranges from 0 to 6, where 6 represents a very restrictive level of regulation. Reform effort is measured as the difference in the Product Market Regulation (PMR) indicator between 2008 and 2013.

OECD's Product Market Regulation indicator ranges from 0 to 6, where 6 represent a very restrictive level of regulation. Reform effort is measured as the difference in the Product Market Regulation indicator between 2008 and 2013.

However, it is also worth stressing that, overall, a significant number of labour and product market reforms were introduced at the national level to boost economic activity and competitiveness, especially as a response to the crisis, and regulatory barriers have decreased in the majority of EU countries. In general, reform effort has been the largest in countries under financial stress, where accumulated vulnerabilities, amplified by the lack of reform efforts in the years before the crisis, hampered the ability of these economies to adjust (Figure II-4-5). Member States with relatively more restrictive regulation in product markets at the beginning of the crisis exhibit, on average, an intensified reform effort afterwards.

The same applies in the case of the labour market reform efforts made since the onset of the crisis, which also responded to the need to modernise labour market institutions, with the average reform intensity over the sample period being higher in countries characterised, on average, by a higher unemployment rate (see Figure II-4-6).

Figure II-4-6 **Unemployment rate in 2008 and subsequent labour market reform efforts[1], 2008-2013**



Science, Research and Innovation performance of the EU 2016

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: European Commission
Note: [1]Reform effort proxied by a non-weighted count of the number of measures undertaken. Calculated from the European Commission's LABREF dataset.

Notwithstanding, the average level of employment protection legislation (EPL) is higher in the EU than in the US, Japan and South Korea and continues to present a high level of EU cross country heterogeneity, with the UK as the best performer, as shown by the EPL index of the OECD reported in Figure II-4-7.

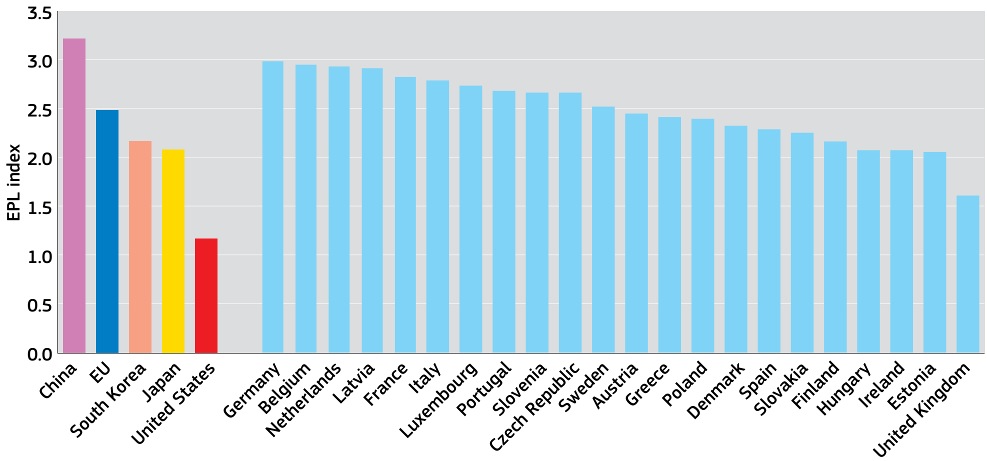
Clearly, these high regulatory barriers in product markets also translate to higher entry and exit costs; in some MSs there is a generally more than average onerous business environment [82], which significantly and negatively affects business dynamics [83]. In this case, the main source of cross-country information is the World Bank Doing Business dataset [84].

(82) World Bank (2013), Doing Business 2014: Understanding Regulations for Small and Medium-Size Enterprises.

(83) See Ciriaci, D. (2014) Business dynamics and red tape barriers, European Economy Economic Papers, 532. World Bank (2013), Doing Business 2014: Understanding Regulations for Small and Medium-Size Enterprises.

(84) This homogeneous data source has the main advantage of allowing cross-country comparison in a field where available (and comparable across time and countries) data is very limited and should be considered a measure of the level of business regulations in a MS. This presents quantitative indicators on the regulations that apply to firms at different stages of their life (regulations for starting a business, dealing with construction permits, acquiring electricity, registering property, acquiring credit, protecting investors, paying taxes, trading across borders, enforcing contracts and resolving insolvency). Therefore, it records all procedures officially required, or commonly done in practice, for an entrepreneur to start up and formally operate an industrial or commercial business, as well as the time and cost to complete them and the paid-in minimum capital requirements.

Figure II-4-7 **Employment protection legislation (EPL), 2013**



Science, Research and Innovation performance of the EU 2016
Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: OECD

If we focus on the quantitative indicators proxying the level of regulation for starting a business, we find, for instance, that if an entrepreneur wants to start a new business in Spain, he or she has to go through ten separate procedures, while doing so in Slovenia requires only two, with a cost of 4.6% of per capita income in Spain and a null cost in Slovenia (Figure II-4-8).

As shown in Figure II 4-8 below, the cost, number of procedures, and days needed to start a business differ substantially among EU countries, with cost peaks observed in Italy, Poland, and Cyprus and time peaks observed in Malta (more than 34 days to start a new business), Austria, the Czech Republic, Luxembourg, and Bulgaria.

Figure II-4-8 **Time and cost needed to start doing business in EU countries in 2008 and in 2014**

	Procedures (number)		Time (days)		Cost (% of income per capita)	
	2008	2014	2008	2014	2008	2014
Belgium	3	3	4.0	4.0	5.2	5.0
Bulgaria	4	4	49.0	18.0	2.0	0.8
Czech Republic	9	9	20.0	19.0	9.6	8.0
Denmark	4	4	6.0	5.5	0.0	0.2
Germany	9	9	17.5	14.5	5.6	8.8
Estonia	5	4	6.5	4.5	1.7	1.4
Ireland	4	4	13.0	6.0	0.3	0.3
Greece	15	5	19.0	13.0	22.5	2.2
Spain	10	6	61.0	13.0	14.9	4.6
France	5	5	6.5	4.5	1.0	0.9
Croatia	8	7	22.5	15.0	10.1	3.5
Italy	6	5	10.0	5.0	18.5	14.1
Cyprus	6	6	8.0	8.0	14.1	12.6
Latvia	5	4	15.5	12.5	2.3	3.6
Lithuania	7	3	26.0	3.5	2.7	0.7
Luxembourg	6	6	25.0	18.5	6.5	2.0
Hungary	4	4	5.0	5.0	8.4	8.3
Malta	-	11	-	34.5	-	11.0
Netherlands	6	4	8.0	4.0	5.9	5.0
Austria	8	8	25.0	22.0	5.1	0.3
Poland	10	4	31.0	30.0	17.5	12.9
Portugal	5	3	4.5	2.5	6.5	2.3
Romania	5	5	9.0	8.0	3.5	2.1
Slovenia	5	2	19.0	6.0	0.1	0.0
Slovakia	6	7	17.5	11.5	3.3	1.5
Finland	3	3	14.0	14.0	1.0	1.1
Sweden	3	3	16.0	16.0	0.6	0.5
United Kingdom	6	6	10.5	6.0	0.8	0.3

Science, Research and Innovation performance of the EU 2016
Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: World Bank - Doing business, 2015

However, in this case the reform effort since the crisis is visible, especially in Portugal and Spain as shown in Figure II-4-9, which reports the absolute difference between the number of procedures and the number of days needed to start a business, and the cost in 2008 and in 2014.

Figure II-4-9 **Reform effort[1] in reducing the time and cost of doing business in EU countries between 2008 and 2014**

	Procedures (number)	Time (days)	Cost (% of income per capita)
Belgium	0	0.0	0.2
Bulgaria	0	31.0	1.2
Czech Republic	0	1.0	1.6
Denmark	0	0.5	-0.2
Germany	0	3.0	-3.2
Estonia	1	2.0	0.3
Ireland	0	7.0	0.0
Greece	10	6.0	20.3
Spain	4	48.0	10.3
France	0	2.0	0.1
Croatia	1	7.5	6.6
Italy	1	5.0	4.4
Cyprus	0	0.0	1.5
Latvia	1	3.0	-1.3
Lithuania	4	22.5	2.0
Luxembourg	0	6.5	4.5
Hungary	0	0.0	0.1
Netherlands	2	4.0	0.9
Austria	0	3.0	4.8
Poland	6	1.0	4.6
Portugal	2	2.0	4.2
Romania	0	1.0	1.4
Slovenia	3	13.0	0.1
Slovakia	-1	6.0	1.8
Finland	0	0.0	-0.1
Sweden	0	0.0	0.1
United Kingdom	0	4.5	0.5

Science, Research and Innovation performance of the EU 2016

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

Data: World Bank - Doing business, 2015

Note: [1]Reform effort is calculated as the absolute difference between the indexes' values in 2008 and 2014.

4.3.3 Business environment for R&I: Judicial and Insolvency frameworks

Business dynamics, entrepreneurship, and reallocation are also favoured in the presence of an efficient insolvency framework, limiting the economic and social consequences of bankruptcy for entrepreneurs (provided that business failure is not due to fraud or dishonest behaviour; Fan and White, 2003, European Commission, 2011). Indeed, relaxing the legal consequences of insolvency could promote entrepreneurship (European Commission, 2003), by providing entrepreneurs with partial insurance against the consequences of failure (Jackson, 1985; Adler, Polack and Schwartz, 2000; Lee et al., 2007). This could be particularly relevant for the more innovation-oriented entrepreneurs, given the higher risk of R&D investment.

For instance, differences in insolvency regimes across MSs may contribute to explain differences in the 'speed' at which resources are released; it takes less than six months for a firm to be resolved in Ireland, for example, while it takes about four years in Slovakia (Figure II-4-10).

In this regard, it is also worth noting that the later a business initiates restructuring proceedings, the higher the costs of restructuring and the lower the management powers as well as the success rate [85].

Including an option to intervene early (in a pre-insolvency phase) increases the chances of survival for an ailing company and minimises the costs of the restructuring for the economy as a whole.

In this regard, as shown in Ciriaci et al. (2015b), the uniformity of approach is limited in the EU, which is also characterised by high heterogeneity in the efficiency of pre-insolvency frameworks [86]. It ranges from a minimum of 0.05 observed in Bulgaria to a maximum level of 0.85 found in the UK (the range of the efficiency indicator is 0-1 and higher levels of the index indicate higher efficiency; *see* Figure II-4-11).

The poor performance of Bulgaria is a combination of very low chances to restructure debt to sustainable levels, of the fact that no debt restructuring is possible, and of the lack of incentives for debtors to enter a pre-insolvency procedure, among other factors. High levels of efficiency are found in Portugal and Italy as a result of their recent reforms, which position themselves close to the UK's performance. Lower levels of efficiency are found, by contrast, in Slovakia, Hungary, and Croatia.

The overall performance of these three countries is, in particular, due to the relatively lower ease and availability of engaging in preventive proceedings and the higher direct and indirect costs of preventive restructuring procedures observed.

[85] To further address some of these inefficiencies, the European Commission issued in March 2014 a Recommendation setting out a series of common principles for national insolvency frameworks, whose aim is to encourage restructuring of viable businesses in financial distress at an early stage, as opposed to insolvency and liquidation, and to encourage a second chance for entrepreneurs.

[86] The methodology adopted in this paper consists in constructing quantitative indicators of efficiency of preventive restructuring frameworks for EU Member States based on the comparison of legal provisions of 27 EU Member States' insolvency frameworks, which have been assessed according to 12 dimensions and was provided by the EC Directorate-General for Justice. Qualitative information on the selected dimensions has been judgmentally converted into ordinal variables, i.e., variables whose increasing order reflects increasing efficiency of the rescue and recovery frameworks in the Member States. See also European Commission (2014), Commission recommendation on a new approach to business failure and insolvency, 12.3.2014 C (2014) 1500 final.

Figure II-4-10 **Enforcing contracts and resolving insolvency, 2014**

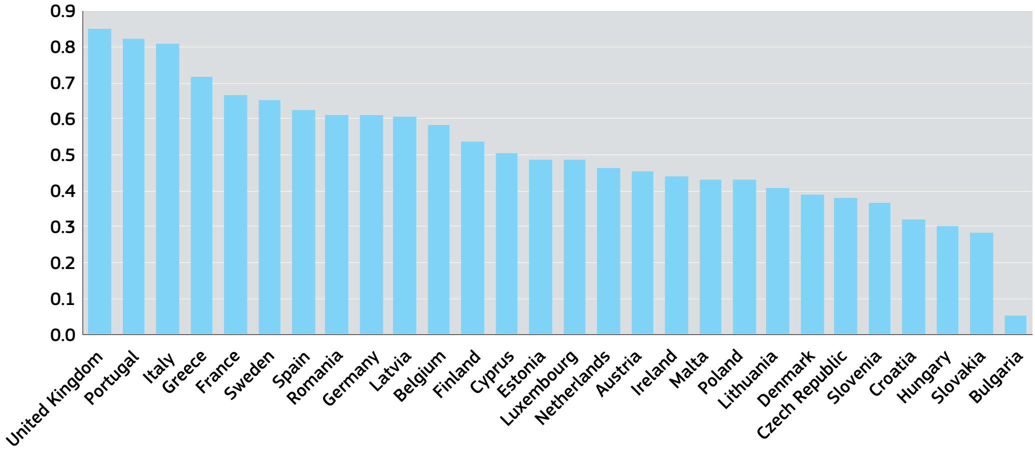
	Enforcing contracts			Resolving insolvency		
	Time (days)	Cost (% of claim)	Procedures (number)	Time (years)	Cost (% of estate)	Recovery rate (cents on the dollar)
Belgium	505	17.7	26	0.9	3.5	89.1
Bulgaria	564	23.8	38	3.3	9.0	33.2
Czech Republic	611	33.0	27	2.1	17.0	65.6
Denmark	410	23.3	35	1.0	4.0	87.5
Germany	394	14.4	31	1.2	8.0	83.4
Estonia	425	21.9	35	3.0	9.0	39.3
Ireland	650	26.9	21	0.4	9.0	87.7
Greece	1 580	14.4	38	3.5	9.0	34.3
Spain	510	18.5	40	1.5	11.0	71.3
France	395	17.4	29	1.9	9.0	77.2
Croatia	572	13.8	38	3.1	14.5	30.5
Italy	1 185	23.1	37	1.8	22.0	62.8
Cyprus	735	16.4	43	1.5	14.5	70.5
Latvia	469	23.1	27	1.5	10.0	48.2
Lithuania	300	23.6	31	2.3	10.0	43.6
Luxembourg	321	9.7	26	2.0	14.5	44.0
Hungary	395	15.0	34	2.0	14.5	40.2
Malta	505	35.9	40	3.0	10.0	39.6
Netherlands	514	23.9	26	1.1	3.5	88.9
Austria	397	18.0	25	1.1	10.0	82.6
Poland	685	19.4	33	3.0	15.0	57.0
Portugal	547	13.8	34	2.0	9.0	72.2
Romania	512	28.9	34	3.3	10.5	30.7
Slovenia	1 270	12.7	32	2.0	4.0	50.1
Slovakia	545	30.0	33	4.0	18.0	54.4
Finland	375	13.3	33	0.9	3.5	90.2
Sweden	321	31.2	31	2.0	9.0	76.1
United Kingdom	437	39.9	29	1.0	6.0	88.6
United States	420	30.5	34	1.5	8.2	80.4
China	453	16.2	37	1.7	22.0	36.0

Science, Research and Innovation performance of the EU 2016
Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: World Bank - Doing business, 2015

In this regard, it must also be stressed that the aforementioned efficiency scores do not reflect the efficiency of the implementation of pre-insolvency frameworks, but only their ex-ante efficiency from a legal point of view [87]. Clearly, the efficiency of the outcomes of these procedures could still face bottlenecks related to, for example, judicial efficiency or the lack of required expertise among legal practitioners.

[87] For methodological details, see Ciriaci et al., (2015a).

Figure II-4-11 **Overall efficiency of the pre-insolvency framework, 2013**



Science, Research and Innovation performance of the EU 2016

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Ciriaci et al., (2015a)

Regarding this, in the aftermath of the crisis, a number of EU countries have undertaken reforms meant to remove bottlenecks hindering the smooth functioning of civil justice, also in light of the European Semester exercise (Lorenzani and Lucidi, 2014) [88]. This reform effort, complementing in many cases other reforms in the areas of business environment, product and service markets, mostly aimed at reducing the length of civil and commercial trials as well as the backlog of pending cases, in order to increase the efficiency of civil justice procedures alongside judicial independence and quality (EC, 2014; Lorenzani and Lucidi, 2014).

However, when it comes to business dynamics, innovation and to the framework conditions enabling and fostering them, the importance of the efficiency of civil justice and insolvency/pre-insolvency procedures goes hand in hand with that of the efficiency with which intellectual property rights are defended. European companies rely on intellectual property rights (IPRs) to recoup their increasingly R&I-intensive but also risky investments in innovation and the benefits from introducing new or substantially improved products and processes into the market; they would like to be reassured that their intellectual property rights will be protected in all EU countries to the same extent. IPRs indeed play a crucial role in Europe's industrial strategy; approximately 40% of GDP and 25% of employment are generated by IPR-intensive industries in the EU.

If creators only have access to national titles, the same right may be treated differently in different Member States and national judges may have different views on the same right. Companies are sometimes forced to apply for the same right in each Member State (e.g., national validation of patents) and this administrative and cost burden absorbs resources that could otherwise be available for investing in R&D and innovation. This situation does not favour the smooth functioning of the single market.

The benefits of the EU single market can only materialise if it has also an IP system that allows a single market for innovation to prosper. In this context, the Unitary Patent package [89], put into force in 2015, contributes substantially to a modern IP system, which will bring considerable advantages and will offer an additional tool to EU

[88] Namely, in the context of the 2013 cycle of European Economic governance, ten MSs received a recommendation in the field of judicial system (BG, ES, HU, IT, LV, MT, PL, RO, SI, SK). In particular, four (IT, LV, SI, SK) were recommended to promote mediation and alternative dispute resolution mechanisms in order to reduce litigation rates.

[89] The need for a unitary patent was agreed upon as one of the five key actions of the Single Market Act I (SMA I). The implementation of the Unitary Patent and Unified Patent Court is a clear example in this sense. This package consists of three elements: (i) a Regulation creating a European patent with unitary effect (or 'unitary patent'); (ii) a Regulation establishing a language regime applicable to the unitary patent; and (iii) an international agreement among Member States setting up a single and specialised patent jurisdiction (the 'Unified Patent Court').

innovative companies that want to market their products throughout the single market.

The Unitary Patent will give innovators and creators access to broader territorial protection at lower costs, trigger a reduction of red tape for companies and make it easier for companies to access the single market and internationalise their activities. It also fosters technological transfer and dissemination of knowledge and boosts creativity across Europe.

By creating a unified system, the legislation will change the way patents are granted and enforced in Europe [90]. Under the new system, a unitary patent will be immediately effective and enforceable in the new 'Unified Patent Court', with decisions on validity and infringement being directly binding throughout the participating Member States. Therefore, the unitary patent will be a third option for companies or inventors seeking patent protection in Europe. It will be a further tool in the inventor's toolbox in addition to national patents and 'classical' European patents, which needs to be validated in each State for which it has been granted (i.e., it has no unitary effect).

4.3.4 Business environment for R&I: access to finance

Resource reallocation is also linked to several other policies. For instance, it is favoured in those MSs where channelling financing to innovative firms is more effective [91]. In simple words, reallocation of resources works with well-functioning financial markets in the sense that resources are channelled from less productive (innovative) to more productive (innovative) firms.

In this respect, the consensus on the fact that the high barriers to accessing finance and the lack of investment resources severely hamper the innovation performances of European industry is broad. Unfortunately, finance for growth is exposed to a series of market failures related to the intrinsic risk of R&D and innovation activities, the difficulties of reaping their benefits, and the asymmetric information permeating the relationship between borrowers, lenders, and equity investors. Credit rationing and suboptimal levels of innovation investments are some of the well-known consequences of these failures.

The interplay of specific economic characteristics — higher/lower shares of small and medium size firms and of medium-/low-tech sectors compared to its main competitors — and institutional conditions — differences in Member States bank-based financial systems and lower/higher capitalised stock exchanges — may make the funding shortfall for innovative projects in some European countries particularly acute. In particular, high-tech start-ups and young innovative SMEs are those more severely financially constrained in various phases of their development, a major barrier to their growth.

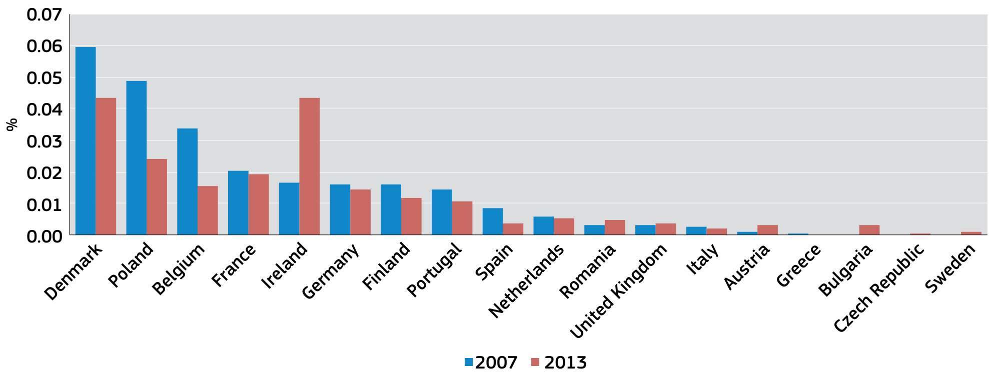
In fact, a company can generally gather its capital from two sources, equity and debt, as well as internal finance, a channel, the latter, particularly relevant for large firms. However, whereas large multinational companies are usually provided with finance by large banks and big finance companies (in addition to shareholders and lenders), younger and smaller firms, which use finance as the fuel needed to pass through a variety of growth stages, are more likely than them to face financial constraints. They face them in their seed and start-up phase, due to the investment risk associated with new, young and innovative business projects that still need to find their way to the market and where public research grants stop and private finance might be attracted, They face them, though, also during their expansion phase, when innovative firms with high potential lack access to growth finance, in particular from venture capital funds. Finally, both large and small innovative firms often face a shortage of higher risk loans to complement venture capital [92].

[90] At present, patents are granted centrally by the European Patent Office but result in a bundle of national patents which have to be enforced separately in each European Union Member State. This country-by-country enforcement can result in increased litigation costs, delayed proceedings and conflicting decisions.

[91] A feature strongly influenced by the high fragmentation of the venture capital market in Europe. See Veugelers, R. (2011), 'Mind Europe's early-stage equity gap', Bruegel Policy Contribution 2011/18, December 2011. Indeed, this is now part of the wider agenda of the European Commission of building a capital market union.

[92] As recently as in June 2014, a new generation of EU financial instruments and advisory services was launched to help innovative firms access finance more easily, through a joint initiative of the EC and the European Investment Bank Group (EIB and EIF). InnovFin — EU Finance for Innovators is the financial instrument under which the EU promotes a range of debt and equity products and advisory services in order to effectively give a boost to the availability of finance for research and innovation activities in Europe. It consists of a range of tailored products — from guarantees for intermediaries that lend to SMEs to direct loans to enterprises — helping support the smallest to the largest R&I projects in the EU and countries associated to Horizon 2020, the new EU research programme for 2014-20. InnovFin builds on the success of the Risk-Sharing Finance Facility, developed under the seventh EU framework programme for research and technological development (FP7), which helped provide over €11 billion of finance to 114 R&I projects worth more than €30 billion.

Figure II-4-12 **Early stage venture capital (seed and start-up) as % of GDP, 2007 and 2013**



Science, Research and Innovation performance of the EU 2016
Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat

In this regard, Figure II-4-12 reports the GDP share of venture capital for early stage firm development in 15 European countries (those for which data were available) in 2007 and 2013 and shows that, in general, venture capital availability, after the crisis started, decreased in the majority of the countries, with some exceptions such as Ireland, Romania, the UK, Austria and Bulgaria). However, in these latter cases, with the exception of Ireland, the 2007 share of venture capital for early stage firms was very low both in relative and absolute terms. All In all, this data confirm the increasing need for this form of financing, which, along with more traditional financial channels, suffered from the economic crisis.

4.4 The low EU adoption of ICT in EU services: a possible consequence of stricter market regulation and lower reallocation efficiency?

A recurrent stylised fact in the empirical literature on innovation is that some EU Member States have adopted information and communication technologies at a slower pace than others, in particular in the services sector [93]. This very same difference in the adoption of ICT is often recalled as the main reason for the difference in productivity performance gap from the 1990s onwards between the EU and the US [94].

Clearly, the reasons behind this trend could be several, but two are particularly relevant in the current economic context and, in particular, in the light of the third pillar of Juncker's investment plan and the need to complete the Single Market.

The first reason is the relatively closed nature of services markets within Europe and, especially in some MSs, which slows down the diffusion of new technologies. According to recent analysis, the innovation impact of the vertical sectoral integration of knowledge-intensive business services (KIBS) into manufacturing (defined as the extent to which manufacturing sectors acquire KIBS innovative knowledge — R&D — through production-based flows to satisfy their final demand), is significantly positive (Ciriaci et al., 2015b). These highly specialised and innovative services perform key activities in innovation systems (e.g., Muller and Zenker, 2001; Tether, 2005), and act as knowledge carriers with respect to other sectors, especially manufacturing ones, working as 'innovation propellers' at the system level (Castellacci, 2008). Those industries which integrate R&D embodied in KIBS production flows

[93] See for example Gomez-Salvador, R., A. Musso, M. Stocker and J. Turunen (2006), 'Labour productivity developments in the euro area', ECB Occasional Paper No 53, October 2006.

[94] Foster, N., Poschl, J., Rincon-Aznar, A., Stehrer, R., Vecchi, M. and Venturini, F. (2013), 'Reducing productivity and efficiency gaps: The role of knowledge assets, absorptive capacity and institutions', in European Competitiveness Report, DG Enterprise and Industry, European Commission.

more intensively and extensively are industries with greater inventive efforts and higher quality patents (Ciriaci et al., 2015b). To the extent to which regulation limits competition in the service sector, and especially in professional services such as KIBS, it limits their productivity and the efficiency of knowledge interaction with manufacturing which occurs through both disembodied and embodied flows of codified and tacit knowledge. More in general, increased productivity growth in services with strong forward linkages with the rest of the economy would translate into increased competitiveness for the industries using services inputs.

Given the relative importance of services in our economies and their increasing vertical integration with the rest of the economy [95], this has an impact on total productivity growth and calls for the completion of the single market in services [96]. Unfortunately, efforts in the direction of liberalising them have been limited relative to the efforts done by Member States in other sectors.

The second reason could be found in the relative rigidity of national labour markets. Fundamental organisational restructuring is often needed to reap the productivity gains from adopting new technology, for instance, due to the automation of certain tasks. This implies that firms need some degree of flexibility to reallocate workers to different tasks, which in turn requires them to have access to adequate initial and vocational training — something that some EU countries have been able to do better than others [97].

As part of this process, resources reallocation is inevitable, given the fact that firms need to restructure, and to focus resources where they are most productive. Unfortunately, the empirical evidence suggests that there are important differences in the extent to which capital and labour flow to innovative firms. For example, according to a recent OECD analysis [98], a 10% increase in the patent stock is associated with an increase in the typical firm's capital stock of about 3% in Sweden and the United States; 1.5% in the United Kingdom and Germany; and 0.5% in Italy and Spain. Notably, these cross-country differences tend be driven by younger firms. These are those that are most likely to introduce radical innovations, and more affected by diverse degrees of administrative costs, regulations, and access to finance.

In line with previous arguments in favour of policies supporting resources reallocation, it is worth emphasising that the same product and labour market reforms that would spur innovation (and its adoption), would also favour a better resource allocation. For instance, employment protection legislation that is too rigid is believed to significantly decrease the ability of innovative firms to attract resources [99].

4.5 Conclusions

The starting point of this chapter has been the consideration that favourable framework conditions stimulate firms to engage in innovation and R&D, and support the diffusion of innovations throughout the economy. In particular, it has focussed on the role and likely impact of product and labour market regulation, red tape barriers, judicial and insolvency frameworks and access to finance on the level of business investment in R&D, through their effects on business dynamics (i.e., on a firm's entry, exit and growth), which may contribute to stronger market selection and post-entry growth, thereby enhancing the ability of firms to achieve sufficient scale to enter global markets and their incentives to innovate.

However, notwithstanding the agreement on the key role of business dynamics for productivity

(95) See, among others, Bourlés, R., Cette G., Lopez J., Mairesse, J. and Nicoletti, G. (2012), 'Do product market regulations in upstream sectors curb productivity growth? Panel data evidence for OECD countries', Review of Economics and Statistics, MIT Press, vol. 95(5); Ciriaci, D. and Palma D. (2012), To what extent are knowledge intensive business services contributing to manufacturing? A sub-system analysis, IPTS WP on Corporate R&D and Innovation, n. 2/2012.

(96) Directive 2006/123/EC Directive on services in the internal Market. http://ec.europa.eu/internal_market/services/services-dir/index_en.htm.

(97) See: http://www.cedefop.europa.eu/en/information-services/vet-in-europe-country-reports.aspx.

(98) Andrews, D., C. Criscuolo and C. Menon (2013), 'Do Resources Flow to Innovative Firms? Cross-Country Evidence from Firm-Level Data', OECD Economics Department Working Papers, forthcoming.

(99) Andrews, D., C. Criscuolo (2013), 'Knowledge-based capital, innovation and resource allocation', OECD Economics Department Working Papers No 146. As stressed by the ECB, this is not an argument to lessen workers' insurance against labour market risks. Rather it is an argument to shift the burden of that insurance away from firms and towards society more widely. See ECB (2014), Structural reforms: learning the right lessons from the crisis, Economic conference, Riga http://www.ecb.europa.eu/press/key/date/2014/html/sp141017.en.html.

and innovation, and despite recent reform efforts, some EU countries are still lagging behind in terms of product and labour market regulation. To thrive on innovation, labour needs to be reallocated within and across firms and sectors (as it may not be efficiently allocated and/or labour-saving technologies have been introduced). In this regard, the relatively stringent employment protection legislation found in some Member States may limit this capacity (or make it less efficient) and harm the most innovative and productive firms and sectors, which would need these resources to undertake their innovative projects and grow. In addition, in the presence of employment protection stringency, displaced workers may suffer longer unemployment spells.

Clearly, as emphasised, the level of business investment in R&D can also be affected by the efficiency of the judicial system and of the bankruptcy regime. In this regard, the analysis has confirmed a high level of cross-country heterogeneity in the EU which may imply, *ceteris paribus*, differences in the extent to which countries are likely to foster experimentation with risky technologies. This is more likely to happen in countries with a more efficient judicial system and high recovery rates, and which do not sanction business failure too much. The same applies to countries where younger and smaller innovative firms have an easier access to capital for their seed and start-up phase where public research grants stop and private finance might be not forthcoming. Due to the investment risk associated with new, young and innovative business projects that still need to find their way to the market, these firms are those more likely to be financially constrained and to also face a lack of financial resources for their expansion phase, in particular from venture capital funds.

Therefore, addressing the causes of MSs relative underinvestment in R&I requires a serious commitment by Member countries to truly investigate the respective country-specific bottlenecks that prevent private R&I investment to converge towards higher levels. It also calls for additional effort at the EU level to improve the business environment and complete the single market [100]. By removing barriers to the free circulation of people, goods, services and capital, the Single Market allows firms to operate on a bigger scale, thereby enhancing their capacity to innovate, to invest, become more productive and generate jobs. Strengthening competition, improving the working of price signals and lowering entry barriers are usually important incentives for investors, the importance of which for R&I investment is not emphasised enough.

Moreover, the empirical evidence suggests that, although conducive framework conditions and a dynamic and healthy business environment are key prerequisites for any innovation system, they are particularly important for the more technologically weak European countries. Overall, the empirical evidence shows that stringent product and labour market regulation and costly and lengthy procedures to start a business, inefficient judicial systems and insolvency frameworks, and limited access to finance tend to go hand in hand. To these bottlenecks, we must add insufficient knowledge and human capital and weak technological capabilities at the firm level, sectoral specialisation patterns, and the absence of critical firm size.

Finally, although not the focus of this chapter, there is no doubt that the adoption and diffusion of new technologies leads to new employment opportunities, not only for individuals endowed with skills that complement them, but also indirectly by improving the overall performance of those sectors and firms that become more innovative and/or productive, stimulating growth which in turn increases consumption

[100] In this regard, it is also important to note that avoiding stifling innovation and competitiveness with too prescriptive and too detailed regulations is particularly relevant when it comes to small- and medium-sized enterprises (SMEs).

and investment. At the same time, investment in education continues to be a necessary pre-condition for achieving better employment prospects as well as a redesign of education policies to better match skill demand and supply. As the erosion of middle-skill employment due to technological progress [101], which is increasingly emphasised by the empirical literature, has also been extending, increasingly, to higher skill levels, leads to the question of which type of skills will be most demanded in the future, remaining a complement to technology rather than being substituted by it, and with a stronger focus on adaptability and flexibility of skills.

(101) In the last two decades jobs requiring medium levels of skills appear to have lost importance relative to those at the bottom and at the top of the skill distribution. Among the possible drivers of this job polarisation, recent advances in computing and information and communication technologies are considered as a main cause (Autor et al., 2006). In particular, digitalisation and automation are deemed to have increasingly replaced labour in more routine occupations (such as, for example, clerical office work, crafts and trade, or plant and machine assembly operations) while advances in communication technologies have increasingly allowed offshoring of such tasks (from high income to lower income countries). At the same time, both high-paying jobs involving more abstract tasks (such as managerial occupations, engineering, or intellectual professions), and low-paying jobs involving non-routine service tasks (related, for example, to personal care, travel, catering, etc.) have benefited from the same technological advances in terms of increased productivity and/or increased demand for their services (Goos et al., 2014). These employment developments are consistent with the increased wage dispersion observed in the last two decades (OECD, 2011): highly-skilled workers at the top of the distribution have reaped the benefits of increased productivity, while wages at the middle of the distribution have been stagnating due to a fall of labour demand.

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5. International knowledge flows

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5.1 Introduction

It is well known that international knowledge flows are positively related to the innovation performance of firms (Fitjar and Rodríguez-Pose, 2013; Gertler and Levitte, 2005). Empirical evidence shows that local knowledge needs to be complemented with international sources of knowledge for innovation (Giuliani et al., 2005). In fact, most innovative products or services are the result of combining knowledge across different geographical scales (Strambach and Klement, 2012) and most valued patents or publications (in terms of citations) tend to be the result of international knowledge links (OECD, 2014).

Until very recently, the international flows of knowledge were highly confined to neighbouring countries (intra-Europe) and other Triad countries (the US and Japan) (Castellacci and Archibugi, 2008) but this has been gradually changing (Chaminade et al., 2014). For example, less than one-third of EU R&D offshoring projects are directed towards other European countries. The bulk of such investment is actually directed to non-European countries, with China and India being the main recipients of R&D offshoring, followed by developed countries (the US for example) and other South-East Asian countries, such as Brazil and Russia (Castellani and Pieri, 2013). This requires a change of perspective. Understanding the extent of the changes in the geography of these international knowledge flows as well as the possible impact of that change is paramount and will be discussed in this chapter.

This chapter aims at understanding how international knowledge flows in Europe have been developing over time and discuss their main drivers and impacts. Of particular interest is to discuss the importance of intra-European knowledge flows vis-a-vis knowledge flows with non-European countries.

The chapter will distinguish between different types of mechanisms for the acquisition and transfer of knowledge. Knowledge can be exchanged internationally intentionally through market transactions, formal and informal networks and foreign direct investments, and unintentionally through networks and the mobility of human capital (also referred to as spillovers) (Chaminade et al, 2015):

- Knowledge exchanged through market mechanisms such as **trade** can be both embodied in artifacts (machinery and equipment) and disembodied (patents). The exports of high-tech goods and services can provide a first indication of the trade of knowledge embedded in goods and services. Global input-output tables can also provide an indication of the trade flows between one country and the rest of the world as well as the value that is captured by individual countries. The international knowledge flows through trade will be discussed in section 5.2.

- Knowledge can be exchanged through **formal and informal networks.** Networks are characterised by reciprocal, preferential and mutually supportive interactions (Powell 1990). In networks one party depends on the resources controlled by another and they are highly based on trust. Mechanisms such as R&D contracts, R&D alliances or research consortia are examples of formal networks for knowledge creation while epistemic communities or communities of practice are examples of mechanisms through which knowledge is transferred in informal networks. The international knowledge flows through research and technological collaboration will be discussed in section 5.3.

- Knowledge flows may also happen when the individuals holding that knowledge move creating **unintentional spillovers** of knowledge. Spillovers tend to occur often in close geographical proximity although they can also take place across large geographical distances, for example though international mobility of researchers (Rosenkopf and Almeida 2003). The drivers of international mobility of human capital — including the international mobility of researchers — are varied and include personal motivations as well as institutional frameworks. The international knowledge flows through the mobility of researchers will be discussed in section 5.4.

- Finally, knowledge flows internationally through **foreign direct investments** particularly –but not exclusively- cross-border R&D investments. The investment of national companies abroad is a form of hierarchy as it relates to functions that the firm has located offshore and over which it exerts control. The international knowledge flows through R&D cross-border investments will be discussed in section 5.5.

For each section, we will start with a general overview of trends, paying particular attention to how Europe is positioned with respect to its competitors. Then, we will investigate the importance of intra versus extra European flows of knowledge and generally discuss the expected impact of the observed trends [102].

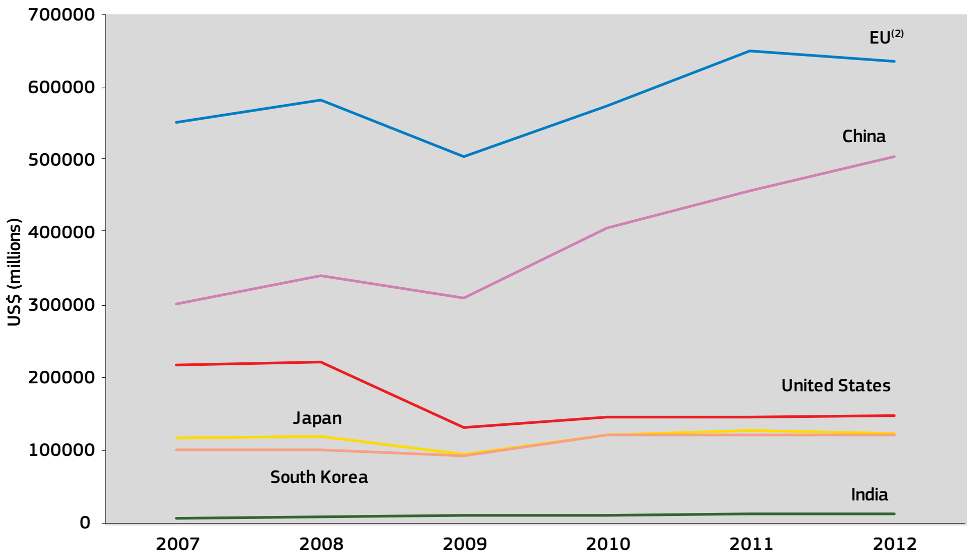
5.2 International knowledge flows through trade

5.2.1 Overall trends

The aim of this section is to discuss how Europe is positioned in terms of the global trade of knowledge embedded in high-tech products and knowledge-intensive services. Of particular interest is to investigate if international fragmentation is increasing or decreasing and what share of value is still kept in Europe.

Figures II-5-1 and II-5-2 show the evolution of high technology exports in absolute and relative terms from the EU to the rest of the world in comparison with a selection of countries. In absolute terms (Figure II-5-1), the EU portrays the largest volume of high technology exports in terms of value (million US $) as compared to the other blocks. In the years after the economic crises (2009 to 2011) the volume of high technology exports increased while the US, Japan and South Korea´s value of high technology exports has stagnated since 2009. Interestingly China has gained momentum and has reduced the gap with the European Union in the same period.

Figure II-5-1 **High-technology exports[1] (current US$), 2007-2012**



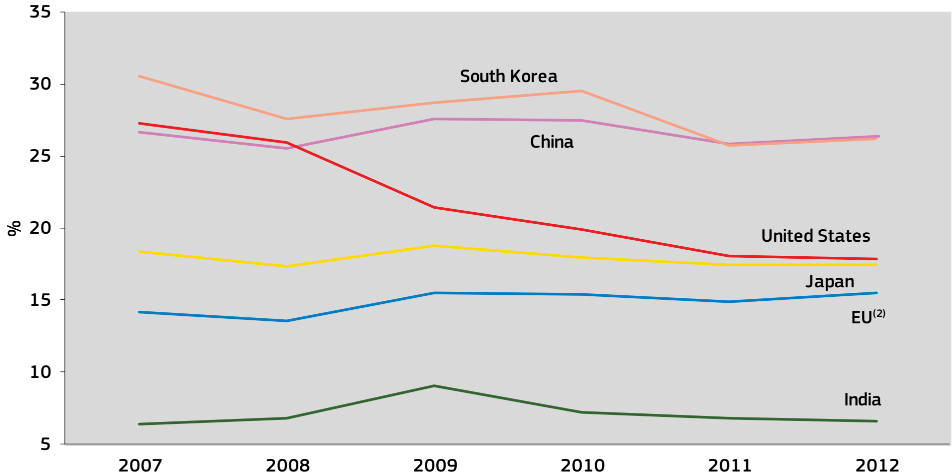
Science, Research and Innovation performance of the EU 2016

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: World Development Indicators
Notes: [1]High technology exports are products with high R&D intensity, such as in aerospace, computers, pharmaceuticals, scientific instruments, and electrical machinery. [2]EU does not include intra-EU exports.

[102] The extent of the analysis is subject to data availability.

However, the situation is slightly different when the analysis is made in relative terms — that is looking at the proportion of exports of high-tech products over the total manufacturing exports. As can be observed in Figure II-5-2, the European Union has one of the lowest percentages of exports of high-tech products over the total manufacturing exports, only above India. In the last years we can observe that the gap with the US and Japan has reduced but this is mostly due to the significant drop of the US rather than improved performance by the EU. China continues to outperform the US, Japan and the EU since 2008, catching up with South Korea in the last period considered. The observed good performance of China can be explained either as a result of higher domestic added value or as reflecting high volumes of high-tech imports that are further assembled and distributed worldwide, as will be discussed later on.

Figure II-5-2 **High-technology exports[(1)] as % of manufactured exports, 2007-2012**



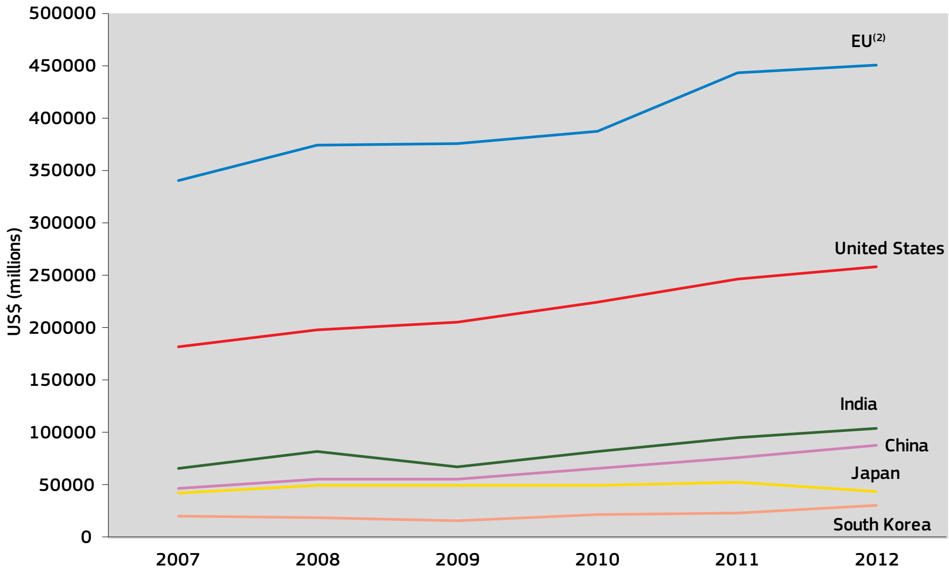
Science, Research and Innovation performance of the EU 2016

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: World Development Indicators
Notes: [(1)]High technology exports are products with high R&D intensity, such as in aerospace, computers, pharmaceuticals, scientific instruments, and electrical machinery. [(2)]EU does not include intra-EU exports.

The EU is performing better in terms of exports of knowledge-intensive services (KIS) [(103)] both in absolute and relative terms, as shown in Figures II-5-3 and II-5-4. In absolute terms the EU is followed by the US and much below by India (reflecting their strong capabilities in software and IT services), China, Japan and, lastly, by South Korea.

[(103)] Commercial knowledge-intensive service exports consist of communications, business services, financial services, and computer and information services.

Figure II-5-3 **Exports of commercial knowledge-intensive services[1] (current US$), 2007-2012**

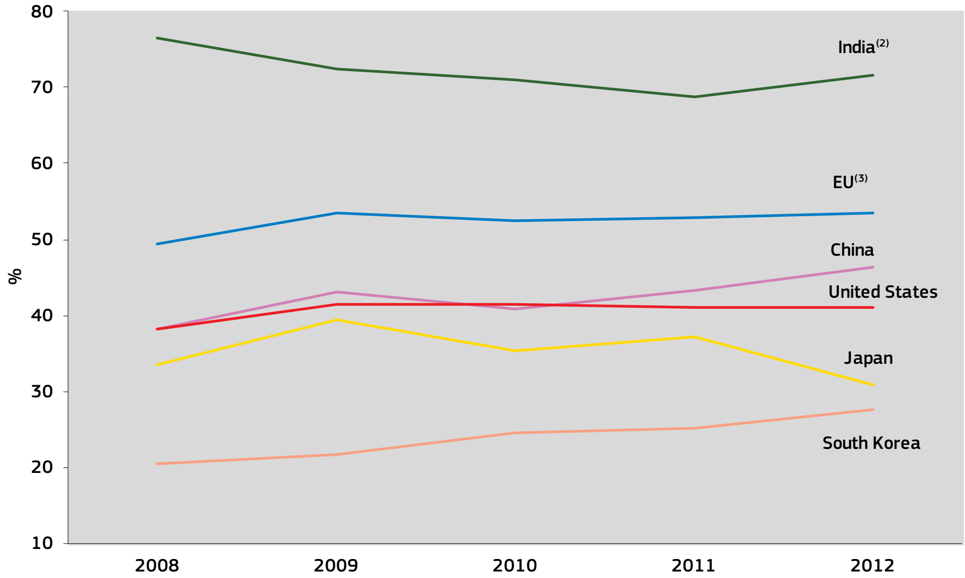


Science, Research and Innovation performance of the EU 2016

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: WTO data based on 'Trade in commercial services, 1980-2013 (BPM5)'
Notes: [1]Commercial knowledge-intensive services include communications, computer and information services, financial services, and other business services. [2]EU does not include intra-EU exports.

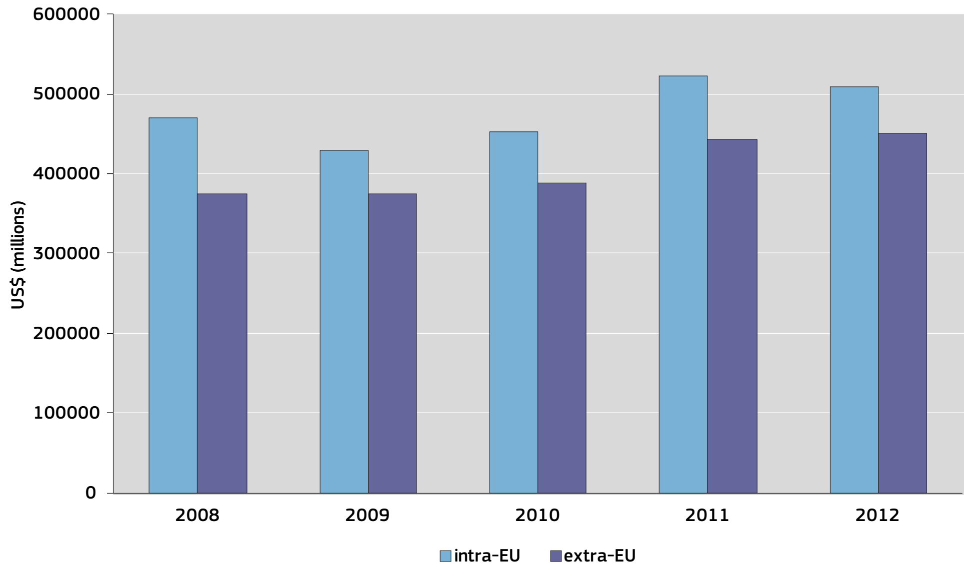
In relative terms, India is substantially above all other countries considered. It is followed by the EU who has been able to maintain a stable proportion of exports of knowledge-intensive services after the crises. Intra-EU flows of knowledge-intensive services have remained above extra-European flows although the later have been growing steadily since 2007, gradually closing the gap with the intra-European flows, as Figure II-5-5 shows.

Figure II-5-4 **Exports of commercial knowledge-intensive services(1) as % of total exports of commercial services, 2008-2012**



Science, Research and Innovation performance of the EU 2016
Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: WTO data based on 'Trade in commercial services, 1980-2013 (BPM5)'
Notes: (1)Commercial knowledge-intensive services include communications, computer and information services, financial services, and other business services. (2)India: Computer and other business services have been estimated by UNCTAD-WTO. (3)EU does not include intra-EU exports.

Figure II-5-5 **Exports of commercial knowledge-intensive services(1) (current US$) – intra-EU and extra-EU, 2008-2012**



Science, Research and Innovation performance of the EU 2016
Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: WTO data based on 'Trade in commercial services, 1980-2013 (BPM5)'
Note: (1)Commercial knowledge-intensive services include communications, computer and information services, financial services, and other business services.

5.2.2 Impact

Looking exclusively at the exports of high-tech products or knowledge-intensive services does not tell us what the domestic contribution to those international knowledge flows is. High volumes of exports of high-tech products or services from the EU do not imply that those high technology products or services have been developed in the EU, only that they are exported from the EU. So the critical question is which added value is generated in Europe and whether that value generation is the result of knowledge intensive activities.

The very recent global input-output tables and related analyses provide a very fine-grained analysis of the positioning of the EU in comparison to other countries in the world and its competitive advantage in terms of knowledge content in trade. The analysis of the global input-output data clearly shows an increasing fragmentation of global value chains, which implies a higher share of foreign added value in the added value within Europe (Timmer et al., 2014; Los et al., 2015).

Looking at the intra-EU flows versus extra-EU, Los et al. (2015) shows that geographical proximity or belonging to a trade block or single market, like the EU, still explains a great deal of the observable geographical patterns of global value chains. However, they also point out that, since 1995, global fragmentation has progressed much faster than intra-EU fragmentation. In other words, the shares of added value outside the EU are rapidly increasing for all products, including high-tech, which suggests a move towards more global knowledge flows embedded in global value chains.

Using global input-output data, Timmer et al. (2014) show that, generally, there is a decrease in the content of low skilled human capital in all manufacturing activities worldwide which points to a global technological shift in manufacturing and a general technological upgrading. However, there are also clear differences between blocks - for example between Europe and China - with regards to the most relevant production factor. While in Europe manufacturing activities are based on high-skilled workers (that is, they are more knowledge-intensive), the activities conducted in China are mainly capital intensive thus showing an enhanced specialisation in high-skills labour in (high income) European countries. In other words, what these results suggest is that the knowledge component (proxied by the importance of qualified human capital) of European trade is *generally* increasing — that is- it relates to all industries and not only the high-tech manufacturing or high-tech services discussed above.

Furthermore, in terms of what factors in the innovation systems affect how much value is captured by a country, the analysis of the global input-output data (van der Marel, 2015) reveals that high endowment of qualified human capital plus high internet connectivity, high R&D spending in terms of GDP and better innovation climate are associated with higher participation in global value chains and higher value capture.

5.3 International research and technological collaboration

The trade of knowledge-intensive business and services is one of several mechanisms that firms and other organisations use to acquire knowledge. Knowledge also flows through collaborative networks.

This section will look at the patterns of research and technological collaboration across national borders. It will investigate the patterns of intra-EU collaboration versus international collaboration (Van Looy et al., 2014). Using co-patenting data (technological collaboration) and the European community innovation survey data (research collaboration), we will present and discuss the patterns of international collaboration for innovation attending to the location of the partner as well as the type of linkage for all EU countries. The data will also allow us to investigate the importance of intra-EU research collaboration versus networks outside Europe, in particular the US, China and India.

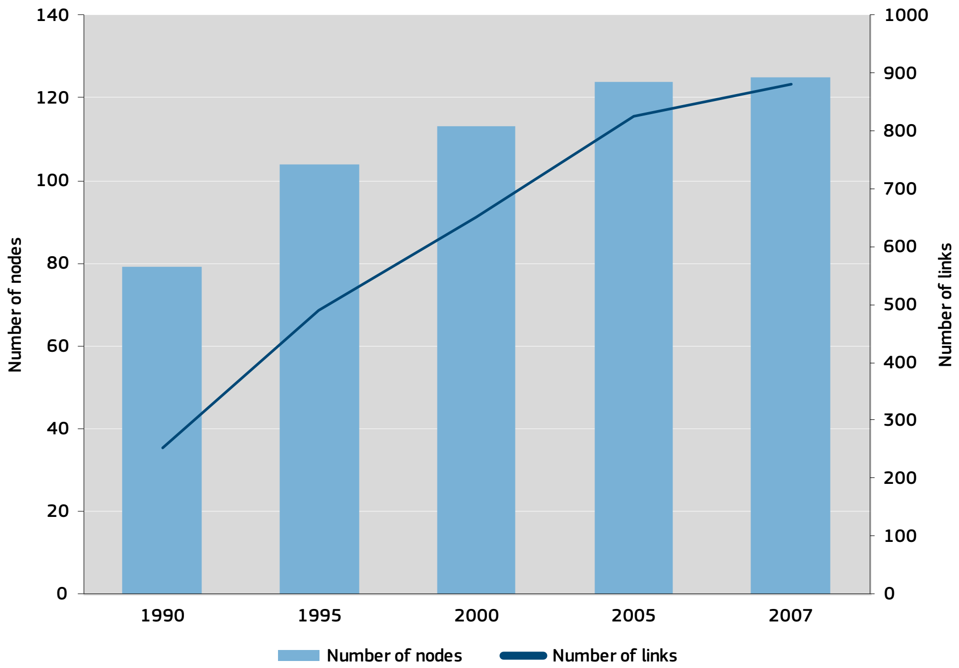
5.3.1 Trends

Technological collaboration

Technological collaboration at the international level captured by the percentage of patents with foreign co-inventors **has intensified** in the last few decades (Paci and Batteta, 2003) while the percentage of patents with only domestic investors has suffered a persistent decline since the early eighties (Van Looy et al., 2014).

Prato and Nepelski (2012) map the international technological collaborations by looking at worldwide patent data between 1990 and 2007 using the PATSTAT data base at the European Patent Office. Their comparison of the networks in 1990 and 2007 shows remarkable differences in the network configuration in the two periods. Clearly, in 1990 international technological collaborations were dominated by the US, Japan and the EU. In 2007, the US continued to play a prominent role in the network, in terms of degree centrality, closeness centrality, strength and betweenness centrality but **the 2007 network of international technological collaborations is much denser — with 125 countries, compared with the 79 in 1996** — and with new actors, notably South Korea, China and other East Asian countries playing a much more active role. See Figure II-5-6 below.

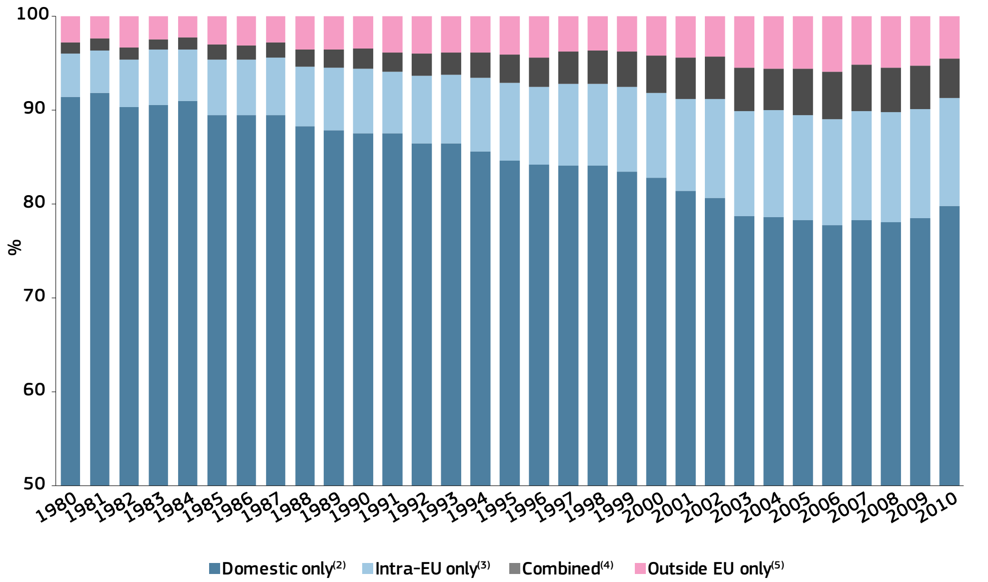
Figure II-5-6 **Evolution of international technological collaborations by number of nodes and links, 1990-2007**



Science, Research and Innovation performance of the EU 2016
Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: De Prato and Nepelski (2014) based on PATSTAT database, version 2010

This increased internationalisation of technological collaboration can also be observed in the EU. Figure II-5-7 shows the evolution in the number of domestic inventions, foreign inventions and combined in the EU between 1980 and 2010 measured through patent applications in the PATSTAT database. **An increasing tendency in the proportion of international technological collaboration over time can clearly be observed although the majority of patent applications continue to be domestic.**

Figure II-5-7 **Evolution in the share of inventions by location of the inventor(1), 1980-2010**



Science, Research and Innovation performance of the EU 2016

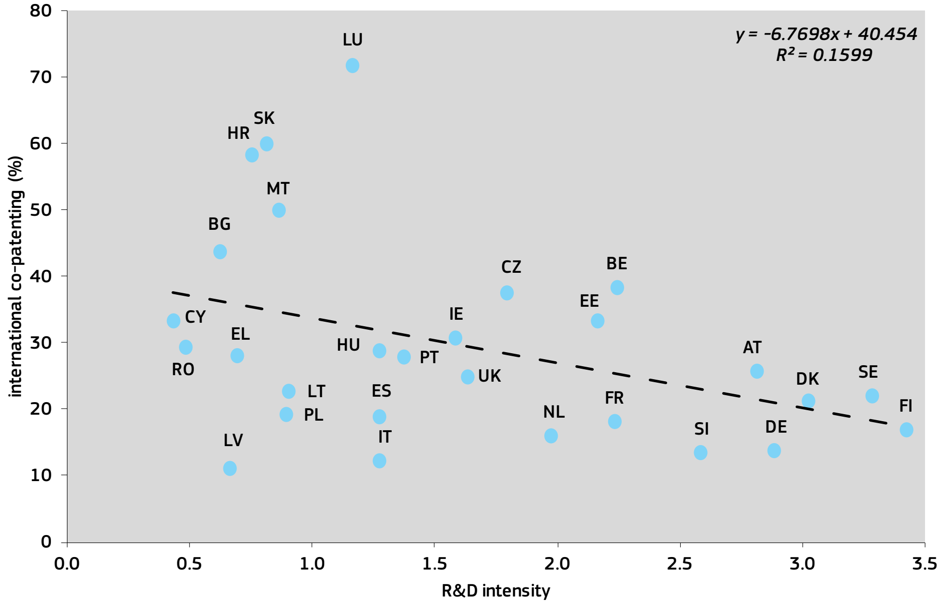
Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Van Looy et al (2014)
Notes: (1)All patent applicants (EPO) are EU applicants. (2)Domestic only: All inventors are from the same country as the applicant. (3)Intra-EU only: At least one inventor is from a different country than the applicant but all inventors are in the EU. (4)Combined: At least one inventor is from the EU and one from outside the EU. (5)Outside EU only: All inventors are from outside the EU.

A further analysis of the location of the foreign partners reveals that most of the international technological collaboration in Europe is within EU27. The proportion of patents combining inventors from the EU and outside the EU are truly scarce (Van Looy et al., 2014). This result is highly coherent with the literature. Geographical distance with the technological partner plays a very important role in the establishment of technological linkages (Paci and Batteta, 2003). One of the main characteristics of networks in general is their reciprocal, preferential and mutually supportive character (Powell, 1990). The basic assumption of network is that of mutual dependence (Chaminade, 2015) and requires the firm and the partner to adhere to a certain structure of exchange (Laursen and Salter, 2014). As compared with knowledge exchange through markets of spillovers, networks are reciprocal -that is bi-directional and long-term- and based on trust. On the other hand, trust is facilitated by geographical and institutional proximity. This is why **the probability of establishing technological collaboration linkages is higher between countries in close proximity**.

The size of the market as well as degree of innovativeness [104] also plays an important role as a driver for the formalisation of technological collaboration networks via co-patenting (Prato and Nepelski, 2012) as well as for patent citations (Paci and Batteta, 2003). The likelihood of establishing international technological networks through co-patenting is inversely related to the innovative capacity of the country measured through GERD as % of GDP, as can be observed in Figure II-5-8 below. Generally, the higher the research intensity of the country, the lower the percentage of international co-patenting. Countries with lower research intensity depend more on international technological collaboration while those countries closer to the technological frontier depend less on international co-patenting.

(104) Measured by patents.

Figure II-5-8 International co-patenting (%)[1] versus R&D intensity, 2012



Science, Research and Innovation performance of the EU 2016

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

Data: OECD, Eurostat

Note: [1]Patent applications to the EPO by application date - % share of patents with foreign co-inventor(s).

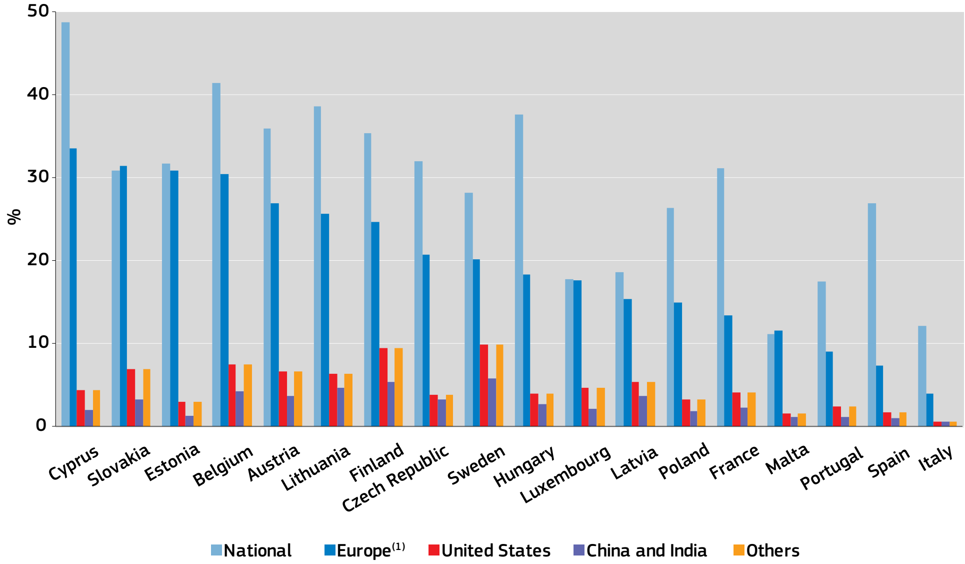
Research collaboration

Another way of looking at international collaboration in innovation is to use the Community Innovation Survey (CIS) data. The CIS asks innovative firms to indicate with whom they collaborated in innovation. Figure II-5-9 plots the percentage of innovative firms that collaborate with national partners, European partners and other international partners. Despite the high variability among European countries, it can clearly be seen that European firms tend to collaborate with national and European partners, thus confirming the results obtained in the analysis of patent data. For Sweden, Finland and to a lesser extent Belgium, Austria, Lithuania and Slovakia, collaboration with US partners is important.

The countries with the lowest percentage of firms collaborating for innovation with European -and generally international- partners is to be found in Italy, Spain and Portugal, all moderate innovators [105]. At the other side of the spectrum we find followers such as Cyprus, Slovakia, Estonia and Belgium with more than 30% of the innovative firms collaborating with other European partners for innovation. Interestingly, the innovation leaders (Sweden and Finland in this graph) are the ones that collaborate more with the US as well as with other international partners (among which are Japan and the Asian tigers).

(105) Based on the Innovation Union Scoreboard, Member States are classified into four performance groups: Innovation leaders (DK, FI, DE and SE), Innovation followers (AT, BE, CY, EE, FR, IE, LU, NL, SI, UK), 'Moderate innovators' (HR, CZ, EL, HU, IT, LT, MT, PL, PT, SK, ES) and 'Modest innovators' (BG, LV, RO).

Figure II-5-9 **% shares of innovative firms that collaborate for innovation - broken down by country of partner, 2010-2012**



Science, Research and Innovation performance of the EU 2016

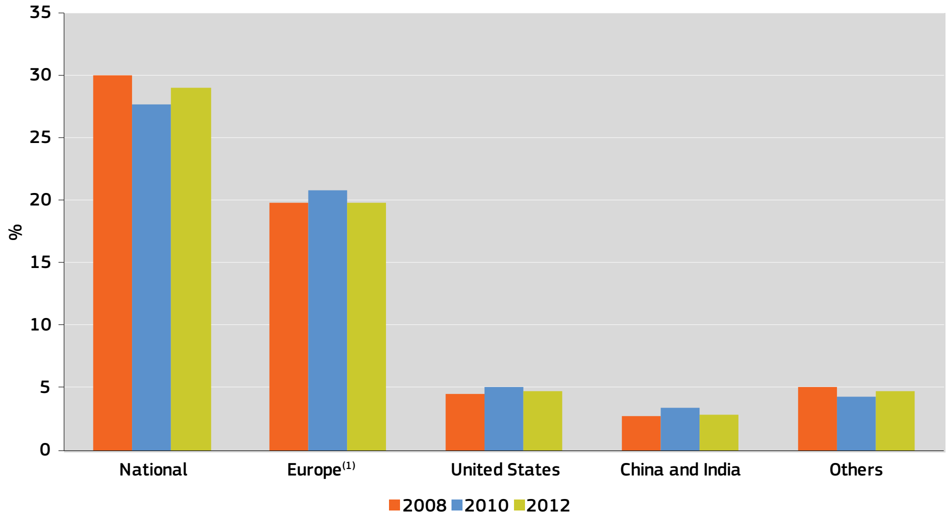
Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies

Data: Eurostat - Community Innovation Survey 2012

Note: [1]Europe includes the EU and the following associated countries: Albania, Bosnia and Herzegovina, Iceland, Kosovo, Liechtenstein, The Former Yugoslav Republic of Macedonia, Montenegro, Norway, Serbia, Switzerland and Turkey.

As a general trend, the percentage of firms that collaborate with China and India for innovation has gradually been decreasing, particularly between the 2010 survey (data corresponding to 2008-2010) and the 2012 survey (data from 2010-2012). See Figure II-5-10. For example, for Sweden –which was the country with the highest percentage of firms collaborating with China and India for innovation- the percentage has dropped from 7.29% in 2008 to 5.8% in 2012. Among the reasons that can explain this recent trend there is the high degree of complexity of coordinating research projects across geographical distances, particularly with partners with high institutional distance, which entail higher costs which tend to offset the potential benefits of the collaboration (Castellani and Pieri, 2013). When the coordination costs are too high, firms may be inclined to substitute or at least decrease the amount of networks in favour of other forms of coordination (offshoring) where they may exert higher control.

Figure II-5-10 **% shares of European[(1)] innovative firms that collaborate for innovation - broken down by partner, 2008-2012**



Science, Research and Innovation performance of the EU 2016

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat - Community Innovation Survey 2008, 2010, 2012
Note: [(1)]Europe includes the EU, EFTA and EU candidate countries. However, the number of countries included in Europe varies between the three versions of the CIS.

5.3.2 Impact of international research collaboration — Is the increasing internationalisation of research collaboration positive or negative for Europe?

International networks are not substituting local or domestic networks but rather complement each other. European firms actively combine knowledge sources on different spatial scales and from various channels and sources in their innovation process (Grillitsch & Trippl, 2013; Trippl et al., 2009; Fitjar and Rodríguez-Pose 2013). International collaboration for innovation can complement local and regional networks in sustaining firms' innovative performance and the generation of 'non-incremental' innovations (Bathelt et al., 2004; Belussi et al., 2010; Chang, 2009; Gertler & Levitte, 2005; MacKinnon et al., 2002; McKelvey et al., 2003; Moodysson, 2008; Ponds et al., 2007).

For European firms, international innovation networks are found to be significant for new to the world or radical product innovation (Nieto and Santamaria, 2007) but their final impact depends on a variety of factors, including the type and location of the partner or the size of the country.

Regarding the types of partners, the impact on the innovation performance is higher when the firm collaborates with international users (Harirchi and Chaminade, 2014; Laursen, 2011) and suppliers (Fitjar and Rodríguez-Pose, 2013). In terms of the size of the country, the degree of international collaboration has a positive impact in small countries but the impact is not significant for innovative firms in large countries. This result reveals that small countries tend to rely much more on international sources of technology and innovation than large countries except if the country is a technological leader, with high R&D intensity, something that is also observable in the previous figures (Ebersberger et al.).

Furthermore, combining domestic and international partners for innovation does not yield similar results in all industries. Although not reported here, both data on technological networks (co-patenting) as well as on research networks (research collaboration) reveal that there is a **high variability in the geographical spread of innovation networks by industry** with traditional sectors showing a more localised pattern of linkages than high-tech industries (Ebersberger et al.; Paci and Batteta, 2003).

High-tech manufacturing industries based on scientific knowledge tend to display a higher propensity to establishing international networks and additionally current evidence suggests that the impact on innovation of combining international and domestic collaboration for innovation is also higher in high-technology manufacturing industries (Ebersberger et al.).

5.4 International mobility of researchers

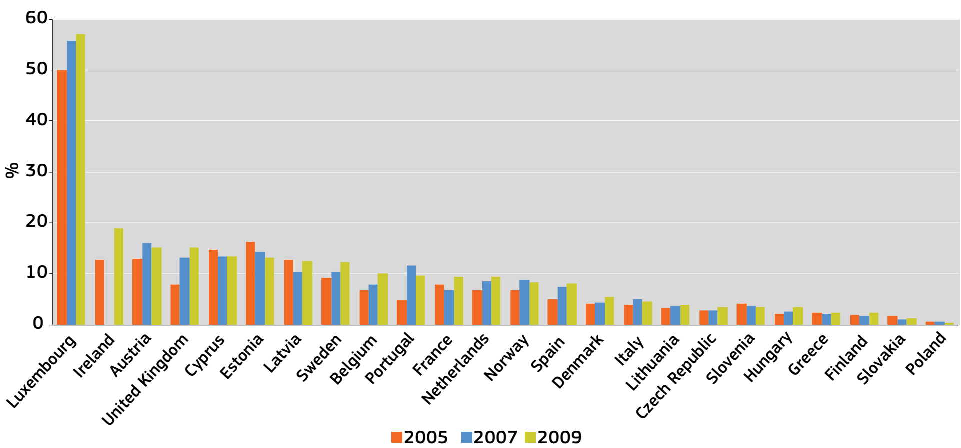
Employee mobility is one of the most important mechanisms for the transfer of knowledge across geographies and organisations since tacit knowledge is sticky in nature and does not flow easily unless the individuals possessing them move. Within the group of knowledge intensive workers, researchers are probably one of the most important collectives. Understanding the trends in the international mobility of researchers and its impact is complex. Their international mobility can be traced by looking at particular groups: scientists, doctorate holders, 'star scientists', as well as using a variety of indicators — from bibliometrics, patent analysis or mobility of R&D personnel- to specific surveys like the one recently conducted by the OECD and Eurostat on the career of doctorate holders (OECD, 2014).

5.4.1 Main trends — Is the international mobility increasing or decreasing? Is Europe gaining or losing talent?

Despite the diversity in data sources, the analysis of the trends in the international mobility of the different collectives of researchers and its impact tends to show a similar picture: **internationalisation is low but it is increasing and this yields positive impacts in terms of scientific quality** (OECD, 2014), **innovation** (Maliranta et al., 2009; Marx, 2011; Song et al., 2003; Trippl, 2009, 2011) **and growth** (Suriñach and Moreno, 2012).

With few exceptions, the general trend in the EU is towards an increasing proportion of foreign-born scientists in the EU states. However, as Figure II-5-11 shows, with the exception of Luxembourg, the proportion of foreign scientists is still rather low and, aside from Sweden, Latvia, Estonia, Cyprus, the UK, Austria, Ireland and Luxembourg the average of foreign-born human resources in science and technology over the total is lower than 10%.

Figure II-5-11 **Foreign-born HRSTC[(1)] as % of total HRSTC, 2005, 2007, 2009**



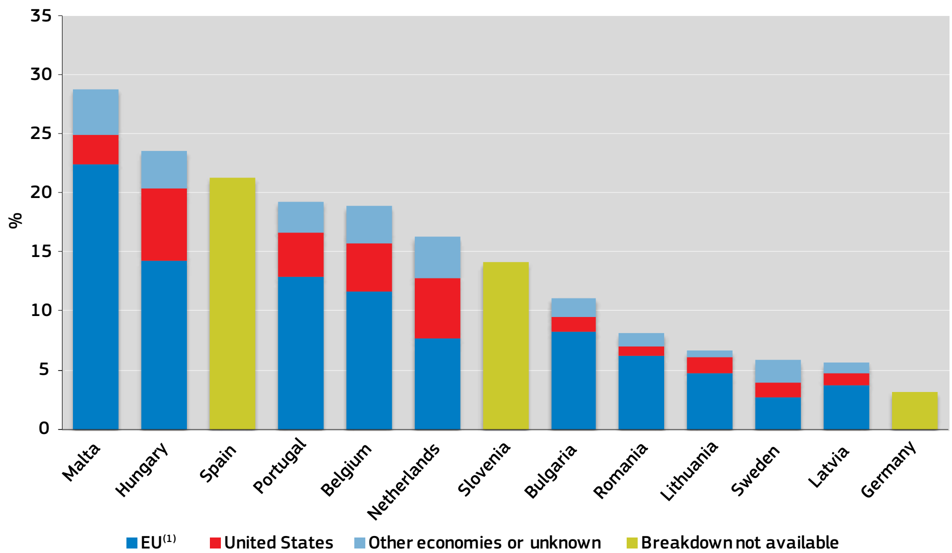
Science, Research and Innovation performance of the EU 2016

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat - Community Innovation Survey 2008, 2010, 2012
Note: [(1)] The Human Resources for Science and Technology Core (HRSTC) population comprises those people who have completed third-level education in an S&T field of study (HRSTE) who also have an S&T occupation (HRSTO). Population from 25 to 64 years.

Proximity plays a crucial role in the mobility patterns. Looking at **international mobility of scientists,** Franzoni et al. (2012) found that most moves tend to happen within neighbouring countries. For example, Germany is the most likely host of inbound scientists from the Netherlands, Belgium, Denmark, Sweden and Switzerland. Similar results were also found by Miguélez et al. (2009) with regards to the mobility of inventors looking at the affiliation of inventors in patent applications in the patent cooperation treaty (PCT). With regards to the mobility to far distant countries, Franzoni et al. (2012) found that language and cultural proximity may play a role (for example, Latin American countries in relation to Spain and Portugal) but also –and to a higher extent- the quality and prestige of foreign research and higher education organisations (for example, top ranked American universities like Stanford, Yale or the MIT).

A similar pattern is observed when looking at the percentage of **doctorate holders** that have lived or stayed abroad in the past 10 years by country of destination. Figure II-5-12 clearly shows that **doctorate holders tend to choose another country in EU27** as their main destination, thus pointing to the **importance of European academic networks and the academic market**. The data also shows significant differences between European countries in the internationalisation patterns of doctoral holders, with Sweden and Germany (innovator leaders) portraying very low numbers of international mobility in sharp contrast with Malta, Hungary and Spain (all three moderate innovators) with at least one fourth of the doctorate holders with international experience. An interesting case is Latvia, a modest innovator with very low levels of mobility. These differences are partly explained by the availability of career opportunities in the country of the PhD. However, they are also due to strong institutional differences in the academic environment between countries as well as general mobility patterns in the respective countries. For example, in Germany the mobility is somehow penalised by the academic community in terms of career opportunities while in other countries, like France or Finland, PhD graduates in certain universities are highly encouraged to work in another university in the country or abroad for a couple of years after PhD graduation before they can be hired in the same university from which they graduated.

Figure II-5-12 **% share of doctorate holders who have lived or stayed abroad in the past ten years by country of citizenship and by region of stay, 2009**



Science, Research and Innovation performance of the EU 2016
Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat, OECD, UNESCO
Note: (1)EU: Croatia is not included.

What the previous data shows is that **there is not any evidence yet to believe that there is a loss of talent in Europe as a whole**- at least when it comes to the mobility of doctorate holders. The international mobility of scientists, in general, and of doctorate holders tends to be mainly intra-EU mobility, which means that the spillovers generated through the mobility of these groups of knowledge-workers tend to remain in the EU. It should be noted, however, that the nature of the data [106] does not provide any clues about trends. Whether the importance of intra-EU mobility of PhD holders has increased or decreased over time and particularly after the crises remains to be studied.

However, one special group of scientists is portraying a different international mobility pattern: the collective of star scientists [107]. Recent data shows that **Europe has been suffering from a net loss of star scientists with a high negative migration balance with the US** which cannot be compensated with the entry of star scientists from Central and Easter Europe (Schiller and Revilla (2010) cf Suriñach and Moreno, 2012). These results are similar to those obtained by Maier et al. (2007). Using data on highly cited researchers worldwide they found that **all countries in Europe showed a negative migration balance except France and Switzerland**. Worldwide, the major net receiver of star scientists is the US, which hosts two-thirds of all highly cited researchers in the world.

5.4.2 Is the international mobility of researchers positive or negative for Europe?

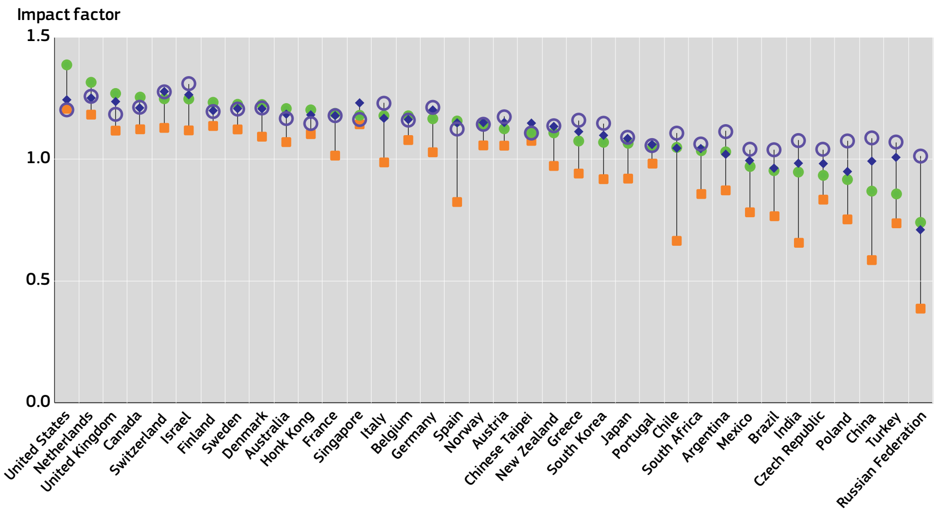
The international mobility of scientists yields, in general, a positive impact both on the host and on the home region. International mobility is associated with higher scientific impact, higher innovation performance and higher growth that go beyond the region in which the scientists are located.

By looking at changes in the affiliation of authors in journal articles, the OECD (2014) tracked the international mobility patterns of **scientists** as well as the impact of the move in terms of citations and concluded that the citations of the scientists who move internationally can be up to 20% higher than those that stay in the same place or country. Figure II-5-13 shows the different citation impact of researchers that have stayed in the same country between 1996 and 2011 (*Stayers*), compared to returnees, new inflows and outflows. Clearly outflows, new inflows and returnees have the highest impact in terms of citations while the lowest impact is for publications of scientists that have remained in the same place.

(106) The data comes from a survey conducted in 2010 in collaboration between the EU and the OECD. Hitherto no longitudinal data is available.

(107) Both Schiller and Revilla (2010) as well as Maier et al. (2007) define star scientists as those researchers that are most frequently cited in their discipline which are identified by ISI web of knowledge (ISI HighlyCited.com).

Figure II-5-13 **Impact factor of scientific publications by mobility patterns of scientists, 1996-2011**



Science, Research and Innovation performance of the EU 2016
Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: OECD

Similarly, the existing literature has well established the positive impact of the **international mobility of doctorate holders in terms of knowledge transfer**. The so-called brain circulation may indicate higher career instability — particularly in the research and higher education sectors where mobility rates are the highest- but it generates benefits to both home and host countries (Edler et al. 2011). Furthermore, brain drain may be offset by inflows of doctorate holders, thus the net results may be positive for the country (Auriol and Freeman, 2013).

The positive impact of the international mobility is particularly clear for star scientists (Suriñac and Moreno, 2011). Using data on the mobility of ***star scientists,*** Trippl (2011) provides evidence on a positive relationship between the mobility of star scientists and knowledge networks in the host region as well as between the host and the home regions. Backward linkages to the home region often remain active (Schiller and Diez, 2010) thus pointing out to the bi-directional (or even multidirectional) nature of their knowledge linkages. Star scientists are often engaged in academic collaboration, research projects with firms, co-patenting or licensing to local firms, more often than non-mobile researchers, although some of these collaborations are sporadic (Trippl, 2011). In this respect, the observed negative flow of star scientists from the EU to mainly the US does not necessarily mean a net loss for the EU in terms of impact, thus so far the linkages with the European home country are maintained.

5.5 R&D foreign direct investments

5.5.1 General trend — Is the EU gaining or losing importance in the global flows of cross border R&D?

The fDi Markets database provides information on the number of cross-border greenfield investment projects announced during the period 2003-2012, including information on countries of origin and destination, nature of the investment and industries around the world in the period between 2003-2012. fDi Markets classifies the investment events according to the main business activities thus making it possible to distinguish investments related to manufacturing from those related to 'R&D' or 'Design, development and testing' (DDT). This data allows us to analyse the patterns of technology-driven investments and their potential differences with other forms of offshoring (for example manufacturing)

Researchers have long assumed that R&D tends to co-locate with production facilities (Liu et al., 2013). While this may be true in some cases (Ernst, 2010), it is not in all, particularly in technology intensive industries (Audretsch and Feldman, 1996; Mariani, 2002).

The following tables provide some evidence in this direction. They show cross-border investments in DDT and R&D activities by area of origin and destination, including projects in manufacturing activities as a benchmark (Castelli and Castellani, 2013). The first thing that can be appreciated is that the amount of cross-border R&D and DDT projects is substantially lower than the number of manufacturing. However, the data also reveals substantial differences in the patterns of internationalisation of R&D and DDT with respect to manufacturing.

Figures II-5-14 and II-5-16 show that cross-border investments in R&D-related activities are less bound by geographic distance than projects in manufacturing activities. For example, while intra-Europe investments in manufacturing account for 47.7% of all cross-border investments of Multinational Corporations (MNCs) from Western Europe, this share drops to 36.1% in the case of DDT projects and 37.3% for R&D (Chaminade et al., 2014). The evidence is consistent with some recent econometric studies showing that geographic distance between the home and host country may be less of an obstacle for R&D-related projects than it is for manufacturing. This is because companies may need to locate R&D investments in distant locations to gain access to specific knowledge which they would not be able to access otherwise (Castellani et al., 2013, Chaminade and de Fuentes, 2012).

Figure II-5-14 Cross-border investment projects in R&D-related and manufacturing activities, by country of origin, January, 2003 - August, 2012

DDT				R&D				Manufacturing			
Rank	Country	Number of projects	% share	Rank	Country	Number of projects	% share	Rank	Country	Number of projects	% share
1	United States	1 804	45.3	1	United States	1 351	42.7	1	United States	5 369	17.6
2	Germany	386	9.7	2	Germany	287	9.1	2	Japan	4 332	14.2
3	United Kingdom	278	7.0	3	Japan	253	8.0	3	Germany	3 689	12.1
4	Japan	274	6.9	4	France	163	5.2	4	France	1 678	5.5
5	France	219	5.5	5	United Kingdom	162	5.1	5	United Kingdom	1 427	4.7
6	India	131	3.3	6	Switzerland	119	3.8	6	Italy	1 055	3.5
7	Switzerland	114	2.9	7	China	97	3.1	7	Switzerland	1 031	3.4
8	Netherlands	84	2.1	8	South Korea	79	2.5	8	South Korea	939	3.1
9	Canada	77	1.9	9	Netherlands	75	2.4	9	Netherlands	799	2.6
10	Sweden	51	1.3	10	Canada	70	2.2	10	Chinese Taipei	717	2.3
11	China	50	1.3	11	India	65	2.1	11	Canada	708	2.3
12	Spain	48	1.2	12	Sweden	57	1.8	12	Spain	699	2.3
13	Finland	46	1.2	13	Finland	40	1.3	13	China	635	2.1
14	South Korea	44	1.1	14	Italy	38	1.2	14	Sweden	632	2.1
15	Denmark	36	0.9	15	Denmark	38	1.2	15	India	605	2.0
	Other countries	338	8.5		Other countries	268	8.4		Other countries	6 239	20.4
	TOTAL	3 980	100		TOTAL	3 162	100		TOTAL	30 554	100
	Top 5	2 961	74.4		Top 5	2 216	70.1		Top 5	16 495	54.0
	Top 10	3 418	85.9		Top 10	2 656	84.0		Top 10	21 036	68.8
	Top 15	3 642	91.5		Top 15	2 894	91.5		Top 15	24 315	79.6
	Top 20	3 787	95.2		Top 20	3 031	95.9		Top 20	26 530	86.8
	Herfindhal Index		0.231		Herfindhal Index		0.208		Herfindhal Index		0.097

Science, Research and Innovation performance of the EU 2016

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

Data: Castelli and Castellani (2013)

The EU as origin of the investments

Looking only at investments **from the EU,** Castellani and Pieri (2013) show that most of the R&D offshoring projects of European firms are directed towards non-European countries and only less than one fourth are intra-European investments. Figure II-5-15 shows that the main non-European recipients of R&D offshoring from the EU are China and India, then the US, Japan and Canada, which together account for 19.90%, further followed by other South-East-Asian countries. Other emerging economies, which include important destinations such as Brazil and Russia, also attract a considerable number of projects.

Figure II-5-15 **Cross-border investments from the EU by region of destination and by nature of the investments, 2003-2012**

	DDT	R&D	Manufacturing
EU15	21.3%	27.4%	19.5%
EU12	10.1%	6.2%	16.1%
Other EU	2.0%	2.5%	4.8%
Developed (United States, Canada, Japan)	18.7%	19.9%	13.4%
South-East Asia	7.6%	9.0%	4.5%
South Korea	1.2%	1.8%	0.7%
Brazil	3.1%	2.6%	3.7%
China	11.2%	13.5%	11.5%
India	13.7%	8.3%	6.3%
Russian Federation	1.5%	2.2%	6.0%
South Africa	0.6%	1.1%	0.7%
Rest of the world	9.0%	5.5%	12.8%
Total number	156	725	12 665

Science, Research and Innovation performance of the EU 2016
Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Chaminade et al. (2014) based on Castellani and Pieri (2013)

The relative importance of China and India as recipients of R&D investments by European firms can be explained by looking at both push and pull factors. On the one hand for European firms, investments in R&D abroad are motivated by the access to knowledge and markets, particularly accessing qualified human resources that are not available in the numbers or quality in the home European regions (Borras and Haakonsson, 2010). Since knowledge is very unevenly distributed across space (Asheim and Gertler, 2005; Malecki, 2010) firms strategically target specific countries and specific regions where that knowledge is located. Offshoring of R&D is used as a mechanism to access ubiquitous knowledge across distance (Liu et al., 2013). On the other hand, the combination of very large growing markets together with a rapid accumulation of technological capabilities (Altenburg et al., 2008) has made China and India very attractive destinations for R&D related investments, particularly in certain regions like Beijing, Shanghai or Bangalore (Chaminade and Vang, 2008; Crescenzi et al., 2012).

Europe as recipient of investments

Europe is also an important recipient of cross-border R&D investments from abroad. Although most of the R&D and DDT related investments worldwide go to China, India and the US, European countries such as the UK, Germany and France are not far behind. In fact, four European countries are among the top 10 destinations of DDT projects and five of them are among the top 10 of R&D projects. See Figure II-5-16.

Figure II-5-16 **Cross-border investment projects in R&D-related and manufacturing activities, by country of destination, January, 2003 - August, 2012**

DDT				R&D				Manufacturing			
Rank	Country	Number of projects	% share	Rank	Country	Number of projects	% share	Rank	Country	Number of projects	% share
1	India	809	20.3	1	China	534	16.9	1	China	4 969	16.3
2	China	511	12.8	2	India	466	14.7	2	United States	2 776	9.1
3	United States	316	7.9	3	United States	249	7.9	3	India	1 879	6.1
4	United Kingdom	261	6.6	4	United Kingdom	187	5.9	4	Russian Federation	1 323	4.3
5	Germany	140	3.5	5	Singapore	151	4.8	5	Brazil	1 061	3.5
6	Singapore	115	2.9	6	France	126	4.0	6	Poland	963	3.2
7	Brazil	99	2.5	7	Germany	108	3.4	7	Mexico	959	3.1
8	Canada	94	2.4	8	Ireland	106	3.4	8	Thailand	941	3.1
9	Spain	91	2.3	9	Spain	90	2.8	9	France	872	2.9
10	France	90	2.3	10	Canada	83	2.6	10	United Kingdom	834	2.7
	TOTAL	3 980	100		TOTAL	3 162	100		TOTAL	30 554	100
	Top 5	2 037	51.2		Top 5	1 587	50.2		Top 5	12 008	39.3
	Top 10	2 526	63.5		Top 10	2 100	66.4		Top 10	16 577	54.3
	Top 15	2 868	72.1		Top 15	2 408	76.2		Top 15	20 145	65.9
	Top 20	3 132	78.7		Top 20	2 638	83.4		Top 20	22 443	73.5
	Herfindhal Index		0.076		Herfindhal Index		0.071		Herfindhal Index		0.051

Science, Research and Innovation performance of the EU 2016
Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Castelli and Castellani (2013)

Europe is an important destination of Chinese and Indian investments abroad. The analysis of all investments by emerging multinationals in Europe indicates that the EU represents 31% of all the outward FDI from China to the world and 33% of Indian outward FDI (Chaminade, 2015). A recent study on the technology driven investments by emerging multinationals in Europe reveals that the investments are attracted to particular technological poles — for example, automotive to Germany, renewable energies to Denmark and ICT more widely spread (Chaminade, 2015).

5.5.2 Impact — Are the new trends positive or negative for Europe?

The existing literature suggests that there is a positive impact between R&D offshoring and firm performance. Piscitello and Santangelo (2009) find that there is a positive impact of offshoring of R&D towards BRICS countries [108] on the knowledge production of OECD based firms, including European firms. However, the final impact is mediated by a series of factors — particularly the time past after the investment, the managerial capabilities to learn from the environment and manage transnational projects or the ability to choose successful R&D projects, all of which influence the cost-effectiveness of the cross-border R&D investment (Castellani and Pieri, 2013; Chaminade, 2015).

The analysis of offshoring R&D projects by European multinationals conducted by Castellani and Pieri (2013) reveals that offshoring of R&D activities has a positive impact in terms of productivity growth of European regions. Offshoring regions have a higher productivity growth relative to non-offshoring regions,

[108] Plus Korea, Singapore and Taiwan.

but the effect of R&D offshoring is slightly decreasing with the number of investments. Further analysis by country of destination indicates that the effect is larger and significant in the case of R&D offshoring toward South-East-Asian countries and also positive in the case of R&D investments towards China. On the other hand, regions which are offshoring R&D intensively towards India experience significantly lower productivity growth rates. One possible explanation for these results may lie in the types of projects. While R&D projects to South East Asia are disproportionally concentrated in high-tech manufacturing (43% of all R&D projects in the area are in these manufacturing industries), R&D offshoring towards India is much more concentrated in knowledge-intensive services (52%). As recent evidence seems to suggest coordinating global value chains in services is much more complex than in manufacturing and the benefits of offshoring may be offset by the high costs resulting from managing these complex value chains (Castellani and Pieri, 2013).

What the existing evidence seems to suggest is that offshoring of R&D tends to complement –rather than substitute- R&D conducted in Europe. However, the benefits from these potential complementarities are not similar for all industries. Piscitello and Santangelo (2009) found that firms in high-tech industries benefit more clearly from complementarities between domestic and offshored R&D to BRICS [109], while firms in low tech industries seem to benefit largely from the R&D offshored to BRICS (and not so much from the domestic).

In the case of inward investments in R&D into Europe a recent study based on a survey undertaken in Germany and Italy on MNEs from advanced countries (AMNEs) and emerging countries (EMNEs) investing in the machinery industry (Giuliani et al., 2014) found that investments by EMNEs are, in fact, more likely to involve local innovation networks in the host countries and create win-win situations in terms of mutual learning than in the case of technology-driven investments by advanced country multinationals (Giuliani et al., 2014). Although one should be cautious with generalisations, these results indicate a positive impact or, at least, to a not generalised predatory behaviour by emerging multinationals investing in technology in Europe.

5.6 Conclusions

In this chapter, we have analysed different mechanisms that facilitate the international exchange of knowledge in Europe, from the trade of high-tech products and services to the mobility of human capital, research and technological collaboration and offshoring of R&D. The previous sections point out some clear trends.

The EU is still performing well in terms of **exports of knowledge intensive goods and services** in a global perspective although we have observed in recent years that China and the US are closing the gap with the EU in terms of knowledge-intensive products and services, respectively. Second, the analysis of the global value chains suggests that the European component of those exports is also very high. Third, the rate of globalisation of value chains is accelerating and it is much faster than the fragmentation at the EU level. This means that although being part of the EU is still important for trading knowledge intensive products, the shares of added value outside the EU and the number of countries participating in the global chain are rapidly increasing. While maintaining the volume of high-tech exports is important, in the long-term it is even more crucial to retain the largest share of value added.

Along the global value chain, advanced countries are specialising in skill-intensive activities like design, R&D or marketing, while emerging economies like China are capital and labour-intensive (Timmer et al., 2914; Van der Marel, 2015). This suggests that Europe's competitive advantage in this increasing global fragmentation of production and trade is based on its innovation performance widely defined (not only R&D).

While traditional trade policies such as removing tariffs, facilitating administrative procedures

(109) Plus Korea, Singapore and Taiwan.

and regulating the single market are effective in promoting the access to global value chains, a different set of policies is needed for upgrading the value chain towards higher added value activities. The analysis of the new global input-output data shows that investments in innovation (R&D, training of human capital, innovation climate) as well as ICT infrastructure are crucial. This suggests a very tight link between innovation and trade which demands high levels of coordination between these two traditionally separated policies.

The analysis reveals that proximity matters significantly for the **mobility of human capital** as well as for the establishment of **collaborative networks**. Both mechanisms are adequate for the transmission of tacit knowledge, requiring face-to-face interaction and trust and are facilitated not only by geographical but also by institutional proximity. In both cases, intra-Europe knowledge flows are more important that extra-Europe knowledge flows, thus pointing to the role of the European market facilitating these forms of exchange. This is particularly clear in the case of some followers and moderate innovators like Hungary, Portugal, Spain or Lithuania for which technological collaboration and, in some cases, international mobility of doctorate holders is important.

Looking at the main motivations for moving to a different country may provide some useful information for the design of policies to attract scientists in Europe. The mobility of scientists could be related to scientific, economic, cultural and personal factors (Schiller and Diez, 2010). Both in the case of outbound mobility of scientists in general (Franzoni et al., 2012), doctorate holders in particular (Auriol and Freeman, 2013) or star scientists (Schiller and Diez, 2010), academic factors are the most important reasons for moving abroad, followed by economic and job-related factors and, to a lesser extent, family or personal reasons [110]. However, being close to family and friends or being in an environment with a similar culture gains importance in the decision to return to the home region (Franzoni et al., 2012; Schiller and Diez, 2010).

This has important policy implications. Attracting talent from abroad as well as retaining local talent in Europe, particularly in the case of star scientists, depends largely on the quality of the research and education facilities (outstanding faculties, colleagues or research teams) and attractive working conditions (including good research environments). This can explain the lower mobility observed in countries like Germany and Sweden (both innovation leaders) and the higher mobility of scientists from moderate innovation countries. Currently, the majority of the programs to facilitate mobility are targeting the economic dimension of mobility (European Commission, 2014) — for example by providing funding to study abroad which may not be a sufficient incentive for the mobility unless the other two conditions (quality of the research and education facilities and attractive working conditions) are met.

The patterns of **offshoring of R&D** as well as trade networks are rather different- more global than intra-European. In other words, trade and investment networks are more dispersed globally than mobility of human capital and **research and technological networks**. These findings are coherent with those obtained by Cassi et al. (2012); Castelli and Castellani (2013); and Prato and Nepelski (2012) who also found that trade and investments are less bounded geographically than other forms of knowledge networks.

Policy action towards internationalisation of innovation activities has to be very aware that, while offshoring of R&D tends to yield positive impacts, **differences across industrial sectors and countries of origin and destination are important**. While the internationalisation of R&D and other innovation activities related to manufacturing may have a positive impact in terms of productivity growth of the home country, offshoring of R&D related to knowledge-intensive services can be more problematic.

On the other hand, the relatively lower organisational problems in high-tech manufacturing and the concentration of cutting

(110) The study of Franzoni et al. focuses only on five scientific disciplines: biology, chemistry, earth and environmental sciences and materials science.

edge technologies developed in South-East Asian countries, contribute to a potentially positive association of offshoring R&D to this regions and the productivity growth of EU regions.

Investment decisions are affected by a wider array of policies and barriers which are typically unrelated with trade issues (Los et al., 2015; World Economic Forum (Wef), 2012). Other investment-related policies — ranging from competition, trade and intellectual property rights to environmental and labour market policies — have a greater impact on technology-driven FDI (Chaminade and Rabelotti, 2015). Difficulties in obtaining short-term business visas for the mobility of personnel, capital restrictions or limitations to move capitals between Europe and the home country are some of the non-traditional investment barriers mentioned by several investors in Europe, headquartered in an emerging country (Chaminade, 2015). Additionally, some countries, like Germany, have restrictions to the access to IP in cases of acquisition [111], which is one of the main reasons causing delays, increases in costs and often requiring changes in the investor strategy. If policy-makers want to influence R&D related investments into Europe a much wider set of policies is needed — one that goes beyond traditional trade regimes and includes, for example, provisions for the mobility of human capital, the management of intellectual property rights and that facilitates the establishment of local linkages with European firms.

(111) The investor must acquire the 100% of the company.

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6. Do research and other sources of innovation drive productivity gains in top European R&D investors?

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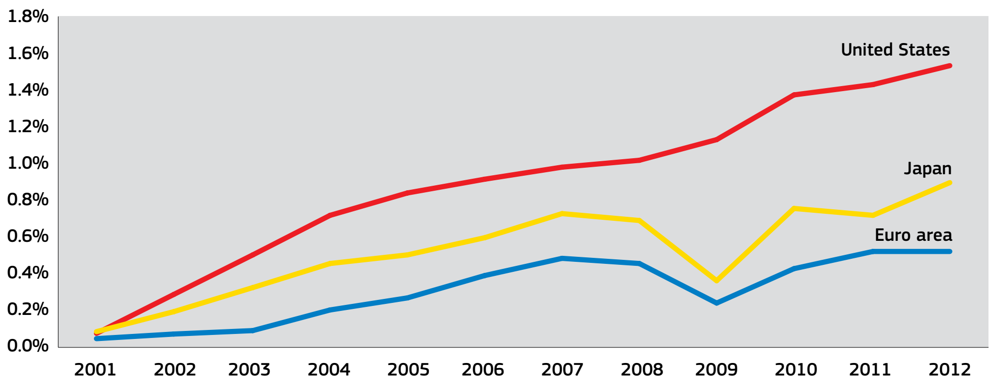
6.1 Introduction

There is long-standing consensus among experts and policy-makers that one of Europe's main impairments to make progress towards sustainable economic growth is its sluggish evolution of productivity. For example, Europe's labour productivity growth continues to be on the decline in the aftermath of the crisis. This is the continuation of nearly three decades of slowdown which result in an increasing gap between the EU and the US. Evidence also shows that one of the main growth detractor factors for the EU economy in the period 2008-2013 has been total factor productivity (TFP), which decreased 0.7 percent in the EU27 [112].

The existing literature and empirical evidence show that causes of this productivity slowdown in Europe may be related to lower investment levels in ICT and in other intangible assets (R&D, skills, organisational capital), particularly in the services sector. Both ICT and intangible assets are interrelated and determine effectiveness in translating investments into development and adoption of new technologies and into successful innovations.

Since the establishment of the 3% R&D intensity target [113] back in 2002, EU policy-makers have strived to design and implement appropriate policy measures to hit this target. According to official science and technology statistics, one of Europe's main weaknesses lies in the level of R&D financed and implemented by the business sector (Business Enterprise Expenditure on R&D– BERD-indicator). Therefore, finding the appropriate measures to incentivise and support the level of R&D investment financed by the business sector remains a major policy challenge.

Figure II-6-1 **The gap in productivity growth rates - annual compound growth in GDP per person employed[(1)], 2001-2012**



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Sources: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies, JRC - Knowledge for Growth Unit
Data: OECD
Note: [(1)]US dollar PPPs at constant 2005 prices.

[112] Van Ark (2014).

[113] A policy response to the need for sustainable growth in the EU has been to set a quantitative target of 3% for the intensity of the R&D investment efforts made in the economy by all economic agents in relation to GDP. While both the public and the business sectors should contribute to it, there is an indication that in reaching such a target the latter should bear the heaviest share, ideally two thirds of the total investment effort.

Beyond the need to increase the amount of money invested in R&D, policy-makers and business leaders should also pay attention to the returns obtained from such investments. Evidence shows that the translation of R&D and innovation investments into higher levels of productivity, better firm performance and ultimately long-term prospects of sustainable economic growth are far from automatic. A better understanding of such transmission mechanisms and of the conditions (both internal and external to the firm) needed to ensure appropriate levels of R&D investment returns is therefore very relevant for policy-makers in charge of designing specific incentives and financial support instruments to increase business R&D.

This chapter provides an overview of the empirical evidence of the link between R&D investments and productivity at a firm level, using data from a sample of the world's top R&D investors [114], representing more than 90% of the R&D financed and implemented by the business sector worldwide. Such evidence shows that the impact of investment in R&D on labour productivity, technical efficiency and ultimately on a firm's overall performance varies among sectors and firms, which calls for the establishment of differentiated support policies. In addition, results show that there are indirect effects of R&D on productivity which cannot be considered in isolation from a broader concept of non-technological innovations, which leads to the need for firms to combine R&D investments with investments in other intangibles and for policy-makers to create the right conditions to allow such indirect effects on productivity to take place –e.g., internationalisation and cooperation.

The chapter is organised as follows. We first analyse the direct link between R&D investments and firms' productivity and efficiency. Second, we look at the indirect link between R&D investments and productivity through the consideration of other related factors such as the degree of a firm's internationalisation, the level of cooperation among firms and investments in other intangible assets beyond R&D, like training or design. We conclude by summarising the main policy implications.

[114] Annual reports and datasets of the EU Industrial R&D Investment Scoreboard are available at: http://iri.jrc.ec.europa.eu/scoreboard.html.

6.2 R&D Investments and firm's productivity

This section is organised into two parts. The first part reviews, although not exhaustively, the general empirical findings of the seminal papers examining the R&D-performance link. The second part collects the main results of studies reporting evidence on how R&D increases the overall performance of R&D intensive companies, largely confirming the findings of the first part and extending them to account for firm heterogeneity.

6.2.1 The determinants of Productivity and Efficiency

A voluminous amount of literature has been devoted to investigating the effects of R&D investment on economic performance of companies, sectors and countries. The knowledge capital model of Griliches (1979) has been the starting point for both 'production function' and 'distance to frontier' approaches, and has remained a cornerstone of the productivity literature for more than 25 years. Stemming from the seminal theoretical work of Griliches, empirical works have commonly found that R&D activities, such as R&D and innovation investments, make a significant contribution to enhancing firms' productivity. The estimated overall average elasticities range from 0.01% to 0.17% [115] and the rate of returns [116] range from 0.10% to 0.43%, depending on the measurement methods and the data used. Griliches and Mairesse (1981), Cuneo and Mairesse (1983) and Hall and Mairesse (1995) empirically validated the relationship between productivity and the level of R&D investments and found that R&D firms have higher R&D returns and higher productivity compared to non-R&D performing firms (Klette, 1996).

[115] R&D elasticity is the degree of responsiveness of output or productivity to changes in the level of R&D. For example, an elasticity of R&D to productivity that equals 0.17 means that for a 1% increase in R&D investment, the productivity increases 0.17%.

[116] The rate of R&D returns is the elasticity of output or productivity growth rate with respect to R&D growth.

Box 1 **Productivity and efficiency: Differences and measures**

Productivity measures the economy's ability to utilise its physical and human resources to generate output and income. Many approaches can be used to calculate productivity. The two most commonly used measures of productivity are partial factor productivity, such as labour productivity, usually measured as the volume of output per hour worked, and multi-factor productivity or total factor productivity (TFP).

TFP is the portion of output not explained by the amount of inputs used in production. TFP plays a critical role when trying to assess economic fluctuations and economic growth as it is an encompassing indicator of the overall improvement of the economy. In fact, the level of TFP not only indicates how intensely the inputs are utilised in production, but it also captures the influence of improvements in production-related factors such as skills, technology, and management practices that are not incorporated in official capital and labour measures.

TFP represents the so-called spillovers or externalities that create societal benefits, arising from returns on inputs that go beyond those that can be internalised by the investor. For these reasons, it is the only sustainable source of long-term economic growth (van Ark, 2014).

At the firm level, when discussing the economic performance of companies, it is common to describe them as being more or less 'efficient' or 'productive'. While the term productivity refers to the volume of output produced by one or more inputs, the term efficiency relates to the comparison between observed and optimal values of output and input. This typically involves the comparison between the observed output to maximum potential output obtainable from the input, or to minimum potential input required to produce the output, or some combination of the two. Technically efficient companies may still be able to increase their productivity, by for example exploiting economies of scale. As changing the scale of production and operations can be difficult to achieve quickly, both efficiency and productivity can be given long-run interpretations.

The methods used to derive measures of efficiency and productivity can be classified into two main groups. The first group of econometric techniques consists of TFP indexes and production functions models which are often applied to panel-data and provide measures of technical change and TFP. The underlining assumption of this method is that all firms are assumed to be technically efficient. The second group of methods includes data envelopment analysis (DEA) and the stochastic frontiers approach, and provides measures of relative efficiency and technical change (when panel-data is available). The estimation of best practice technology is still achieved from a production function, where it is assumed that the 'best' companies in the sample are producing in a technically efficient way.

Also, evidence shows that the impact of publicly funded R&D on productivity is somewhat smaller than private R&D (Griliches, 1986; Levy and Terleckyj, 1983) but still positive, excluding the possibility of a crowding out effect of governmental R&D (Scott, 1984). Other studies have confirmed the positive direct impact of government R&D and in some cases that the long-run impact of public research is higher than the private, especially when the private R&D intensity is high (Guellec and van Pottelsberghe de la Potterie, 2001 and 2004). Public R&D can therefore be very valuable to the economy, particularly in a context of high business R&D intensity.

Some empirical studies assessed the causal link between R&D and productivity. It seems that R&D is causing TFP (Rouvinen, 2002) and that, despite some evidence of feedback effects, the causation runs mainly from R&D to TFP (Franzen, 2003).

Among the studies investigating the R&D-productivity link, it is possible to distinguish various strands of research which derive from the classical knowledge capital model of Griliches.

In particular, the heterogeneity across sectors and the differences among countries have been some of the most explored. The empirical work of Bart Verspagen (1995) showed what the other studies have confirmed, i.e., the R&D elasticity is especially higher for firms in high-technological sectors than in medium- and low-technological sectors. In the same article, the author also reported the lack of statistically significant difference across nine OECD countries. The same exercise has been applied to compare the returns to R&D between Germany and Sweden (Lööf et al. 2004) and between the US and France (Hall and Mairesse, 1996). These studies reach the same conclusion of similar results across the countries examined.

Other studies concerning the presence of intra-firm and intra-country spillovers and technological opportunity derive from the work of Griliches (1979) and Jaffe (1986). Jaffe defined technological opportunity as the exogenous variation in the state of technology (costs and the difficulty of innovation in different technological areas). In his article, he quantified the impact of technological opportunity and the spillovers of R&D to other firms. He found that the elasticity of R&D to profits is increased by the R&D of technologically similar firms, and that the involuntary spillovers of knowledge lower the profits and market value of low R&D-intensive firms. The impact of R&D spillovers across countries is somehow less clear. In fact, while Lichtenberg (1992) achieved the main conclusion that countries benefit more from their own R&D, Griffith et al. (2004), with a cross-country and cross-sector analysis, showed a positive impact of R&D spillovers from frontier to non-frontier countries.

More recently, the heterogeneity among firms' productivity has received a lot of attention. From the theoretical model of Melitz (2003) on trade and productivity, a growing empirical literature has documented that firm-level differences in productivity, export status, size, R&D, technology, ownership status, and other characteristics are crucial to understanding differences in firms' returns to R&D (Aw et al. 2011). Dorazelski and Jaumandreu (2013) relaxed the linear R&D capital accumulation assumption of Griliches (1979 and subsequent works), by modelling the interactions between current and past investments in knowledge in a flexible fashion. Allowing R&D and productivity to be endogenous, they find that the impact of current R&D on future productivity depends crucially on current productivity.

Additionally to the firm, sector and country heterogeneity, the link between R&D and productivity is subject to nonlinearity. The empirical study of Kancs and Siliverstovs (2012), based on the sample of world top R&D investors (*EU R&D Scoreboard* data), reported evidence of this nonlinear effect of R&D. A more detailed description of this and other evidence obtained analysing this sample is included in later sections.

6.2.2 Evidence from top corporate R&D investors

Productivity measures based on sector- or country-level data cannot take into account the widely observed heterogeneity in size, age, production technologies and productivity levels of producers. The advantage of relying on firm data is that it allows analysing such company heterogeneity. In addition, micro-data can provide a deeper understanding of firm dynamics, i.e., the reallocation of resources arising from the expansion and contraction of existing firms, as well as entry and exit of firms.

In this Section, the main findings from studies carried-out by authors working at the Joint Research Centre of the European Commission (EC-JRC) on the impact of R&D on productivity using firm level data on world top R&D investors are reported.

6.2.2.1 Description of the Data

The *EU R&D Scoreboard* presents a ranking of the world companies that invest the most in R&D and analyses them on the basis of a series of economic and financial indicators. The 2500 world top R&D investors analysed in the 2014 *EU R&D Scoreboard* edition represent more than 90% of the total expenditure on R&D financed and performed by the business sector worldwide. The *EU R&D Scoreboard* panel data set contains economic and financial information indicators (e.g., R&D investment, net sales, operating profits, employees, market capitalisation) [117] as well as information on the structure of the subsidiaries of the 2 858 most important R&D-intensive firms worldwide from 2004 to 2012. Data is organised at three digit level sector, using the Industry Classification Benchmark (ICB), as well as at geographical level, according to the location of the company's headquarters.

Figure II-6-2 reports the average number of employees across world regions and by sector group. The largest companies belong to low-tech industrial groups and are located in the Brazil, Russia, India and China (BRIC) countries, Switzerland, and other countries (RoW), while the smallest companies are in the European and US high-tech sectors (7.8 and 9.2 thousand employees, respectively). In general, the more technological intensive, the smaller the companies are, except for Japanese companies that have very similar company sizes across the different sector groups.

Figure II-6-2 **Average number of employees in knowledge intensive companies by sector (thousands)[1]**

Sector	World Region				
	EU	Japan	United States	Rest of the world	Average across geographical areas
High	7.8	18.6	9.2	12.7	10.2
Medium-high	19.8	18.9	22.8	21.2	20.4
Medium-low	43.2	16.6	34.4	37.7	35.1
Low	46.6	13.5	18.3	65.0	40.5
Average across all sectors	22.1	18.0	14.7	23.2	

Science, Research and Innovation performance of the EU 2016

Sources: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies, JRC - Knowledge for Growth Unit

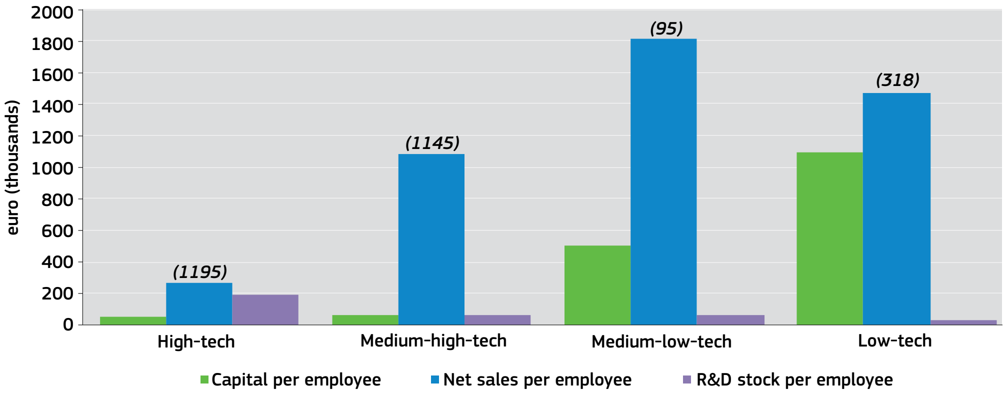
Data: EU R&D Scoreboard, 2004-2014

Note: [1]Average values (or calculations) covering the period 2004-2012.

Figure II-6-3 reports some of the main statistics such as the average capital per employee, R&D stock per employee, labour productivity (measured as net sales per employee) and the number of companies by sector group. The capital and R&D stocks are calculated from the annual capital and R&D expenditures using the perpetual inventory method with a fixed depreciation rate of 10%. Low and medium-low tech firms are the more capital intensive, and also the more productive. Figure II-6-4 shows the same statistics across world regions. Europe appears to be the region with the highest sales per employee and capital intensity.

[117] The data set is compiled from companies' annual reports and accounts. In order to maximize the completeness and to avoid double counting, the consolidated group accounts of the ultimate parent company are used. Companies which are subsidiaries of another company are not considered separately. Where consolidated group accounts of the ultimate parent company are not available, subsidiaries are however included. In case of a demerger, the full history of the continuing entity is included, whereas the history of the demerged company goes only back as far as the date of the demerger to avoid double counting. In case of an acquisition or merger, the estimated figures for the year of acquisition are used along with the estimated comparative figures if available.

Figure II-6-3 **Capital, net sales and R&D stock per employee by sector group[(1)]** *(number of companies in brackets)*



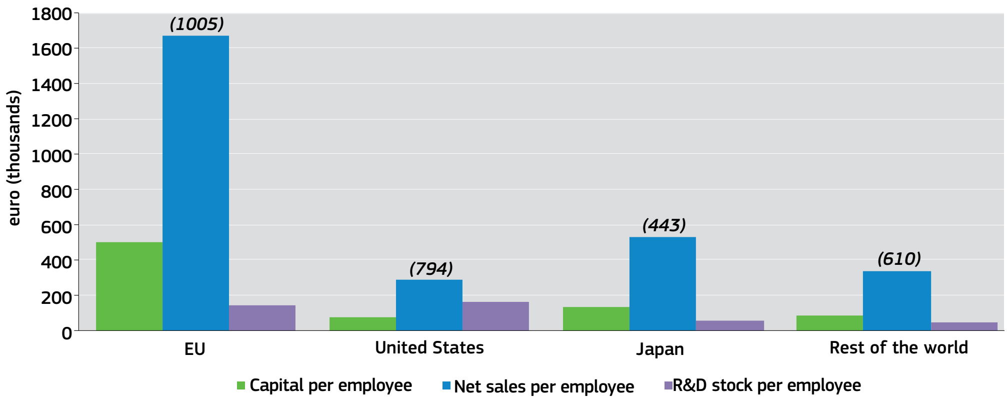
Science, Research and Innovation performance of the EU 2016

Sources: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies, JRC - Knowledge for Growth Unit

Data: EU R&D Scoreboard, 2004-2014

Note: [(1)]Average values (or calculations) covering the period 2004-2012.

Figure II-6-4 **Capital, net sales and R&D stock per employee by world region[(1)]** *(number of companies in brackets)*



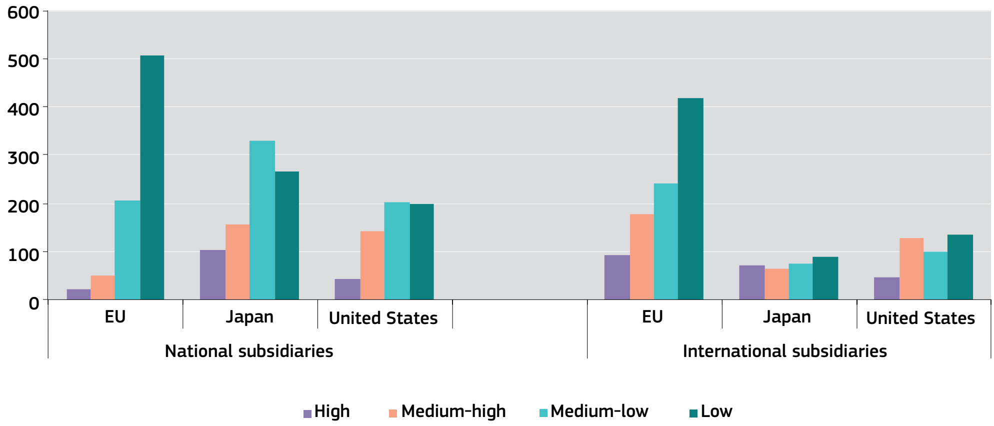
Science, Research and Innovation performance of the EU 2016

Sources: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies, JRC - Knowledge for Growth Unit

Data: EU R&D Scoreboard, 2004-2014

Note: [(1)]Average values (or calculations) covering the period 2004-2012.

Figure II-6-5 **Number of national and international subsidiaries by sector group[1]**



Science, Research and Innovation performance of the EU 2016

Sources: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies, JRC - Knowledge for Growth Unit

Data: EU R&D Scoreboard, 2004-2014

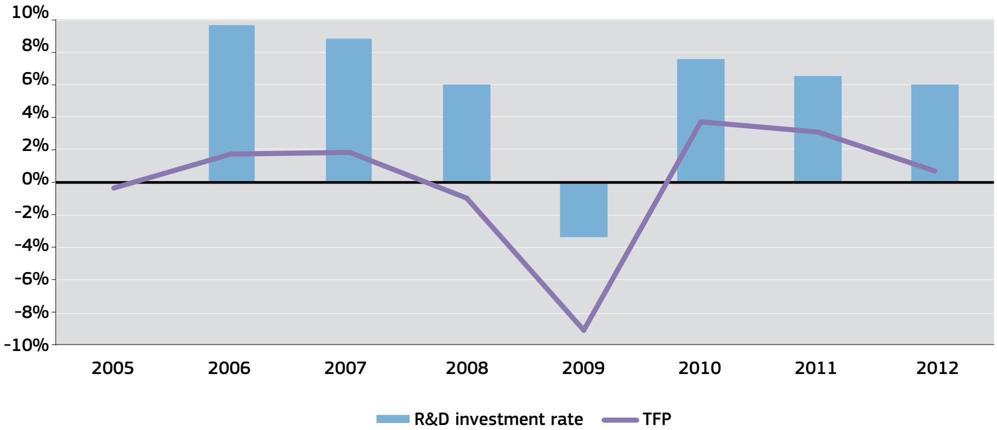
Note: [1]Average values (or calculations) covering the period 2004-2012.

On the other hand, the R&D intensity of firms located in the US is the highest. The panel data set also contains information on the number and location of the subsidiaries and branches. Figure II-6-5 reports the absolute numbers of national subsidiaries and international subsidiaries in the EU, US and Japan by sector group. Top European R&D investing companies tend to locate their high and medium-high tech subsidiaries abroad rather than nationally. The reverse pattern is adopted by Japanese companies, while US firms have a more homogenous distribution of their high-tech companies and a higher concentration of domestic low-tech ones. In absolute numbers, the European companies in the R&D Scoreboard sample have many more international subsidiaries than the US and Japan, while Japanese firms locate their affiliates mainly in their home country.

The data set also contains data on cost of raw material, and measure of TFP can be retrieved [118]. Figure II-6-6 presents a comparison between the estimated measure of firm-level TFP and the aggregate R&D investment growth rate. It seems that the TFP trend over time picks up the same dynamic of the R&D growth rate, confirming the link between productivity and R&D investment.

(118) The TFP is measured as the residual from the estimation of a dynamic Cobb-Douglas production functions using the Blundell and Bond (2000) estimator.

Figure II-6-6 **The link between total factor productivity (TFP) and R&D investment (annual growth rates)[1]**



Science, Research and Innovation performance of the EU 2016

Sources: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies, JRC - Knowledge for Growth Unit

Data: EU R&D Scoreboard, 2004-2014

Note: [1]Average values (or calculations) covering the period 2004-2012.

The strong relationship between R&D and productivity could also be the key to understand the productivity gap between Europe and its core competitors in the last two decades.

Additional to the institutional characteristics of the EU economy (such as the regulation of product and factor markets, or efficiency of the legal and institutional systems), and/or by the industrial structure of the EU economy, this gap can also be the result of some intrinsic characteristics of EU firms and of their strategies.

6.2.2.2 Analyses and Results

Using the *EU R&D Scoreboard panel data*, Castellani and Schubert (2014) investigated the role of R&D investment and the extent to which R&D explains the gap with respect to US and Japan. In general, their results confirm the notion that R&D is extremely important for the generation of competitive advantage not only measured in terms of productivity, as already found in earlier contributions, but also in terms of technological efficiency. In fact, when controlling for R&D the observable efficiency and productivity gaps with the US largely disappear.

The study of Castellani and Schubert (2014) first provides an overview of the efficiency [119] and productivity [120] differences across regions and sectors. They find that the efficiency/productivity gaps are most clearly observable in two sectors, namely services and high-tech manufacturing. This could be due to the fact that Japan and the US are more specialised in services (in particular the US) and high-tech than most European countries. Japanese firms are both more productive and efficient than European ones after controlling for time, sector, and other confounding factors. Compared to the EU, the US definitely displays a productivity advantage, which however is much smaller than the one between Japan and Europe. Having provided evidence on the size of the regional efficiency and productivity differences as well as the sectors they originate from, the study investigates whether these differences arise from higher (or lower) levels of overall R&D spending, or from the countries superior (or inferior) abilities to transform a given amount of R&D into gains concerning efficiency

(119) The technical efficiency is derived using the Order-m estimator proposed by Cazals et al. (2002).

(120) Castellani and Schubert (2014) opt for labour productivity (net sales per employee) as it is simpler to deal with due to the the amount of missing data in the variables needed to compute TFP.

or productivity. Results confirm the positive relationships between R&D and efficiency and productivity, respectively.

When analysing the impact of R&D on labour productivity, it is interesting to distinguish between the direct impact on production (scale effect) and the indirect impact obtained via technological efficiency. While technological efficiency helps companies to reduce the distance with respect to benchmark companies using similar levels of input, the impact on production measures scale effectiveness, i.e., the capacity of firms to establish an efficient scale for their operations. The results referring to these decompositions (see Figure II-6-7) show that the two transmission channels are of similar magnitude, with the scale effect being in general slightly more important (54%). Via this direct channel, R&D could help smaller firms to grow (via product innovation) and reach an efficient scale. Comparing regions, the impact of R&D investments on labour productivity is higher for the US (an average of 0.83 points of the labour productivity increase is due to R&D investments — for the EU is 0.57, for Japan 0.64 and for the rest of the world 0.44). In addition, results show that 34% of the US productivity is driven by R&D, where this Figure is about 30% for Japan and about 25% for the EU.

Figure II-6-7 **Decomposition of the R&D effect on productivity[1]**

	EU	United States	Japan	Rest of the world
Total effect	0.57	0.83	0.64	0.44
Direct effect (scale effect)	0.31	0.45	0.35	0.24
Indirect effect (tech. efficiency)	0.26	0.38	0.29	0.20
Difference 95%-5%-quantile	2.27	2.41	2.17	3.24
Relative change due to R&D	25.11	34.44	29.49	13.58
% Direct effect	54.39	0.54	0.55	0.55

Science, Research and Innovation performance of the EU 2016

Sources: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies, JRC - Knowledge for Growth Unit

Data: EU R&D Scoreboard, 2004-2014

Note: [1]Average values (or calculations) covering the period 2004-2012.

In addition to the different channels through which R&D contributes to productivity and efficiency gains, it is important to recognise that Europe can hardly be conceived as a region with homogenous industrial structures. Thus to speak of 'European' efficiency or productivity gaps might be misleading, or at the very least hide important differences under a perspective that focuses on averages.

A comparative analysis of companies located in European Southern states (Spain, Greece, Italy and Portugal) with companies located in the rest of the EU shows that companies located in these Southern countries are less efficient, while productivity levels are similar. However, results are different when we look at the capacity of firms to translate R&D into efficiency and productivity. In this case, companies located in Southern EU MS show similar capacity to transform R&D into efficiency but the gains on productivity are half the one observed for companies located in other MS. This means that productivity gains for firms in Southern EU countries come from sources different than R&D. This result is consistent with the industrial structure of these countries, dominated by medium and low-tech sectors. As the relevant analyses described above have shown, productivity gains in these sectors are driven by investments in physical capital rather than by investments in R&D. The importance of R&D investment for such sectors lies more in the reduction of inefficiencies. The policy implications of these findings are discussed in the conclusions chapter.

An empirical analysis of Kancs and Silverstovs (2012), performed on a panel of 1 129 companies from OECD countries taken from the *EU R&D Scoreboard* for the years 2006 and 2007, confirms previous theoretical and empirical works showing that current and past investments in R&D do not have to increase firm productivity linearly; this is due to complementarities, economies of scale in the accumulation of knowledge and obsolescence of some of the previously acquired, the importance of absorptive capacity and critical mass. It also looks at the argument that productivity of R&D investment may be sensitive to the level of technological sophistication (i.e., cumulative R&D investments done in the past). Such impact can be positive (higher productivity) because of the so-called 'standing on shoulders' effect, or negative due to the so-called 'fishing out' effect (the discovery of new ideas gets more difficult after prior R&D has helped to discover the easiest ones).

The study looks at two questions: how R&D investments affect firm productivity at different levels of technological sophistication; and what the inter-sectoral productivity differences are with respect to such response of productivity to R&D. The results suggest that: (i) the impact of R&D investment on productivity increases with the degree of technological sophistication (R&D intensity) of the firm, ranging from -0.02 to 0.33, (ii) the relationship is nonlinear and only after a certain critical mass of R&D is reached, the productivity growth is significantly positive; (iii) sectoral differences are important, and firms in high-tech sectors not only invest more but also get more productivity gains from their R&D investment.

These results advocate for differentiated R&D investment and support measures that take into consideration firm heterogeneity. It calls for a combination of measures to stimulate the level of R&D investments in high and medium-tech sectors with measures aiming at reinforcing the absorptive capacity and allocation efficiency of R&D investment in low-tech sectors.

An analysis of Montresor and Vezzani (2015) quantifies the R&D impact on a firm's production output and compares it with the impact of other input factors (labour and physical capital), using a sample of more than 1 000 top R&D investors from the *EU R&D Scoreboard* for the period 2002-2010. The methodology applied (quantile estimation of the firm's production function) brings interesting results showing important differences across sizes and sectors. Knowledge capital (R&D) is the most important factor to explain output growth only for high-tech sectors. In this case returns to scale do not decrease even for the largest companies. In these high-tech sectors, technical progress (i.e., the increase of a firm's production output that is not explained by the increase of its production inputs over time) remains positive and stable across all sizes (about 1.6% per year).

For medium and low-tech sectors, physical capital appears to be a more important factor to increase a firm's output, while technical progress starts to be positive after a certain size has been reached and increases as firm size increases (see Figure below).

Results show that labour exhibits constant returns across all sizes of companies in medium and low-tech sectors, hence labour substitution issues seem to take place there. This is not observed for high-tech sectors where labour seems to be substituted by physical capital and knowledge as firm size increases.

6.2.2.3 Additional Evidence from European R&D investors

An additional set of analyses was performed on the basis of an unbalanced longitudinal database of 577 top European R&D investors over the period 2000-2005, constructed from data taken from the R&D Scoreboard and the Value Added Scoreboard elaborated by the UK Department of Trade and Industry (DTI) [121].

[121] The UK R&D Scoreboard was an annual publication elaborated from 1991 to 2010 and can be considered as the precursor of the EU R&D Scoreboard published by the European Commission since 2004.

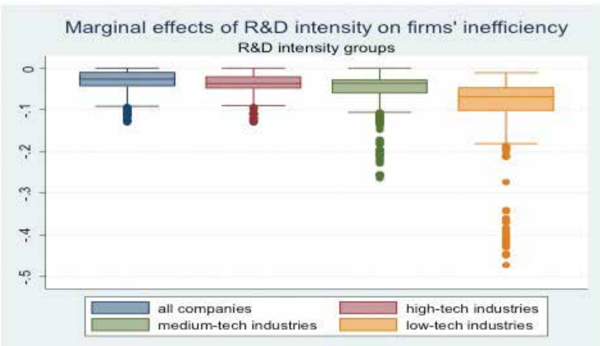
Ortega et al. (2011) studied the R&D-productivity link, and found that the elasticity of productivity with respect to the knowledge stock increases monotonically from low to high-tech sectors (from 0.03-0.05 up to 0.14-0.17). A reverse pattern emerges in relation to the physical capital-productivity link, i.e., higher impact for low, medium and high-medium tech sectors than for high-tech ones. This suggests the importance of embodied technological change for all sectors except for high-tech where R&D and new products are key factors for technological progress.

Measuring the technical inefficiency of individual firms using the stochastic frontier technique, Kumbhakar et al. (2012) were able to separate efficiency gains/losses (moves towards or away from the frontier) from shifts in the production possibility (i.e., technical change and shifts or changes of shape of the frontier). Also, the study refrained from assuming a common technology for all firms in the sample, and estimated group-specific technology levels (low, medium-high and high tech).

Results from this study show that the overall elasticity of labour productivity to R&D investments is positive (between 0.09 and 0.13) and increases steadily from low to high-tech (0.16-0.18 in the later — meaning a 10% increase in R&D stock leads to 1.6-1.8% in productivity). Physical capital also increases labour productivity, but this is more concentrated in low and medium-high tech, and is not significant for high-tech. In terms of efficiency, high R&D-intensive and capital-intensive companies are likely to operate closer to the technological frontier. When distinguishing between sectors, higher impact is found for high-tech sectors. Looking at firm-specific technical efficiency (TE) estimates, results show that the highest impact of R&D on efficiency is found for low tech sectors, where a larger number of companies show low TE (see Figure II-6-7 and II-6-8). This suggests companies in these sectors are underinvesting in R&D.

Such findings lead to interesting policy relevant messages. Targeted R&D support in high and medium-tech sectors can help economies to promote technological change (outward shift of the frontier) and help companies to create and conquer new markets. R&D support in low tech sectors can help companies to reduce inefficiency and business to remain competitive.

Figure II-6-8 **Technical Efficiency by R&D intensity groups**



Source: Kumbhakar et al. (2012)

Figure II-6-9 **Descriptive statistics on firm-level technical efficiency (as illustrated in Figure II-6-8)**

Efficiency (TE)	Number of observations	Mean	STDV	Min	Max
Whole sample	1 787	0.822	0.1597	0.145	1.000
High-tech	600	0.819	0.1473	0.161	1.000
Medium-tech	671	0.870	0.1182	0.284	1.000
Low-tech	516	0.732	0.2086	0.041	0.970

Science, Research and Innovation performance of the EU 2016
Sources: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies, JRC - Knowledge for Growth Unit
Data: Kumbhakar et al. (2012)

Different emphasis and selection of adequate instruments in R&D support (e.g., R versus D, size of projects, etc.) in accordance to sectors needs and broader policy objectives (e.g., long-term technological progress vs. survival/revitalisation of 'older'/less R&D intensive industries) seems therefore the right approach for policy design. Finally, the results of the previous study are confirmed: while in low tech-sectors investment in physical capital is more effective than R&D to increase production efficiency and labour productivity, the opposite is true for high-tech sectors.

6.3 Other Factors Influencing the R&D-Productivity Link

In this section, the analysis of the relationship between R&D and productivity is extended by taking stock of recent empirical evidence on a series of factors that indirectly affect such a link: the degree of a firm's internationalisation, the level of cooperation with other firms and the firm's investment in other intangible assets (beyond R&D), like training or design.

6.3.1 The impact of multinationality and industrial diversification on the R&D/productivity link

There is convincing evidence that productivity and R&D intensity are significantly higher in multinational firms, as opposed to purely domestic firms. The positive relationship between internationalisation and firm performance is indirect and highly context-dependent. Indeed, multinationality per se has no impact on firm value, but it enhances the value of R&D or advertising spending (Morck and Yeung, 1991). The lack of a direct effect of multinationality on firm performance may be explained by the fact that geographical dispersion increases organisational complexity and thereby amplifies the costs of offshoring. Moreover, R&D intensity, product diversification, country of origin, firm age, and firm size significantly affect the performance gains attributable to internationalisation (Bausch and Krist, 2007).

The link between *industrial diversification* and firm productivity/performance has attracted substantial research, but the evidence is not unequivocal. The analysis of Castellani and Schubert (2014) tested to what extent firm's internationalisation strategies affect productivity differences across world regions, and if they can moderate the R&D-productivity link.

The study has been carried-out using the same panel of top R&D investors (from the *EU R&D Scoreboard*). The focus of the study is mainly on geographical diversification, which is used as a proxy for internationalisation of production and other firm activities (or multinationality) [122], and industrial concentration, both within national borders and abroad. For the purpose of this study, a set of indicators of geographical and sectoral diversification has been constructed using additional information on the subsidiaries structure of these companies, as provided by the Ownership Database of Bureau van Dijk. Results show that a firm's multinationality is positively correlated with the firm's R&D investments and negatively correlated with its productivity. In fact,

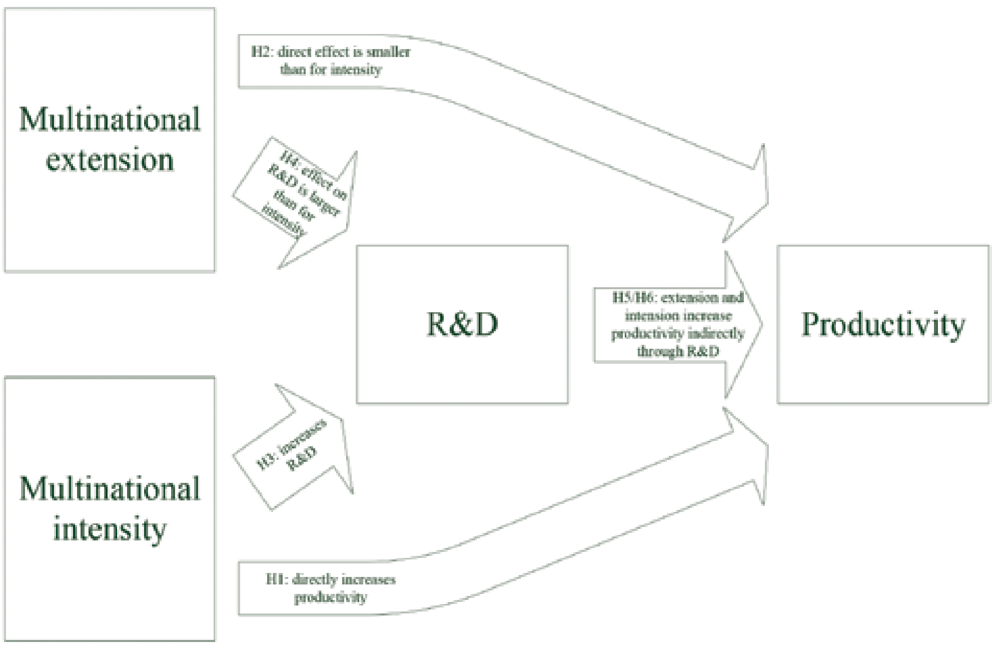
(122) Unfortunately, the authors were not able to distinguish firms internationalizing production or rather other firm activities, such as sales or R&D. This is on the agenda for an extension of this work.

while multinationality creates incentives to invest in R&D, it also creates organisational complexity that may dampen productivity. This pattern is accentuated in medium-tech R&D sectors as in such industries the learning opportunities are more limited, so the organisational costs may outweigh the benefits from internationalisation. At the same time, multinationality boosts the productivity effect of investments in R&D, by enabling firms to reap higher benefits from international operations, possibly allowing them to absorb more knowledge from foreign markets.

On the other hand, industrial concentration has no significant correlation with firm productivity, but it is positively correlated with R&D intensity. Indeed, a firm exploring activities in different sectors abroad will have a higher incentive to invest in R&D. This is consistent with the idea that these firms need to put substantial efforts into leveraging learning opportunities stemming from international activities. However, these efforts may end up increasing organisational costs, and thus lowering productivity.

Based on the same data, a new study of Castellani et al. (2015) analyses in more detail the different channels through which multinationality can affect firm's productivity and differentiates the effects of multinationality on productivity at the intensive margin (how large is the share of international activities) and at the extensive margin (how much are multinational activities dispersed). The results show that while multinationality always increases incentives for investing in R&D, only multinationality at its intensive margin contributes to greater productivity (geographical dispersion appears at some point to be detrimental). These findings qualify previous evidence based on an analysis of a sample of European top R&D investors taken from the 2009 edition of the EU R&D Scoreboard [123]. In that study, results indicated a positive impact of globalisation on a firm's R&D productivity, particularly for European companies with a higher share of subsidiaries in North America.

Figure II-6-10 **A Scheme for a Multinationality-Productivity Model**



Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Castellani et al. (2015)

[123] Cincera M. and J. Ravet (2011).

6.3.2 Cooperation, R&D and productivity

Greater competition, the demand for higher-quality customised products and services, and fast delivery are just a few of the characteristics that shape the organisation of many industries. In this setting, rarely does a single company have the full range of expertise needed for prompt and cost-effective innovation. As a consequence, there is a growing awareness that R&D and innovation rely crucially on networks of cooperative agents.

In fact, the lack of cooperation among European organisations could be one of the factors that hindered European economic growth (Morgan, 1997, p492). McCann and Ortega-Argiles (2013, p416) suggest that the 'transatlantic productivity gap' from the 1990s onwards may have been 'due to the more limited ability of EU industries and firms to adopt and to adapt to new technology and innovations emerging from different sectors.' Hence, a European economy where firms, universities, and other organisations are better connected through richer collaborative networks may contribute to innovation, productivity growth, and economic prosperity.

Among the benefits of cooperation, the empirical literature has identified a number of advantages. R&D Cooperation can enable the participants to accelerate existing research activities in order to quickly create new knowledge. Partners of a R&D alliance may benefit from cooperation by accessing a pool of complementary knowledge and assets. Collaborative R&D may allow partners to internalise the inherent spillovers (such as the threat of imitation which might reduce the incentives of individual firms to engage in research). Lastly, cooperating on R&D allows sharing the costs and risks of innovation (Aschhoff and Schmidt, 2008).

Studies on R&D cooperation have not only investigated the rational and determinants of cooperation, but also evaluated the effects of cooperation on performance. Belderbos et al., (2004) investigated the impact of cooperation on either growth of innovative sales, or growth of labour productivity. They observed that cooperation with competitors and suppliers helps improve labour productivity, while cooperation with universities and competitors helps create new-to-the-market sales. Amoroso (2014), using a sample of Dutch manufacturing firms, reports a higher level of TFP for cooperative companies and higher TFP growth for the innovative ones. Moreover, allowing TFP to be dependent on firms' past choices of R&D, innovation and cooperation, a positive relationship between R&D cooperation and TFP is found.

6.3.3 Beyond R&D: investment in other intangible assets and productivity

Investment in R&D is only part of a firm's innovative efforts. Turning knowledge and new discoveries into new processes, products and services is indeed a complex process requiring multiple and interrelated tangible (e.g., machinery, laboratories) and intangible resources. At a macroeconomic level, there is evidence showing the increasing importance of investments in intangible capital for aggregated productivity growth in the US, Europe and Japan [124]. Macro-level studies rely on a classification of intangible assets that distinguishes three main categories [125]: computerised information (software and databases), innovative property (R&D, mineral exploration, entertainment and artistic originals, design and other development costs) and economic competencies (branding, which includes marketing and advertising, training and organisational capital). This classification is a point of reference for microeconomic studies which identify three main groups of expenditures relevant for innovation: (1) those related to R&D activities, (2) those that underlie organisational practices including customer satisfaction, product quality, design and brand reputation and (3) those related to human capital, such as investments in personal skills and training.

The literature showing a link between innovation expenditures and productivity at a firm level is also broad [126] and confirms that innovation leads to a better revenue per employee performance.

(124) Corrado, C., J. Haskel, C. Jona-Lasinio and M. Iommi (2013).

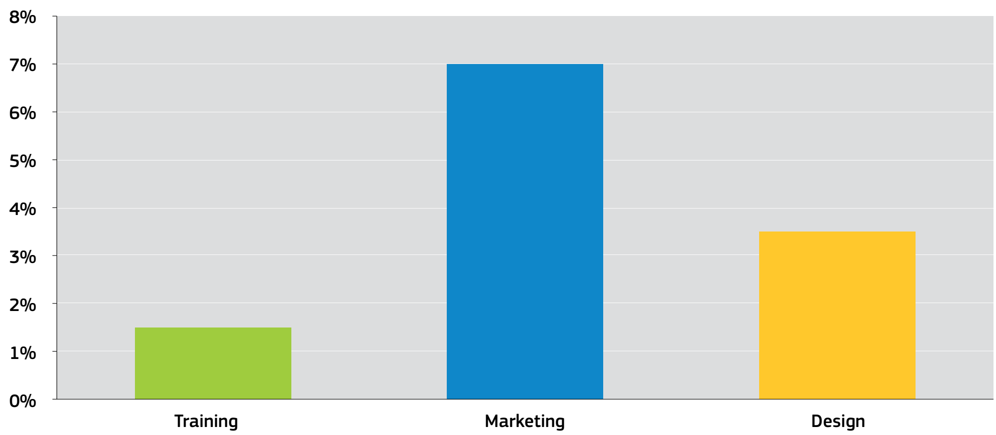
(125) Corrado et al. (2005).

(126) See Mohnen, P. and Hall, B. (2013) for a review.

And this is the case for all the types of innovation considered: product, process, organisational and marketing innovations. Measuring to what extent the different intangible expenditure categories of firms (e.g., R&D, software, design, branding, training) account in total firm's productivity impact remains a challenge, as well as the measurement of the complementarity between R&D and other innovation expenditures [127]. One important obstacle is the availability of proper data at company level. Existing evidence informs on the complementarity between different types of innovation, particularly about the importance of combining product innovation with marketing and organisational innovation [128].

An analysis carried-out by the European Commission (JRC) based on company data from the Community Innovation Survey [129] shows that a firm's innovation-driven investments in training, design and marketing have a strong impact on that firm's innovative performance, measured as the share of sales coming from new products over total sales (see Figure II-6-11).

Figure II-6-11 **Impact of training, marketing and design expenditures on innovative sales**



Science, Research and Innovation performance of the EU 2016
Sources: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies, JRC - Knowledge for Growth Unit
Data: Ciriaci, D., F. Hervás (2012), Eurostat - CIS3 1998-2000

While the results show that economies of scale are important for training and marketing expenditures, suggesting barriers for SMEs, this is not the case for design expenditures. In addition, the impact of design on innovative sales is not affected by the firm R&D intensity, which makes it a cost-efficient innovation driver for both SMEs and less R&D intensive firms.

(127) See Montresor, S., G. Perani and A. Vezzani (2014) for a detailed discussion on the definition of intangible assets, its conceptualisation and the challenges related to its measurement, accounting and disclosure at company level.

(128) Mohnen, P. and Hall, B. (2013).

(129) Ciriaci, D. and F. Hervás (2012).

6.3.4 Conclusions: How To Increase The Gains From Firm's R&D Investments In Europe?

This section takes stock of the main findings related to the impact of R&D and innovation investments on a firm's productivity obtained from the analysis of top global R&D investors. Main policy-relevant conclusions are identified in order to inform policy intervention and public support to business R&D and innovation investments in Europe.

From the analysis of the direct link between R&D investments and firm's productivity, the following empirical evidence deserves to be highlighted:

- There is evidence of a positive direct link between R&D and labour productivity at the firm level, with higher returns to R&D investments in high-tech sectors. In low R&D intensive sectors, investments in physical capital have a higher impact on labour productivity.

- Different measures of productivity (labour, total factor productivity, efficiency) and different methodologies (accounting approach, technological frontier) confirm the robustness of the finding of positive R&D returns, especially for companies operating in high-tech sectors.

- Returns to R&D investment in the form of productivity increases are nonlinear: returns are positive only after a minimum critical mass is reached and the degree of impact increases as the R&D intensity of the firm increases.

- Efficiency (optimal use of resources) is the only channel for productivity improvements in low-tech sectors. In high-tech sectors, shifts of the technological frontier (technological progress) also matter.

- Knowledge capital (R&D) is the more important factor to explain output growth only for high-tech sectors and, in this case, returns to scale do not decrease even for the largest companies.

This evidence clearly makes the case for business R&D support policies and instruments capable of differentiating across sectors and companies, given the nonlinearity of the impact of R&D investment on a firm's productivity and the differences in the returns depending on the R&D intensity of the firm. In addition, R&D support policies in high- and medium/high-tech sectors may promote the technological change that is sought for the EU's medium and long-term competitiveness (shift of the technological frontier). R&D support for less intensive R&D sectors and companies can help to increase efficiency and to allow companies to overcome the crisis and remain competitive, while the best channel in these sectors to boost productivity and output growth is through investments in physical capital.

The comparative analysis of the R&D-productivity link in R&D intensive companies based in the EU against companies located in the US and Japan, provides the following results:

- Much of the productivity gap observable for the firms located in Europe is actually attributable to lower R&D spending. In addition, results indicate that 34% of the US productivity is driven by R&D, while this Figure is about 30% for Japan, and about 25% for the EU.

- At the same time, there seems to be some evidence that firms in some parts of the world are more successful in reaping the benefits from R&D than others, in particular as concerns labour productivity: European firms are less able than the US and Japanese firms.

- Likewise, top Southern European R&D investors are less able to transform R&D into productivity than their counterparts in the rest of Europe. At the same time, they display at least an equal labour productivity which suggests that their source of competitiveness lies elsewhere.

These results, first of all confirm the importance of effective national and EU-level policy support for business R&D, to keep and, where necessary, restore the competitive advantage of leading European R&D investing firms. Second, the evidence that firms show different levels of capacity to translate R&D into productivity depending on their location, suggests that not only the level of spending is important but also that firms are able to make use of it. For policy, this suggests that a non-differentiating focus on R&D levels as a means to promote growth and competitiveness will probably miss the needs of firms or industries which have not yet developed R&D capabilities to the same degree as others. In addition, these differences may be due to institutional problems in the home countries (e.g., innovation or investment unfriendly regulation) which very often go hand in hand with the lack of genuine R&D-related capabilities possessed by the firms.

Finally, the evidence confirms the relevance of other factors having an influence on the R&D-productivity link:

- The degree of multinationality of top R&D investors (measured in terms of number and geographical dispersion of subsidiaries), a proxy for the degree of firms' internationalisation, has a positive effect on firms' R&D investment levels. In addition, it increases firms' capacity to translate R&D into productivity.

- At the same time, the link between multinationality and productivity is negative, particularly when it is based on a higher geographical dispersion. This probably reflects the negative impact of the resulting organisational complexity.

- Evidence shows a higher level of productivity for cooperative companies and a higher productivity growth for the innovative ones. Moreover, allowing the productivity to be dependent on firms' past choices of R&D, innovation, and cooperation, a positive relationship between R&D cooperation and TFP is found.

- Investment in other intangible assets such as job training, design and marketing positively affects firms' innovativeness, particularly when combined with R&D investment.

These results confirm the need to accompany business R&D support measures with a broader set of innovation policies aiming at increasing the capacity of companies to translate R&D into productivity gains, as well as to translate these investments into successful innovative products and services. The collaborative and usually multinational nature of the European level innovation support is, in this respect, clearly an important element, because it facilitates knowledge and capability transfer across firms and countries. Likewise, the widening in scope of support instruments is important, in order to cover the whole innovation chain, from more basic research until development and market launch investments for new products.

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7. High growth firms in Europe

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7.1 Introduction

In recent years, a large number of contributions have shown that a small number of high growth firms (HGFs) contribute disproportionally to job creation. The growing body of literature shows that most of these enterprises are young, small and innovative. The nexus between age, size, innovation and rapid growth emphasises the importance of entrepreneurial dynamism for economic growth and structural change.

For this reason policy-makers in Europe have shown increased interest in HGFs in the recent years. The European Commission announced in the Communication 'Europe 2020 Flagship Initiative Innovation Union' to design 'future EU research and innovation programmes to ensure simple access and stronger involvement of SMEs, in particular those with a high growth potential' (EC 2010). The Horizon 2020 programmes include an emphasis on SMEs, among them the aim to support European innovative SMEs to become leading enterprises. The employment contribution of high growth firms also constitutes one of the four components of the new innovation output indicator that is used to measure the impact and pillars of innovation across Member States (EC 2013).

In the aftermath of the economic crisis in Europe, countries face the challenge to embark on a new sustainable growth path and to create jobs. HGFs can provide an important contribution to this task, as they are innovative and disproportionally create jobs. However, the empirical evidence on high growth firms is still fragmentary. This hinders the formulation of effective policies aiming to increase the number of high growth firms. For this reason this chapter presents an overview on the existing knowledge regarding the state of HGFs in Europe and provides novel evidence on European HGFs.

The evidence on HGFs shows that there are striking differences across EU Member States with regard to HGF presence. These differences are related to differences in aggregate economic performance, institutions, innovation and technology as well as to entrepreneurial ecosystems. Framework conditions that support the reallocation of market shares to more productive companies are important for the emergence and the number of HGFs in a country. However, framework conditions may not be enough. Entrepreneurial opportunities do not emerge out of the blue but require appropriate knowledge bases and are often dependent on local spillovers.

The evidence on the innovation behaviour of HGFs shows a strong context-dependency related to country comparative advantages and industry affiliation. Policies to mobilise HGFs therefore need to be broad-based and specific at the same time. Thus, existing R&I policies that target ambitious research projects at the firm level and the generation of differentiated knowledge bases can also provide effective support for HGFs.

7.2 The dynamics of new high growth firms: What do we know?

The interest in HGFs is associated with a shift of industrial and innovation policies towards growth-oriented enterprise policies as emphasised by Mason and Brown (2014). HGFs contribute to productivity growth, job creation and promote innovation, export-orientation and internationalisation. The most important direct contribution of HGFs is their disproportional employment generation (Coad et al. 2014). There is now ample evidence for a large number of European Countries (e.g., Storey 1994, Anyadike-Danes et al. 2009, Henrekson and Johansson 2010) that a small number of fast growing firms create a large share of jobs. These studies show that around 3 to 6 percent of the fastest growing firms generate up to

70% of new jobs in established firms. However, many of these studies used different definitions for HGFs, different datasets and terminology (cf. Henrekson and Johansson, 2010) which makes a comparison of the alternative findings difficult [130]. In addition, different concepts have been proposed that are quite similar from a policy perspective to the concept of HGFs.

For example, Cincera and Veugelers (2013) introduced the term young leading innovators (yollies) in their analysis of the differences between US and European leading innovators. Based on their findings they argue that the observed R&D deficit within the European Union relative to the United States can be traced back to the fact that Europe has a lower number of yollies and that European leading innovators have a lower R&D intensity than US leading innovators. From a conceptual perspective yollies are quite different from HGFs. Yollies are defined in terms of age not of growth. However, from a policy perspective the yollies and HGFs are quite close. The above-average presence of HGFs and Yollies in an economy signals economic dynamics, reallocation of market shares to more efficient firms and the presence and efficient use of knowledge resources in an economy. Figure II-7-1 presents a selected list of different definitions of HGFs and labels for fast-growing firms that are used in the literature and in this chapter.

Unfortunately, much of the evidence on high growth firms is fragmentary. Many studies use different methodologies to identify HGFs in an economy which makes it difficult to compare results over time and across countries. However, there is mounting evidence about robust regularities of HGFs at the firm level (cf. Coad et al. 2014, Henrekson and Johansson 2010) [131]. The most important insight from this literature is that only a subset of firms grows fast and that most firms have modest (or even zero) growth rates. Thus HGFs are important drivers of job creation and economic growth. Most studies show that that the majority of HGFs are small and medium-sized enterprises (with less than 50 employees), but that they are well established (over five years old). Although HGFs are young, most HGFs are not start-ups (Mason and Brown 2014). And there also exists an important subset of older and larger HGFs (e.g., Acs et al. 2008, Hölzl 2014). Mason and Brown (2014) emphasise that the fact that most HGFs are established enterprises has not been taken into account in the design of many growth-oriented enterprise policies that aim at foster HGFs. Most policies target start-ups in high technology sectors (e.g., OECD 2010, Empirica et al. 2013a, 2013b). In these sectors market failures related to uncertainty and risk of entrepreneurial projects are likely most pressing. However, the evidence also shows that HGFs are distributed across all sectors, with no identifiable bias towards high technology industries (e.g., Bleda et al. 2013, Anyadike-Danes et al. 2009, Daunfeldt et al. 2015). If anything, HGFs are overrepresented in service sectors, especially in knowledge-intensive services (Henrekson and Johansson 2010) that offer high market potential for new ideas and new ways of doing business compared to manufacturing industries where sunk costs related to set-up costs and tangible capacities are high (Hölzl 2015).

(130) Coad et al. (2014) argue that the controversies about the definitions of HGFs in the academic literature are related to the fact that economic and management theory does not provide much guidance on how to measure HGFs.

(131) The use of the OECD-Eurostat definition of HGFs by statistical offices and the increased use of this definition by researchers increased the comparability of results across studies.

Figure II-7-1 **Definitions and terminology related to the phenomenon of high growth firms**

Terminology and abbreviation		Use in literature	Use in Chapter
High growth firms/ enterprises	HGFs	different definitions (e.g. top 1% or 5% of the fastest growing firms. Eurostat-OECD defintion. Birch index)	denotes firms that are HGFs according to the Eurostat-OECD definition - annualized growth rate of 20% or 10% over a three year period: HGF (10%) denotes use of the 10% growth requirement. HGF (20%) use of the 20% growth requirement
Gazelles	-	different definitions, sometimes used as synonym for HGFs; Eurostat and OECD (2007) define gazelles as young HGFs (less than 5 years of age)	not used in the chapter
High impact firms	HIF	Acs et al. (2008) define HIF as firms whose sales have at least doubled over a four-year period and which have an employment growth quantifier of two or more over the same period. Gives some weight to absoute growth.	not used in the chapter
Young leading innovators	Yollies	Cincera and Veugelers (2013): large R&D intensive firms that were founded after 1975	used as in Cincera and Veugelers (2013)
Young highly innovative companies	YICs	Schneider and Veugelers (2010): new, small, and high R&D intensive firms	not used in the chapter
Super high growth firms	-	denotes high growth firms that display persistent high growth over longer time periods. («Apples» and «Googles»).	not used in the chapter
Hidden champions	-	denotes usually larger firms (> 50 Mio. € turnover or > 500 employees) that are unknown to the larger public but are among the (world) market leaders in their (sub)markets	not used in the chapter

Many studies show that high growth at the firm level does, on average, not persist over time (Parker et al. 2010, Daunfeldt and Halvarson 2015). Most HGFs are HGFs once in their lifetime. But HGFs display a better growth performance even after their high growth phase compared to non-HGFs (Hölzl 2014) and recent evidence by Ciraci et al. (2013) indicates that the employment growth of innovative HGFs is more persistent than growth of non-innovative HGFs. In this regard a message from the firm-level literature on HGFs is that it is very difficult to target potential HGFs on an ex ante basis without extensive (and likely expensive) screening and due diligence processes (Coad et al. 2014). This should not come as a surprise, since the firm growth literature emphasises the importance of heterogeneity at the firm level and further shows that firm growth is highly idiosyncratic (e.g., Coad 2009). It is well known that enterprise growth is complex and largely context-dependent. Businesses in different markets are confronted with different competitive market environments, different entrepreneurial ecosystems, and different framework conditions, have different capabilities and make use of different business models and innovation strategies.

While it is very difficult to find determinants that allow one to identify HGFs at the firm level on an ex-ante basis, available evidence also shows that there are important differences in the presence of HGFs and firm growth dynamics across countries (e.g., Bravo-Biosca 2010, OECD 2014). Figure II-7-2 presents the distribution of HGF firm shares and HGF employment shares across EU28 Member States with the exception of Greece. Here we identify HGFs with the HGF (10%) definition which measures firm growth over a three year period and defines those firms as HGFs that have an annualised growth rate of 10% or more over this three year period and had more than 10 employees at the beginning of the period. The enterprise share is calculated as the ratio of HGFs to number of firms with more than 10 employees at the end of the period.

Figure II-7-2 shows stark differences across countries. The lowest HGF (10%) share is recorded for Romania (2.4%) followed by Croatia (3.4%) while Slovakia (13.8) and Sweden (13.6%) recorded the largest shares of HGFs. With regard to employment in HGFs, the lowest shares are again observed for Romania and Croatia (both 6.0%) while the largest are recorded for Slovakia (20.6%) and Lithuania (19.6%).

Figure II-7-2 **High growth firms (10%), 2012**

	HGF (10%) enterprise share	HGF (10%) employment share
Belgium	8.6	8.2
Bulgaria	10.4	17.7
Czech Republic	11.7	19.2
Denmark	10.7	13.6
Germany	12.1	14.2
Estonia	7.1	12.7
Ireland	6.9	:
Greece	:	:
Spain	8.0	10.3
France	10.4	14.7
Croatia	3.4	6.0
Italy	5.8	9.7
Cyprus	6.4	6.7
Latvia	11.7	16.3
Lithuania	11.4	19.6
Luxembourg	9.6	9.4
Hungary	10.7	16.1
Malta	9.9	8.7
Netherlands	10.0	12.3
Austria	7.0	8.6
Poland	8.9	16.0
Portugal	7.9	12.9
Romania	2.4	6.0
Slovenia	7.9	9.6
Slovakia	13.8	20.6
Finland	10.4	:
Sweden	13.6	17.5
United Kingdom	11.7	17.2
Norway	10.5	12.0

Science, Research and Innovation performance of the EU 2016

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat; WIFO calculations

The differences across countries are striking. These differences may be related to differences in the ability to generate successful high-potential entrepreneurial ventures. But given the evidence that highly productive firms coexist with low productivity firms even within narrowly-defined sectors (e.g., Syverson 2014), research has emphasised resource misallocation as an important source of productivity differentials. This research has established that cross-country differences in productivity may be linked to the heterogeneity in firm performance within industries (Andrews and Cigano 2014, Bartelsman et al. 2013, Hsieh and Klenow 2009). This strongly suggests that differences in HGFs may be related to differences in the ability of economies to direct resources to the most productive firms. HGFs may thus play an important role in fostering economic growth that goes beyond the direct impact of job generation. HGFs are thought to have above average levels of productivity growth (e.g., Du and Temouri, 2015) and above average innovation-intensity and a strong export orientation. Thus HGFs promote economic growth and structural change at the aggregate level by providing 'an important Schumpeterian stimulus with economies by increasing competition, promoting innovation and increasing the efficient resource allocation within economies' (Mason and Brown 2014).

However, cross-country evidence on HGFs is still largely missing. One of the few studies that provides evidence is Bravo-Biosca (2010). Using a dataset of 11 countries for the time period 2002 to 2005, Bravo-Biosca (2010) shows that higher HGF shares and more dynamic firm growth is associated with higher productivity growth at the country level. He also shows that European countries exhibit, on average, a higher share of slow-growing and stagnant firms when compared to the US. However, the evidence for the US shows declining HGF shares over the time period 1994-2012 (Clayton et al. 2013). Also the evidence by Haltiwanger et al. (2014) and Decker et al. (2014) suggests that the business dynamics also slowed down in the US n high-technology industries. This is confirmed by the comparative evidence provided by Criscuolo et al. (2014) who show that the main differences in firm dynamics between the US and European countries is not related to the size distribution of firms or their age distribution but to the growth performance of firms, echoing the results by Bartelsman et al. (2009). However, Andrews and Cigano (2014) find that more productive firms are likely to account for a much larger share of employment in the US and some northern European countries than in Continental and Southern European economies.

This novel evidence suggests that the presence of HGFs provides an indication of the efficiency of the process of resource allocation that is pivotal for structural change and economic growth. The lack of yollies and HGFs in many European countries may signal weaknesses. The lack of HGFs is unlikely to be purely the result of missing innovation projects and low start-up rates. The huge differences across countries suggests that country-wide institutions, entrepreneurial framework conditions, regulations as well as the relative specialisation patterns and the economy-wide ability to profit from radical technological revolution capabilities matter most and may be reflected in the share of HGFs. Countries such as Italy, Portugal and Spain show below-average HGF enterprise shares (10%) and HGF employment shares (10%).

7.3 High growth firms in Europe: country-specific determinants

While the evidence on HGFs at the national level is often fragmentary, the cross-country evidence is (still) largely missing. Only a few studies (e.g., Bravo-Biosca et al. 2013) provide evidence on cross-country differences and determinants of HGFs across countries. In order to fill this gap this chapter presents indicative evidence on the state on HGFs in the EU28 countries with special reference to the impact of the economic crisis on HGFs and the link between country capabilities and the presence of HGFs.

7.3.1 European high growth firms and the economic crisis

In aftermath of the economic crisis in Europe, HGFs are often considered to be an important ingredient in growth strategies that allow countries to embark on a sustainable growth path and to create new jobs. However, HGFs can also be affected by the economic crisis. While many studies of firm growth over the business cycle show that the growth rate of firms with extreme growth events is only weakly correlated with the business cycle (Higson et al. 2002, 2004; Hölzl and Huber 2014), evidence on HGF shares clearly suggests that HGF shares are affected by demand developments (e.g., Hölzl 2011).

Unfortunately, time series on the country level are not yet available for all EU28 countries. The HFG (10%) indicators depicted in Figure II-7-2 have a short time dimension. However, Eurostat provides time series data for HGF (20%) shares for 10 EU Member States (CZ, EE, ES, HU, IT, LT, LU, PT, RO, SI) for the time period 2008-2012. This data allows for studying the impact of the economic crisis (and business cycles) on the share of high growth firms [132]. A readily available measure of short-run economic performance is the gap between actual and potential GDP (potential GDP is the maximum amount an economy can turn out when it is most efficient, i.e. at full capacity) [133]. For the EU28 as a whole, the output gap fell from a level of +2.7% in 2007 to a -3.4% in 2009 during the financial crisis. For the Baltic states, values as high as -10% were recorded during this time. After the crisis in 2009, the gap closed for many countries but economic activity remained below the production potential for most of the EU Member States. For most of the Southern Member States the output gap increased again in a second dip in 2012. Thus, for many countries in the sample the time period under consideration covers a period of economic downturn. As high growth firm shares are calculated using a three-year period also the output gap was aggregated over three years for the purpose of providing evidence on the impact of the crisis on high growth firm shares.

Figure II-7-3 presents the results of a simple regression of the output gap on high-growth firm shares at the NACE (rev. 2) one-digit and two-digit breakdown. Country and industry dummies are used to control for fixed country and industry effects. The regressions do not utilise the complete panel structure of the data because missing observations are recorded for some timer series. Different types of regressions have been run checking the robustness of the results (country-industry dummies, using every second year observation), also two different levels of aggregation for the output gap have been used. The results reported in Figure II-7-3 are quite similar across the specifications and the NACE breakdowns. There is a clear relationship between the output gap and the share of high growth firms: an output gap (economic crisis or business cycle downturn) is associated with a lower share of HGFs, while an economic expansion is associated with a larger share of HGFs. We also present results for the entry rate to put the results for the HGF (20%) share into perspective. The average impact of the economic crisis on the entry rate was of similar magnitude in terms of percentage point changes (columns (5) and (10) in Figure II-7-3). However, the entry rate is, on average, more than twice the magnitude of the HGF (20%) share. Thus the impact of the crisis on HGFs is likely to be more severe than for other indicators of business dynamics such as start-up rates.

(132) Here, it is important to note that a different HGF definition is used. However, two HGF definitions (HGF (10%) and HGF (20%) are closely related. The correlation of the HGF (10%) with the HGF (20%) share for the year 2012 at the NACE (rev. 2) two-digit breakdown shows a strong cross-sectional correlation of 0.82 for the 10 countries. At the NACE rev. 2 one-digit breakdown the correlation is even stronger (0.89). For this reason, the results reported for the HGF (20%) share should also provide indication on HGFs in general, and the HGF (10%) measure that is used in the remainder of the chapter.

(133) Data on the output gap is from the Ameco database (series AVGDP) that measures the output gap at 2010 market prices.

Figure II-7-3 **Regression[1][2] of output gap on HGF (20%) share, 2007-2012**

Variable	NACE rev. 2 one-digit industries					NACE rev. 2 two-digit industries				
	HGF (20%) share of enterprises				Entry rate	HGF (20%) share of enterprises				Entry rate
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Output gap 3-year average	0.202** (9.574)		0.203** (12.248)	0.237** (10.579)		0.154** (5.076)		0.157** (6.191)	0.203** (5.560)	
Output gap 2-year average		0.167** (8.279)					0.164** (5.754)			
OG					0.187** (4.557)					0.168** (7.389)
Country dummies	y	y				y	y			
Industry dummies	y	y				y	y			
Country x industry dummies			y	y	y			y	y	y
Every second year observation				y					y	
Observations	630	630	630	357	705	2 404	2 404	2 404	1 362	2 669
R-squared	0.52	0.50	0.76	0.81	0.69	0.22	0.23	0.57	0.62	0.68

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Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies, JRC - Knowledge for Growth Unit

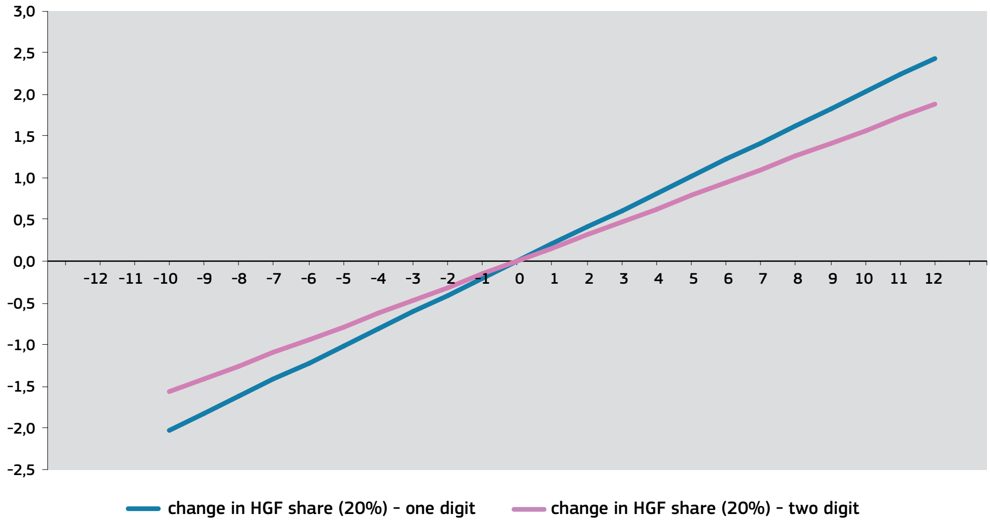
Data: Eurostat, DG Economic and Financial Affairs; WIFO calculations

Notes: [1]Countries used in the regression analysis: CZ, EE, ES, IT, LT, LU, HU, PT, RO, SI. [2]t-values are in parentheses; * and ** denote statistical significance at the 5% and the 1% level. respectively.

The estimated coefficients on the output gap variables reported in Figure II-7-3 can be interpreted as percentage point change in the HGF (20%) share when the output gap changes by 1%.

Figure II-7-4 summarises the results of equations (3) and (8) for the one-digit and two-digit NACE (Rev. 2) breakdowns, respectively. According to these estimates the share of high growth firms (20%) is, on average, reduced by an output gap of -5% by approximately 0.8 percentage points. This is a substantial number as the unweighted mean of the HGF (20%) share in the two-digit sample is 3.9%. However the standard deviation of 4.94 suggests that there is much heterogeneity across industries.

Figure II-7-4 **Estimated average change in percentage points of the share in high growth firms (20%) in relation to changes in the output gap(1)(2)**



Science, Research and Innovation performance of the EU 2016

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat, DG Economic and Financial Affairs; WIFO calculations
Notes: (1)Countries used in the analysis: CZ, EE, ES, IT, LT, LU, HU, PT, RO, SI. (2)The lines are based on the results on Figure II-7-3 in column (4) for one-digit industry and column (8) for two-digit industry. The output gap refers to three-year averages. The time period covered is 2007-2012.

Figure II-7-5 presents the results at the sectoral level using the NACE (rev. 2) two-digit breakdown and the Eurostat taxonomies of knowledge-intensive services and technological intensity in manufacturing industries. The second column presents unweighted sectoral averages of the HGF (20%) share for the year 2012 and the third column presents the percentage change of the HGF share (20%) to a one percent change in the output gap for the 10 countries for which time series information on the HGF (20%) share is available. Service sectors — with the exception of low knowledge intensive market services — have, in general, a markedly higher HGF (20%) share than manufacturing industries.

The reaction to the output gap in the third panel of Figure II-7-5 shows the strongest impact for the low knowledge-intensive market services followed by the manufacturing industries (except low-technology manufacturing) that are generally considered to be more sensitive to business cycle influences than service industries (e.g., Hölzl, Kaniovski, Reinstaller, 2015). This is likely related to the fact that the economic downturn in many of the countries also led to a substantial decline in consumption that affected domestic oriented low-knowledge-intensive market services more severely than during normal business cycle downturns, where consumption remains relatively smooth compared to other economic aggregates.

Figure II-7-5 **HGF (20%) shares and the effect of the output gap at the sectoral level, 2012[(1)(2)]**

	HGF (20%) share	Percentage change of the HGF (20%) share when the output gap changes by one percentage point
High-tech and medium high-tech manufacturing	2.8%	5.9%
Medium low-tech manufacturing	2.8%	7.8%
Low-tech manufacturing	2.2%	2.1%
Knowledge-intensive financial services	5.1%	5.8%
Knowldege-intensive market services	4.8%	3.9%
Knowledge-intensive high-tech services	5.1%	4.4%
Low knowldege-intensive market services	2.8%	8.3%

Science, Research and Innovation performance of the EU 2016

Source: DG Research and Innovation – Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat, DG Economic and Financial Affairs; WIFO calculations
Notes: [(1)]Countries used in the analysis: CZ, EE, ES, IT, LT, LU, HU, PT, RO, SI. [(2)]The percentage change of the HGF share (20%) when the output gap changes by one percentage point is derived from sector regressions using the NACE rev. 2 2-digit industry breakdown. All regressions use time and industry dummies. The output gap coefficients are significant at the 1% level of statistical significance with the exception of the coefficient for low technology manufacturing which is statistically significant at the 5% level.

In summary, HGF dynamics at the country level are affected by business cycles and economic shocks, also in knowledge-intensive and technology-intensive sectors. During economic downturns there are a lower number of HGFs that can support innovation and investment as potential HGFs face demand shortages that do not allow them to transform themselves into actual HGFs. A message to take away from this is that economic policy should assure access to finance for potential HGFs in economic downturns, so that firms with high growth potential can be retained and reach their growth potential in the economic recovery.

High growth firms and country capabilities

The striking differences in HGF (10%) shares across EU Member States documented in Figure II-7-2 suggests that country capabilities related to institutions, regulations, labour skills and innovation capabilities are important drivers of the differences in HGFs share dynamics.

Indicators of institutions and capabilities at the country level are often interrelated and highly correlated among each other. This presents a challenge to the analysis of country-level country capabilities. Simple scatter plots and regression analysis are unlikely to be informative for uncovering robust associations between these country capability indicators and HGF shares at the country level. For this reason principal component analysis is used. Principal component analysis allows for the constructing of new summary variables that capture and summarise different aspects of national capabilities. The set of variables used is depicted in Figure II-7-6. The first three indicators (Government effectiveness, regulatory quality and rule of law) capture broad institutional characteristics and the efficiency of public administration of countries. The second set of indicators captures innovation capabilities related to R&D (R&D intensity and researcher intensity). The third set of indicators captures education outputs (labour force with upper secondary education and labour force with tertiary education). The indicator on FDI inflows (in% of GDP) measures the attractiveness of a country for foreign direct investment. The manufacturing share (% GDP) and the employment share in industry indicate the manufacturing base of a country that is generally considered to be a determinant of competitiveness. Trade in services (% of GDP) covers the export share of services of countries and can be considered as a country characteristic. We also use broad variables related to the financial system (domestic credit to the private sector by banks and stock market capitalisation) as the effectiveness of the financial system is of high importance for potential high growth firms. Last but not least we use the indicator of complexity of exports derived from the product space literature. This indicator captures latent information on both the depth and the breadth of the knowledge base of countries that are associated with their exports (for details see Box 1).

Figure II-7-6 **Variable list for analysing the relationship between high growth firm shares and indicators of country capabilities**

Variable	Source
Government effectiveness	Worldwide governance indicator database, World Bank
Regulatory quality	Worldwide governance indicator database, World Bank
Rule of Law	Worldwide governance indicator database, World Bank
R&D intensity	Eurostat
Researcher intensity (per millon people)	Eurostat
Labour force with upper secondary education	Eurostat
Labour force with tertiary education	Eurostat
FDI flows (% of GDP)	World Bank
Manufacturing share (% of GDP)	Eurostat
Employment in industry (% of total employment)	Eurostat
Trade in services (% of GDP)	Eurostat
Domestic credit to private sector by banks (% of GDP)	World Bank
Stock market capitalization (% of GDP)	World Bank
Complexity of Exports	WIFO calculations (Reinstaller et al. 2012)

Figure II-7-18 in the appendix presents the results of the principal component analysis using time-aggregated indicators for the period 2009 to 2012. The analysis leads to the identification of three distinct principal components that summarise the information contained in the 14 indicators of country capabilities. The components are ranked according to their ability to explain most of the variations in the data.

The three components have an interpretation that is quite clear:

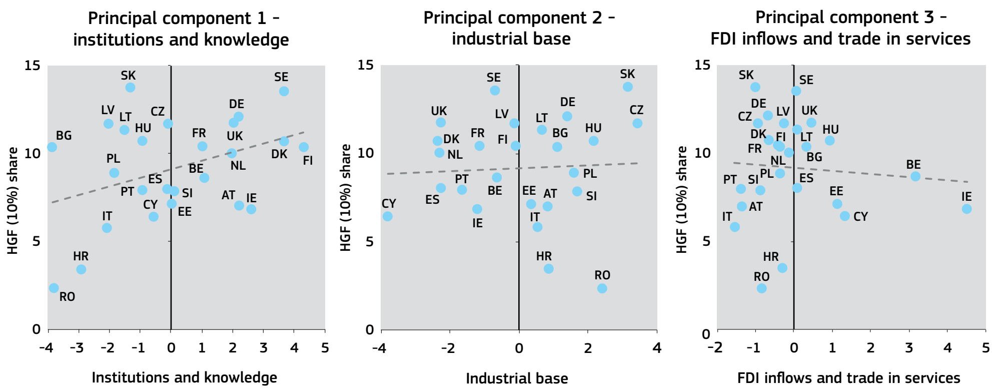
- Principal component 1 (PC1) can be interpreted as a stage of development indicator that combines institutional quality with high innovative capacity. The factor loadings and the correlation analysis in Figure II-7-18 show that PC1 is highly correlated with the governance indicators, R&D intensity, researcher intensity and complexity of exports. This confirms that institutional variables and R&D indicators are highly correlated at the country level. The first principal component explains around 40% of the total variation of the 14 indicators of country capabilities.
- Principal component 2 (PC2) captures the industrial base as it is strongly correlated to the variables manufacturing share (% of GDP), employment in industry and labour force with upper secondary education. Interestingly PC2 (manufacturing base) is weakly negatively correlated to knowledge indicators such as R&D intensity and researcher intensity

and strongly negatively correlated to the governance indicators and the labour force with tertiary education, as well as the indicator measuring domestic credit to the private sector by banks (% of GDP). This suggests that PC2 primarily captures the low technology and medium-low technology manufacturing activities. This principal component accounts for 26% of the total variation of the 14 indicators of country capabilities.

- Principal component 3 (PC3) is an indicator of FDI inflows and trade in services. Interestingly the correlation analysis shows that PC3 is largely independent of institutional quality that is often emphasised in the literature. This principal component accounts for 11% of the total variation of the 14 indicators of country capabilities.

Figure II-7-7 shows the relationship between the HGF share (10%) in 2012 and the summary indicators of country capabilities identified with the principal component analysis. At the macroeconomic level only the first principal component ('institutions and knowledge') shows a significant relationship to the country HGF share (10%). The other two components do not show a strong relationship to the HGF indicator. This analysis clearly confirms that HGF shares are related to differences in institutions and innovation capabilities. HGFs do not thrive in an institutional vacuum but need appropriate framework conditions and an appropriate entrepreneurial ecosystem. However, the results also indicate that principal component 2 ('industrial base') and principal component 3 ('FDI inflows and trade in services') show no strong relationship to HGF shares for the countries in the analysis at the country level.

Figure II-7-7 **Principal components of country capabilities and country HGF (10%) shares, average values for 2009 to 2012**



Science, Research and Innovation performance of the EU 2016
Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat, DG Economic and Financial Affairs; WIFO calculations

Box 1 **The complexity of exports and the product space literature**

International trade is an important factor that helps to explain differences in economic structure and performance across countries (Matsuyama 2009). Drivers of this process are innovation, i.e., the creation of new varieties of products, market selection and changes in demand at the product level. The fact that the product mix exported by countries provides an indicator of competitiveness of countries has been emphasised in a series of contributions by Hidalgo et al. (2007), Hidalgo and Hausmann (2009) and Felipe et al. (2012). They show that the process of economic development of countries is related to changes in the product mix of a country that is exported. The overall complexity and sophistication of a country's export products is a key indicator which is closely associated with technological, economic and institutional capabilities at the country level. In the long run differences in abilities to accumulate capabilities to produce new improved products can explain differences in country performance.

In the present analysis we use two indicators derived from this literature to study its relationship to high growth firms at the -industry-country level. The first indicator is the complexity score associated with the export mix. The product complexity score (short complexity) can be interpreted as capturing latent information on both the depth (capability to produce exclusive products due to high levels of accumulated knowledge) and the breadth of the knowledge base (capability to produce many products with different knowledge bases) needed to produce products in a specific product class or sector. The product complexity score is constructed using network methods on the basis of information on how many countries produce specific products and on how diversified the trade-structure of these countries is. For details on the calculation of the indictor see e.g., Reinstaller et al. (2012).

The second indicator is the revealed GDP per capita of the actual export mix at the industry level of a country which can be interpreted as a measure for the implicit productivity of the export basket of a country. This indicator was proposed by Hausmann, Hwang and Rodrick (2007) and based on the idea that the growth performance is related to the specialisation in specific products or product categories. The indicator is calculated in two steps: First, the implied productivity of a product is calculated as export-weighted GDP per capita across countries. Implied productivities are then aggregated at the industry-country level using export weights of products associated with the specific export mix.

The data to construct these indicators comes from the BACI database on bilateral trade flows compiled by CEPII. It contains data for 232 countries and economies and 5 109 product categories. A detailed description of the data is provided by Gaulier and Zignago (2010).

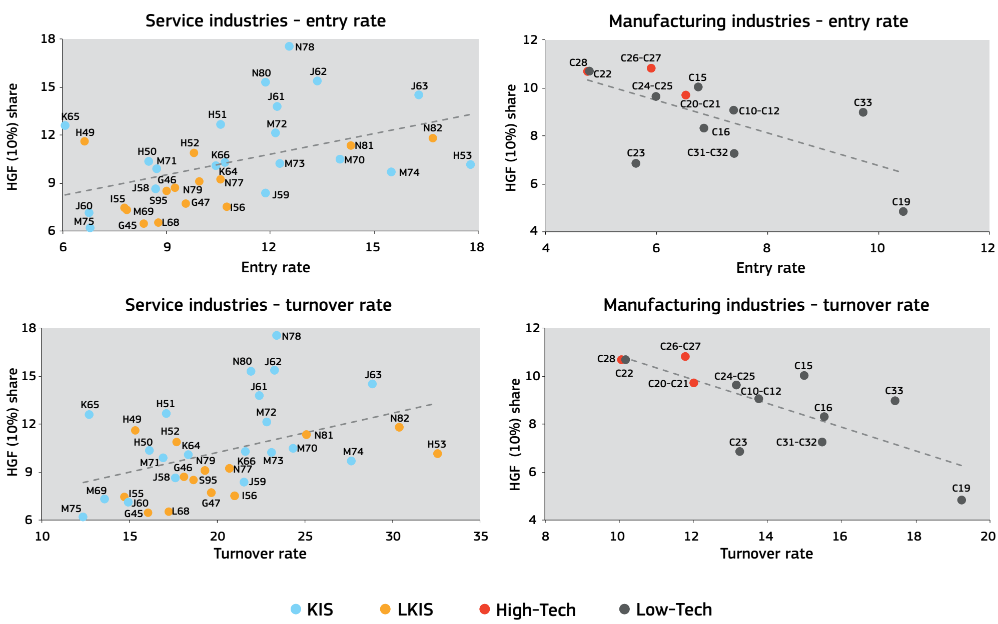
7.4 High growth firms in Europe: start-up dynamics, competitiveness and R&I at the sectorial level

There is considerable heterogeneity of HGF (10%) shares across countries and sectors that is likely associated with differences in firm dynamics, in international competitiveness of countries (at the industry level) and differences in innovativeness.

Indicators of start-up dynamics and HGFs shares

The emergence of high growth firms is often put in relationship with business dynamics, i.e., the entry and exit of new firms. It is well known that entry and exit rates are different across sectors and countries. One determinant of entry rates are administrative entry barriers such as the cost and time to set up a new enterprise. This aspect has received much attention. These administrative entry barriers are likely to be relevant for service sectors, where regulatory entry barriers, 'red tape', and product market regulation are important obstacles to self-employment and firm growth. However, a large part of entry barriers are structural and related to the competitive interaction in markets. Advertising, high capital intensity and cumulative R&D can create sunk costs and entry barriers (e.g., Sutton 1998, Dosi 2007). This complicates the relationship between business dynamics and high growth firms. It might not necessarily be true that higher entry- or turnover rates (share of entry and exit over all firms in an industry or economy) increase the number of high growth firms. The structure of entry seems to be more relevant than the number of entrants. In industries with high entry barriers only 'higher quality' and more ambitious entrepreneurial projects will be realised because of the higher cost of entry. Hölzl (2015) documents that higher sunk costs are associated with a higher share of stable firms, a lower rate of reallocation of market shares but not with a lower overall productivity growth in Austrian manufacturing industries. The evidence on the relationship between entry and turnover rates and the HGF (10%) share depicted in Figure II-7-8 confirms this view. For service industries (both knowledge-intensive sectors and low-knowledge intensive sectors) there is a positive association between entry and turnover rates and the share of high growth firms, while for manufacturing industries (both high-technology and low-technology sectors) the relationship between entry and turnover rates and the share of HGFs (10%) is negative. This implies that, in comparison to the number of entrants or the turnover of firms, the structure of entry and exit is more relevant for the development of successful high growth firms.

Figure II-7-8 **Entry and turnover rates and HGF (10%) shares at sector level[(1)], average values for 2009 to 2012**



Science, Research and Innovation performance of the EU 2016

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

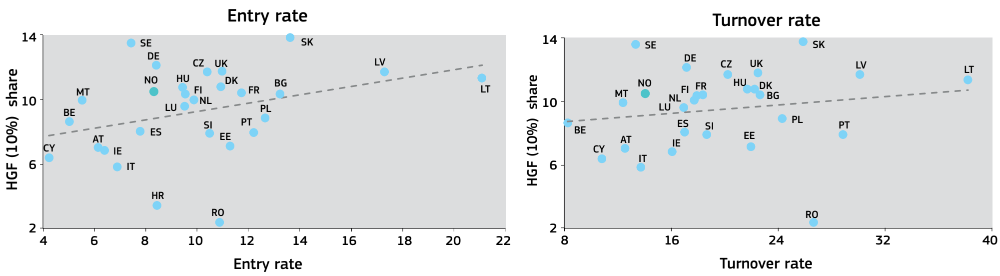
Data: Eurostat; WIFO calculations

Note: [(1)]Industry values are unweighted averages across countries.

Figure II-7-9 depicts the relationship between entry and turnover rates at the country level. As expected from the heterogeneous results at the industry level (Figure II-7-8) the relationship is generally weak.

The findings imply that policies should focus primarily on creating framework conditions and entrepreneurial ecosystems for potentially fast growing firms. This is in line with the evidence that there is little difference with regard to entry rates between most European Countries and the US, the big difference is about post-entry growth processes of firms between Europe and the US (Bartelsman et al. 2009, Criscuolo et al. 2014). Policies to support the emergence of high growth firms should not focus on supporting start-ups alone, they should target both ambitious entrants and ambitious established enterprises and focus on the development of differentiated knowledge-bases and capabilities that allow valuable entrepreneurial experimentation and support thereby the emergence of HGFs.

Figure II-7-9 **Entry and turnover rates and HGF (10%) shares at country level, average values for 2009 to 2012**



Science, Research and Innovation performance of the EU 2016
Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat; WIFO calculations

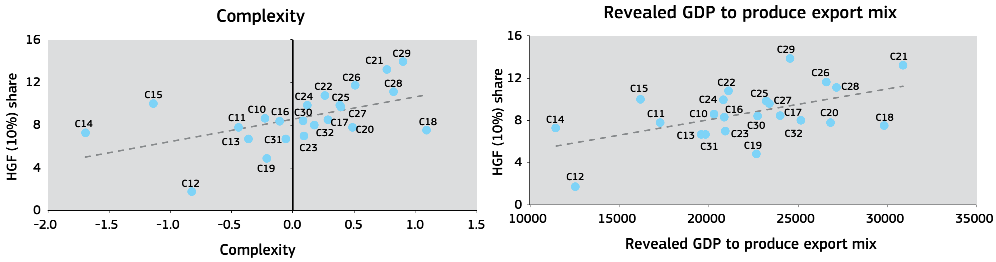
International competitiveness and HGF shares

International trade allows firms to tap into markets outside their home market. For this reason the internationalisation of innovative SMEs ranks high on the policy agenda in Europe. In particular, in small countries firms can reach their growth potential only by exporting. The product space literature (Hidalgo and Hausmann 2009 and Hidalgo et al. 2007, Hausmann et al., 2007) allows for extracting indicators from trade data that provide information about the economic development and competitiveness at the country and industry level. These indicators capture the knowledge-base of a country or sectors. Such indicators have been used to study structural change of productive structures for the EU Member States (Reinstaller et al. 2012). Here, two indicators are used to study the link between HGFs and international competitiveness. The first indicator is the complexity score of the export mix (short complexity) that captures the depth and the breadth of the knowledge base of economies or industries in an economy. While the change over time of this indicator allows for assessing the upgrading of productive structures or stasis in development across countries and sectors, here we focus on complexity as a measure of competitiveness. A high score of complexity shows that the products exported rely on many competences and are relatively unique in the world market, i.e., there are only few exporters in the world. The second indicator we use is the revealed GDP per capita associated with the export mix of a country or sector.

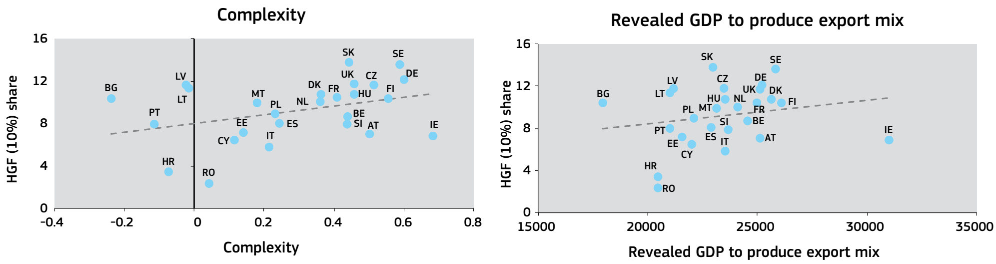
Figure II-7-10 presents the relationship between the complexity indicator and the HGF (10%) shares. The values for complexity are averaged over the 2009 — 2010 period. The HGF (10%) shares in 2012 and the complexity scores are aggregated at the industry level — panel (a) — and at the country level — panel (b). It depicts both the complexity and the revealed productivity of the export mix. The results show that the complexity scores have a higher relationship with the HGF (10%) shares both on the aggregated industry and the country level. The industry results confirm that sectors with a higher complexity score, implying a broader and deeper knowledge base in the industry, are associated with a higher share of HGFs (20%) (Colombelli et al. 2014).. The revealed GDP to produce the export mix also shows a positive association. This evidence suggests product baskets that are associated with a higher implied productivity and a higher complexity offer more opportunities for HGFs.

Figure II-7-10 Relationship between trade-based measures of economic development and high growth firms (10%) at industry[(1)] and country level, average values for 2009 to 2012

(a) Industries (aggregated across countries)



(b) Countries (aggregated across industries)



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

Data: Eurostat, World Bank, BACI database; WIFO calculations

Note: [(1)]Industry values are unweighted averages across countries.

At the country level, the association between complexity and the share of HGF (10%) is less clear than at the industry level but substantially stronger than the association with the implicit productivity of the export mix. The available evidence (Reinstaller et al. 2012) also suggests that the complexity score is a better indicator of competitiveness in the sense of structural change and upgrading of production structures.

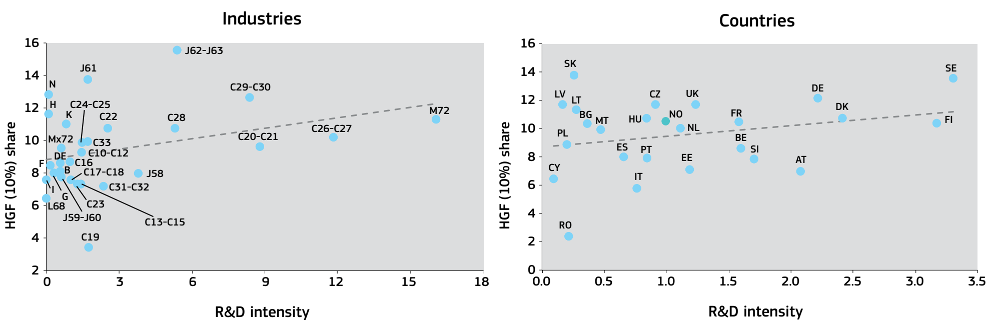
Overall, these results suggest that the improvement of international competitiveness by upgrading productive structures is also associated with an economic process where HGFs are the carriers of such a change. However, the upgrading potential is unevenly distributed across countries because it is deeply rooted in current capabilities and the industrial specialisation of countries. The investment focus of the European Commission on specific technologies such as key enabling technologies is important as such technologies tend to be more complex. They draw on large and different knowledge bases and foster the emergence of new entrepreneurial opportunities. At the same time, the heterogeneity in competitiveness at the country level may require support of the development of productive structures and a diversification of knowledge bases to support structural change and innovative HGFs in less advanced regions in Europe.

Indicators of innovation activities and HGF shares

Research and innovation is an important source of new knowledge and central to the creation of new competences at the country level. The evidence on the sectoral distribution of HGFs reviewed so far suggests that most high growth firms are in knowledge-intensive services, but also that high-technology sectors have a larger share of high growth firms than low technology sectors Daunfeldt et al 2015). Most formal innovation activities related to R&D and patents are located in manufacturing industries, while service industries have, in general, a lower R&D and patent intensity. Figure II-7-11 confirms that there is a positive association between R&D intensity and HGF (10%) shares for the manufacturing sector at the industry (aggregated across countries) and at the country levels (aggregated across industries), respectively.

The left panel of Figure II-7-11 also shows that most industries cluster on the left side of the diagram. Only a few industries are on the right side of the diagram with a very high R&D-intensity. But those industries with a high R&D intensity display an above average share of HGFs. This suggests that mobility barriers associated with R&D (cf. Figure II-7-8) are compensated by larger opportunities to grow. The result by Ciraci et al. (2013) is relevant to explain these patterns. They show that firms with innovation activities have a higher probability to achieve sustained high growth.

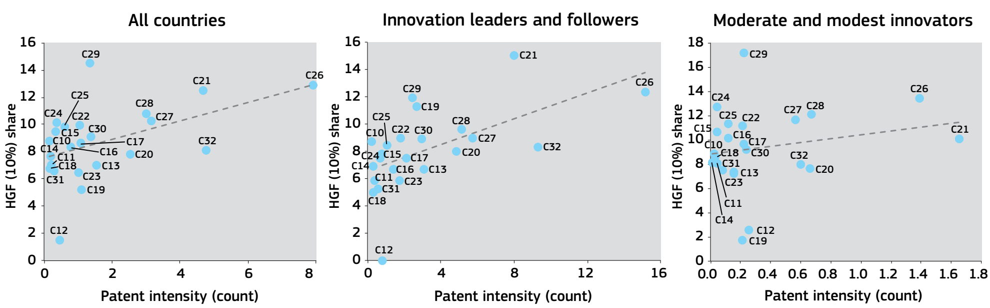
Figure II-7-11 R&D intensity and HGF (10%) shares at industry[1] and country level, average values for 2009 to 2012



Science, Research and Innovation performance of the EU 2016

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat, OECD; WIFO calculations
Note: [1]Industry values are unweighted averages across countries.

Figure II-7-12 Patent intensity (patents per 1000 employees) and HGF (10%) shares at industry level[1], average values for 2009 to 2012



Science, Research and Innovation performance of the EU 2016

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: EPO, OECD; WIFO calculations
Note: [1]Industry values are unweighted averages across countries.

Figure II-7-12 presents evidence on the relationship between patent intensity and HGFs. Patenting is highly concentrated in certain industries, because in different technological fields patents have a different importance to protect new knowledge. For high-growth entrepreneurial ventures patents can play a very important role in order to attract external sources of financing, as patents can be more easily analysed in due diligence processes and provide a formal right of protection against the commercialisation of the innovation by other firms. On the other hand, extensive patent networks can hinder the entry of new ambitious firms because patenting may increase the cost of activity. In such a case one would expect a negative relationship between patenting and the HGF share. The evidence in Figure II-7-12 suggests that there is generally a weak positive relationship between patents and the share of HGFs (10%). The relationship is stronger for the countries classified as innovation leaders and innovation followers according to the Innovation Union Scoreboard than for countries classified as moderate or modest innovators. This mirrors the links established earlier that HGFs are more innovative in economies where the appropriate broad knowledge-base is available. This is especially true for high-technology sectors. Overall the evidence suggests that for high-technology industries patenting is associated with a higher HGF (10%) share.

However, innovation and patent intensity does not necessarily need to be strongly associated with the presence of HGFs. The evidence for firms in the biotechnology industry that covers products related to DNA/RNA, proteins and other molecules, cell and tissue culturing and engineering or bioinformatics. In this industry high growth firms may be underrepresented because most biotech firms aim at patenting products or processes and to sell their patent (or their company) to a large chemical or drug company. Growth might then be realised in the company that acquires the patent (or the firm). However, the evidence provided in Figures II-7-7 and II-7-8 also shows that, despite the recent acquisition boom of large firms, there are still many technological opportunities that are open for small and young firms that can render them high growth enterprises (cf. Hölzl and Friesenbichler 2008).

7.5 Research and innovation behaviour of high growth firms

Until now we used shares of HGFs at the country and industry level to provide evidence on HGFs in Europe. However, industry and country information may not tell the whole story. There is sample evidence that there are innovative firms in low-technology and low knowledge-intensive industries and firms without innovation activities in high-technology and knowledge-intensive industries. Innovation activities are largely firm-specific, therefore the use of industry indicators can be problematic as firm-specific information is masked. The Community Innovation Survey micro data at the safe centre at Eurostat allows looking at the innovation behaviour of HGFs and non-HGFs in more detail.

This data allows studying the innovativeness of HGFs and potential differences in the innovation behaviour between HGFs and non-HGFs. This data allows going beyond the straightjacket of identifying the innovativeness of HGF by using industry averages. The analysis provides evidence as to whether HGFs are different from non-HGFs in their innovation behaviour.

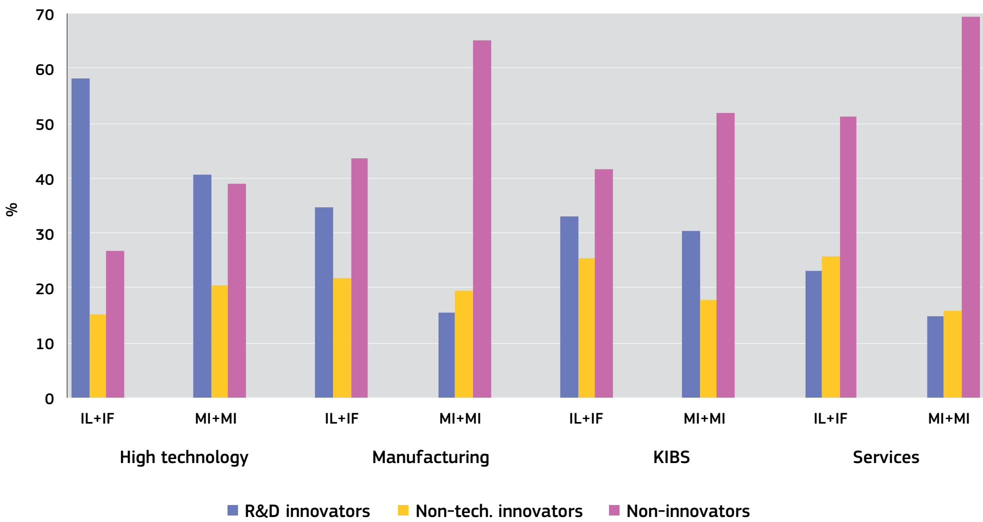
Enterprises can be grouped according to their innovation activities and three types of firms can be distinguished (e.g., Hölzl and Janger 2014):

- R&D innovators: The subset of innovative firms that perform their own R&D activities.
- Non-technology innovators: Innovative firms that do not perform their own R&D
- Non-innovators: Firms that do not perform innovation activities.

Innovative firms introduced a new or significantly improved product or process and/or have ongoing innovation projects. The distinction between R&D innovators and non-technology innovators is based on the fact that, in comparison to non-technological innovation, R&D activities are generally more costly and uncertain but provide — if successful — a stronger firm-specific competitive advantage. The evidence by Ciraci et al. (2013) shows that intramural R&D activities tend to stabilise a firm's growth pattern over time. Innovative HGFs are more likely to repeat high growth episodes in comparison to HGFs that do not perform R&D in-house.

Figure II-7-13 reports the results for country groups and broad sectors. The distribution across country groups and across industries shows marked differences. HGFs in innovation leader and innovation follower countries are more likely to be R&D innovators than HGFs in countries belonging to the group of moderate or modest innovators, and these differences are lager in manufacturing industries than in services. This suggests that the competitive advantage of HGFs is not independent from the comparative advantages at the country level (cf. Hölzl 2009). R&D active HGFs are more numerous in countries where R&D and innovation is a central source of competitive advantage. However, the distribution of HGFs across innovator types crucially depends on the industry of activity. Both the industry and the country context matter. HGFs in high technology industries are much more likely to be R&D innovators than firms located in manufacturing, knowledge-intensive market services or the service sector as a whole. This evidence is interesting, as it clearly shows that the innovativeness of HGFs is context-specific. It depends on the country and industry of activity [134].

Figure II-7-13 **HGFs - distribution by innovator type across broad sectors (%)[1]**



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Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat - CIS micro data accessed at the Eurostat safe centre
Note: [1]The percentage values are averages for the CIS 2010 and the CIS 2012 survey waves.
IL = Innovation leader; IF = Innovation follower; MI = Moderate or modest innovator.

[134] Results from quantile regressions (not reported here) confirm the importance of country-dependency of R&D in an even more pronounced way. Being a R&D innovator in manufacturing industries in innovation leader and innovation follower countries is statistically significantly and positively associated with higher firm growth, while in moderate and modest innovator countries the association becomes negative even for very high firm growth rates. However, for moderate growth rates there is a positive association for both country groups.

A second question that can be answered using firm-level data is whether the innovation behaviour of HGFs is different from non-HGFs. Figure II-7-14 shows the shares of R&D innovators for broad sectors and for the two country groups used in the report. The results clearly indicate that the differences in R&D innovator shares are much larger between the different sector groupings than between HGFs and non-HGFs. The innovativeness of HGFs depends not primarily on their HGF status but on industry affiliation. Firms in high technology manufacturing are more likely to perform R&D activities than firms in other industries; therefore, HGFs in high technology manufacturing industries are likely to be more R&D active than HGFs in other sectors. The lowest number of R&D innovators is found in the low-knowledge intensive market services among both HGFs and non-HGFs.

Figure II-7-14 **R&D innovator shares for different groups of sectors**[1]

	Innovation leaders and innovation followers		Moderate and modest Innovators	
	HGF	non-HGF	HGF	non-HGF
High-technology manufactuing	58%	58%	41%	41%
Medium high-technology manufacturing	45%	51%	30%	38%
Medium low-technology manufacturing	25%	28%	15%	18%
Low-technology manufacturing	24%	23%	13%	10%
Knowledge-intensive market services	28%	20%	27%	21%
Knowledge-intensive financial services	26%	23%	11%	13%
Knowledge-intensive high-technology services	49%	43%	43%	39%
Low knowledge-intensive market services	9%	8%	5%	5%

Science, Research and Innovation performance of the EU 2016

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

Data: Eurostat - CIS micro data accessed at the Eurostat safe centre

Note: [1]The percentage values are averages for the CIS 2010 and the CIS 2012 survey waves.

Knowledge and information sources are important for the innovation process within firms. Knowledge and information obtained from different sources differs to some extent. Otherwise, firms could substitute knowledge from one source with knowledge from other sources without any impact on the innovation process. Academic research provides knowledge that is essential to industrial innovation activities, but in general does not provide much information that is relevant for the applied set of problems on which firms tend to focus in their innovation projects. Thus, agreements and collaborations with universities provide firms with access to scientific knowledge, while agreements with other firms typically focus on the development side of R&D. Customers and suppliers provide yet other sorts of knowledge that are highly relevant for successful innovation projects. In this chapter information sources are grouped in four distinct groups:

- Information sources that are internal to the enterprise or the enterprise group.
- Market sources of information from suppliers, clients from the private sector, clients from the public sectors, enterprises from the same industry and, last but not least, information from consultants an d commercial labs.
- Information sources related to research such as government and other research institutes, universities and other higher education institutions as well as scientific journals and technical publications.

- Other sources related to professional and industry associations and conferences, trade fairs and exhibitions.

In this analysis we concentrate only on innovative firms (innovative HGFs and innovative non-HGFs) as in the Community Innovation Survey only firms with innovation activities are asked the question on the importance of different knowledge for innovation activities. Figure II-7-15 reports the evidence at the country group level for the CIS 2012. The assessment of the importance of the different knowledge sources is very similar across HGFs and non-HGFs within the same country group. The differences between HGFs and non-HGFs are small and in most cases statistically not significant. When testing for the significance a matching algorithm was used that assures that industry affiliation, firm size and country affiliation of HGFs and non-HGFs are matched [135]. The results for the CIS 2012 reported in Figure II-7-15 suggest that the main differences between HGFs and non-HGFs concern information sources related to research. HGFs assess information sources from universities and journals as slightly more important than non-HGFs. However, the differences are small even if they are statistically significant.

Figure II-7-15 Information sources for innovative activities across country groups[1]

	Innovation leaders and innovation followers			Moderate and modest innovators		
	HGF	non-HGF	Difference	HGF	non-HGF	Difference
Internal	**0.71**	**0.68**	**NS**	**0.62**	**0.63**	**NS**
Market	**0.42**	**0.39**	**NS**	**0.42**	**0.42**	**0.01***
SSUP	0.52	0.48	NS	0.59	0.58	NS
SCLPR	0.57	0.53	0.03**	0.50	0.50	0.01*
SCLPU	0.26	0.24	0.02*	0.25	0.25	-0.01*
SCOM	0.45	0.43	NS	0.41	0.41	NS
SINS	0.29	0.27	NS	0.34	0.34	0.01**
Research	**0.27**	**0.25**	**0.03*****	**0.26**	**0.25**	**0.02*****
SUNI	0.27	0.26	0.03***	0.23	0.23	0.02***
SGMT	0.16	0.14	NS	0.18	0.17	NS
SJOU	0.38	0.35	0.03***	0.37	0.36	NS
Other	**0.38**	**0.36**	**NS**	**0.37**	**0.35**	**NS**
SCON	0.46	0.43	NS	0.43	0.41	NS
SPRO	0.30	0.28	0.02*	0.32	0.30	NS

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Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat - CIS 2012 micro data accessed at the Eurostat safe centre; WIFO calculations
Note: [1]The degree of importance has been rescaled: A value of 0 indicates «not used», a value of 0.333 indicates «low importance», a value of 0.666 indicates «medium importance» and the maximum value of 1 «high importance». NS indicates that the difference is not statistically significant. *, ** and *** denote statistical significance at the 10%, the 5% and the 1% level of significance, respectively.

The results for the CIS 2010 (not reported here) show quantitatively different but qualitatively very similar patterns. The most striking differences are for internal knowledge sources, where statistically significant results are observed for the CIS 2010 survey wave but not for the CIS 2012. Overall, the most important information source for innovation for both HGFs and non-HGFs are information sources internal to the enterprise or enterprise network,

[135] We used the coarsened exact matching algorithm proposed by Iacus et al. (2011) to control for the potentially confounding effects of country, industry and size that could drive differences. If HGs would be small firms and non-HGFs large established R&D performers evidence on raw data could be misleading. Matching allows one to compare similar firms and to provide more precise information on the differences between HGFs and non-HGFs.

indicating that innovation projects require a strong internal base of knowledge in order to be able to absorb external knowledge. Also important are market-related knowledge sources such as clients and customers from the private sector and suppliers.

Figure II-7-16 presents the results at the level of industry groupings. Differences between HGFs and non-HGFs can be observed in high technology manufacturing in particular, where HGFs assess many information sources to be more important than non-HGFs. However, the differences between HGFs and non-HGFs are quite small compared to the level of the assessment, except perhaps the assessment of importance of universities as a source of knowledge. However, even for HGFs in high-technology sectors sources of information internal to the enterprise and market sources of information related to clients, suppliers, competitors, sources of information from journals and technical publications as well as other information from conferences are ranked higher than universities as sources of innovation. This clearly suggests that universities and research are relevant for innovative HGFs but that universities are not a primary information sources for innovative HGFs. It is also important to see that the differences between HGFs and non-HGFs are much smaller than the differences among HGFs across the different industry groupings. This suggests that HGFs are embedded in industry-specific innovation systems and have quite similar innovation processes than non-HGFs that are located in the same industries. The evidence on differences between HGFs and non-HGFs with regard to the most valuable cooperation partner is also instructive in this respect. Figure II-7-19 in the appendix again shows that the assessment of the most valuable cooperation partner depends largely on the industry context.

Figure II-7-16 **Information sources for innovative activities across industry groupings[1]**

Information source	High-tech maufacturing		Medium high-tech manufacturing		Low and medium low-tech manufacturing		Knowledge-intensive services		Low knowledge-intensive services	
	Mean HGF	Difference between HGF and non-HGF	Mean HGF	Difference between HGF and non-HGF	Mean HGF	Difference between HGF and non-HGF	Mean HGF	Difference between HGF and non-HGF	Mean HGF	Difference between HGF and non-HGF
Internal	**0.72**	**0.01****	**0.71**	**NS**	**0.63**	**NS**	**0.75**	**0.01***	**0.59**	**NS**
Market	**0.44**	**0.03*****	**0.41**	**NS**	**0.42**	**NS**	**0.45**	**NS**	**0.40**	**NS**
SSUP	0.55	0.03*	0.56	0.02*	0.61	NS	0.50	NS	0.57	NS
SCLPR	0.62	0.03**	0.54	NS	0.53	NS	0.59	NS	0.46	NS
SCLPU	0.26	NS	0.25	NS	0.24	NS	0.35	NS	0.24	NS
SCOM	0.46	NS	0.40	NS	0.42	NS	0.47	0.01*	0.39	NS
SINS	0.33	0.03*	0.32	NS	0.32	NS	0.34	NS	0.33	NS
Research	**0.35**	**0.04*****	**0.27**	**NS**	**0.24**	**NS**	**0.32**	**NS**	**0.21**	**NS**
SUNI	0.37	0.06***	0.28	0.01*	0.22	NS	0.32	0.02*	0.16	NS
SGMT	0.22	0.03**	0.15	0.01*	0.16	NS	0.22	NS	0.14	NS
SJOU	0.45	NS	0.37	NS	0.35	NS	0.43	NS	0.32	NS
Other	**0.43**	**NS**	**0.36**	**-0.02***	**0.36**	**NS**	**0.39**	**NS**	**0.35**	**NS**
SCON	0.54	0.03*	0.43	-0.01*	0.43	NS	0.46	NS	0.40	NS
SPRO	0.32	NS	0.30	NS	0.28	NS	0.31	NS	0.30	NS

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Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat - CIS 2012 micro data accessed at the Eurostat safe centre; WIFO calculations
Note: [1]The degree of importance has been rescaled: A value of 0 indicates «not used», a value of 0.333 indicates «low importance», a value of 0.666 indicates «medium importance» and the maximum value of 1 «high importance» . NS indicates that the difference is not statistically significant. *, ** and *** denote statistical significance at the 10%, the 5% and the 1% level of significance, respectively.

There are, of course, limits to this evidence as all countries are grouped together and not much can be said about the quality of information that HGFs and non-HGFs obtain from the different information sources. However, this new evidence suggests that there is a strong context-dependency in innovation activities of HGFs with regard to country-specific and industry-specific attributes. Except for high technology manufacturing industries the differences of using different information sources between HGFs and non-HGFs are negligible and even for high technology manufacturing the differences are quite small. From this, it follows that innovation processes of HGFs do not systematically differ from non-HGFs in the same industry. This suggests that many of the innovation policies that target ambitious research projects at the firm level and foster the generation of new knowledge bases will, in principle, also be effective for supporting HGFs, if such policies are effectively embedded in the entrepreneurial ecosystem.

7.6 Research and innovation policies for new HGFs

The findings collected in this chapter provide new evidence on HGFs in Europe. To summarise the findings:

- HGFs are affected by economic downturns.
- HGFs shares at the country and industry level are positively associated with research and innovation activities and international competitiveness.
- HGFs shares are only weakly associated with entry rates and firm turnover rates (especially in manufacturing)
- The innovation behaviour of HGFs is context-specific and not systematically different from non-HGFs that operate in the same country and industry. This context-dependency is related to country-specific comparative advantages and industry-specific innovation processes.

In addition, the literature on HGFs emphasises that HGFs are often already established firms and that they are difficult to target on an ex-ante basis. HGFs are also important drivers of resource reallocation and can thereby promote structural change in economies.

7.6.1 Framework conditions are of central importance...

In order to foster the emergence of HGFs broad framework conditions that support the reallocation of market shares to more productive companies need to be in place. Frictions related to regulations and policies that hamper the processes of reallocation of resources to more efficient uses hold HGFs back. Not only product market regulations fall into this category but also the appropriate development of financial systems and the general efficiency of the public administration and the rules of law that are more systemic in nature and more difficult to achieve. At the EU level barriers that affect the functioning of the Single European Market are of central relevance for HGFs. Thus one element is the promotion of a growth-oriented business environment with regulations that promote economic growth, including public administration efficiency (e.g., Friesenbichler et al. 2014, Cuaresma et al. 2014, Bravo-Biosca et al. 2013).

7.6.2 But also the creation of opportunities for HGFs

However, framework conditions are not enough to support the emergence of HGFs and to ensure that HGFs are the carriers of structural change. Conducive framework conditions are necessary but not sufficient for HGFs to emerge. But simply creating supportive framework conditions for start-ups through grants and subsidies is also likely to be inefficient (Mason and Brown 2014). Such policies may have a value in the start-up phase but lose their effectiveness when firms become established and networking and customer interaction become more important. Localised spillovers, knowledge bases and information networks become even more central in the post-entry growth phases of enterprises where customers play a more important role than in the start-up phase.

The context-dependency of the innovation behaviour of HGFs together with the evidence that

HGF shares are closely related to international competitiveness documented in this chapter strongly emphasises that HGFs can only thrive in ecosystem that provide appropriate knowledge bases and local spillovers. Entrepreneurial opportunities do not emerge out of thin air. HGFs often emerge in response to disruptive technical change. In order to profit from such changes appropriate knowledge bases need to be in place. Entrepreneurial opportunities emerge in environments with appropriate knowledge bases and are often dependent on local spillovers. This suggests that HGFs can support structural change towards new sectors but in order to do so they can only start by building on existing academic and industrial knowledge bases. In this respect policies to foster HGFs are closely related to policy initiatives that support 'smart specialisation', or better 'smart diversification'. These concepts emphasise that structural change is, most of the time, a cumulative process and that it is very difficult to develop new specialisation patterns out of the blue. This presents a particular problem for countries in which industrial restructuring is necessary. The emergence of HGFs requires appropriate policies and institutions.

On the one hand, a picture emerges that policies to mobilise HGFs to drive industrial restructuring should be conceived in a broad way and cover such different areas as education policies, research, technology and innovation policies that allow the emergence of entrepreneurial opportunities. On the other hand, such policies should take into account the specific market failures (framework conditions) and specific systemic failures (creation of new opportunities, interaction of different actors in the innovation system or the entrepreneurship ecosystem). This view should guide policy-making, as it is well known that policies that target such failures have, in general, a larger impact than policies that try to replicate elements of existing success stories such as Silicon Valley in environments that are not suited for such transplants.

7.6.3 And what about R&I policies?

The finding that HGF shares are higher in R&I intensive and knowledge-intensive sectors points directly to the importance of R&I policies to support the emergence of HGFs. Research and innovation policies are also instrumental for supporting the development and diversification of knowledge bases at the European, national and regional levels, respectively. Together with the evidence on the innovation behaviour of HGFs and the arguments that HGFs are difficult to target, this suggests that it might not be necessary to support HGFs through new instruments. By contrast, many of the innovation policies that target ambitious research projects at the firm level and foster the generation of differentiated knowledge bases will, in principle, also be effective for supporting HGFs, as long such policies are effectively embedded in the specific entrepreneurial ecosystem and do not simply foster incumbent R&D performers.

7.7 Appendix

A1. Data sources

For the analysis presented in this chapter, the definition of HGFs proposed by Eurostat and the OECD (2007) is used. Accordingly, we define HGFs as firms that achieved an annualised growth rate of 20% (original formulation) or 10% (as used for the new Innovation Output Indicator (IOI)) over a consecutive three year time period. The population of firms is restricted to enterprises that had at least 10 employees at the beginning of the time of measurement, in order to capture only firms that contributed substantially to employment generation.

Data for both definitions is published by Eurostat and the OECD. The Entrepreneurship indicator program dataset in Eurostat's corporate demography database provides time series data for HGFs at the country level using the 20 percent growth threshold (HGF (20%)). A drawback of this dataset is that time series data are only available for a limited set of countries (consistent time series data is only available for CZ, EE, ES, HU, IT, LT, LU, PT, RO and SI).

The second dataset captures high growth enterprises (growth by 10% or more). Here, information on the number of HGFs and the employment in HGFS using the 10 percent growth threshold is available (HGF (10%)). Data is available for all EU28 countries except Greece. Numbers and employment in the population of firms with at least 10 employees are not available in this dataset. In order to construct HGF shares data on the number of firms with at least 10 employees from the Structural Business Statistics (Annual enterprise statistics by size class) has been added [136]. While information on HGFs is also available for 2013, the latest information on the share of firms with at least 10 employees is for 2012. Therefore, the analysis is limited to the HGF (10%) share in 2012.

A2. Country groups and industry groupings

The country grouping is based on the distinction between innovation leaders, innovation followers, and moderate and modest innovators in the Innovation Union Scoreboard (European Innovation Scoreboard). For the CIS data is not available for all countries. Figure II-7-17 provides an overview on the data coverage.

Figure II-7-17 Countries classified by group with data coverage in CIS

Country		Country group	CIS 2012	CIS 2010	HGF
BE	Belgium	Innovation Follower			✓
BG	Bulgaria	Modest Innovator	✓	✓	✓
CZ	Czech Republic	Moderate Innovator	(✓)	✓	✓
DK	Denmark	Innovation Leader			✓
DE	Germany	Innovation Leader	✓	(✓)	✓
EE	Estonia	Innovation Follower	✓	✓	✓
IE	Ireland	Innovation Follower	✓		✓
EL	Greece	Moderate Innovator			
ES	Spain	Moderate Innovator	✓	✓	✓
FR	France	Innovation Follower	(✓)	✓	✓
HR	Croatia	Moderate Innovator	✓	✓	✓
IT	Italy	Moderate Innovator	✓	✓	✓
CY	Cyprus	Innovation Follower	✓	✓	✓
LV	Latvia	Modest Innovator	✓	✓	✓
LT	Lithuania	Moderate Innovator	✓	✓	✓
LU	Luxembourg	Innovation Follower	(✓)	✓	✓
HU	Hungary	Moderate Innovator	✓	✓	✓
MT	Malta	Moderate Innovator			✓
NL	Netherlands	Innovation Follower			✓
AT	Austria	Innovation Follower			✓
PL	Poland	Moderate Innovator			✓
PT	Portugal	Moderate Innovator	✓	✓	✓
RO	Romania	Modest Innovator	✓	✓	✓
SI	Slovenia	Innovation Follower	✓	✓	✓
SK	Slovakia	Moderate Innovator	✓	✓	✓
FI	Finland	Innovation Leader			✓
SE	Sweden	Innovation Leader	✓		✓
UK	United Kingdom	Innovation Follower			✓
NO	Norway	Innovation Follower	(✓)	✓	✓

Science, Research and Innovation performance of the EU 2016

(136) Data is available up to the year 2012. If the 2012 value was not available past values have been used to estimate the number of firms with at least 10 employees in 2012.

The industry grouping follows the Eurostat aggregations of technology-intensive manufacturing industries based on NACE Rev. 2 and the Eurostat aggregations of services according to knowledge intensive activities. Details can be found at the Eurostat homepage: http://ec.europa.eu/eurostat/cache/metadata/DE/htec_esms.htm.

A3. Principal component analysis

Figure II-7-18 **Principal components capturing important characteristics of country capabilities**[1]

	Factor loadings				Correlation[2]		
	PC1	PC2	PC3	Unexplained	PC1	PC2	PC3
Government effectiveness	0.36	0.13	-0.01	0.08	0.95	-0.49	0.19
Regulatory quality	0.35	0.15	0.09	0.12	0.92	-0.40	0.30
Rule of Law	0.37	0.14	0.01	0.05	0.97	-0.48	0.22
R&D intensity	0.30	0.32	-0.10	0.11	0.91	-0.19	-0.06
Researcher intensity (per million people)	0.29	0.27	-0.13	0.21	0.86	-0.25	-0.08
Labour force with upper secondary education	-0.21	0.38	0.12	0.27	-0.28	0.85	-0.22
Labour force with tertiary education	0.26	-0.21	0.22	0.32	0.51	-0.63	0.59
FDI flows as % of GDP	0.03	-0.16	0.61	0.20	-0.01	-0.03	0.88
Manufacturing share (% of GDP)	-0.15	0.44	0.29	0.17	-0.08	0.86	0.01
Employment in industry (% of total employment)	-0.28	0.29	0.12	0.20	-0.50	0.87	-0.23
Trade in services (% of GDP)	0.14	-0.18	0.58	0.13	0.23	-0.25	0.93
Domestic credit to private sector by banks (% of GDP)	0.26	-0.33	-0.03	0.24	0.42	-0.85	0.34
Stock market capitalization (% of GDP)	0.28	-0.03	-0.23	0.36	0.66	-0.61	-0.06
Complexity of Exports	0.24	0.35	0.21	0.19	0.80	0.04	0.27

Science, Research and Innovation performance of the EU 2016

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

Data: Eurostat, World Bank. BACI database; WIFO calculations

Notes: [1]Data are averages for the years 2009 to 2012. [2]Correlation coefficients above 0.8 are highlighted in orange.

A.4 Most valuable innovation partners for HGFs and non-HGFs

Figure II-7-19 **Most valuable innovation partner for innovation activities**

		Other enterprises within the enterprise group	Suppliers	Clients or customers (private sector)	Clients or customers (public sector)	Competitors or other enterprises in your sectors	Consultant and commercial labs	Universities	Government and private research institutes	No answer
		Innovation leader and innovation follower countries								
High-technology manufacturing	non-HGF	7%	7%	9%	0%	4%	1%	7%	3%	62%
	HGF	3%	6%	11%	2%	1%	4%	7%	4%	63%
Medium-high-technology manufacturing	non-HGF	9%	8%	10%	1%	1%	2%	6%	3%	60%
	HGF	12%	5%	12%	0%	4%	1%	5%	2%	59%
Medium-low and low-technology manufacturing	non-HGF	7%	10%	8%	0%	2%	2%	3%	2%	66%
	HGF	5%	10%	6%	1%	1%	1%	3%	3%	70%
Knowledge-intensive services	non-HGF	9%	6%	10%	1%	2%	2%	4%	1%	65%
	HGF	6%	5%	9%	1%	4%	4%	4%	2%	64%
Low knowledge-intensive services	non-HGF	7%	12%	4%	1%	3%	2%	1%	0%	70%
	HGF	5%	11%	3%	3%	3%	2%	2%	0%	71%
		Moderate innovator and modest innovator countries								
High-technology manufacturing	non-HGF	8%	5%	5%	0%	1%	2%	7%	5%	67%
	HGF	8%	6%	8%	0%	2%	3%	4%	4%	63%
Medium-high-technology manufacturing	non-HGF	10%	5%	4%	0%	2%	3%	5%	5%	67%
	HGF	10%	7%	5%	1%	3%	4%	5%	3%	62%
Medium-low and low-technology manufacturing	non-HGF	5%	6%	3%	0%	1%	2%	3%	4%	76%
	HGF	4%	5%	4%	0%	2%	2%	2%	3%	78%
Knowledge-intensive services	non-HGF	8%	7%	6%	1%	3%	3%	6%	4%	62%
	HGF	10%	8%	7%	1%	4%	2%	6%	4%	58%
Low knowledge-intensive services	non-HGF	4%	6%	2%	0%	1%	2%	2%	2%	80%
	HGF	4%	7%	1%	1%	1%	2%	2%	1%	82%

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Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat - CIS 2012 micro data accessed at the Eurostat safe centre; WIFO calculations

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8. Innovation, skills and job creation

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8.1 Introduction: background and policy context

Whereas the theoretical and empirical literature agrees upon the positive impact of innovation on productivity growth (see Hall et al. 2010 for a survey), the evidence is less clear for employment growth. From a theoretical point of view there are different channels through which innovation affects employment, some being labour-increasing and others being labour-saving. Hence, it is an empirical question whether, and to what extent, innovation creates jobs or whether it leads to 'jobless' growth or even to labour displacement. It has been argued that the strong positive link between value creation through productivity growth and job creation has been weakened and has led to jobless growth since the economic crisis of 2009 (Brynjolfson and McAfee 2012).

An interesting issue is the policy debate on the effects of innovation on employment growth as it relates to the role of skills. On the one hand, certain skills like engineering skills, mathematical or management skills, skills in software development and multimedia or more general competences in problem-solving, communication and literacy are needed to develop inventions and foster innovation and as a potential result also stimulate employment growth. The EU acknowledges the important role of skills in the Agenda for New Skills and Jobs, another flagship initiative within the Europe 2020 strategy. Skills development forms one of the four main areas of this Agenda. The EU aims at increasing the proportion of 30-34 year old people with a tertiary degree to 40% by 2020 and at promoting vocational training, continuing training and lifelong learning to equip people with the skills needed to succeed in the labour market of today and tomorrow. Against this backdrop, understanding and measuring the type of skills needed to foster innovation becomes crucial.

On the other hand, innovation might not only have a quantitative effect on overall employment but also a qualitative effect. The use of new technologies in production, the introduction of new products or organisational changes might also change the skill requirements of firms and thus the skill structure of the labour force (skill-biased technological change). This might have strong effects on the job market and requires a change in the skills supply. Understanding this phenomenon would also help to better grasp the ability of countries to generate higher value-added jobs and potentially reduce the time span for an efficient reallocation of the work force.

Against this backdrop, this chapter studies the complex relationship between skills, innovation and employment growth. It summarises the main findings from the literature and provides recent empirical evidence for European countries on the following three key questions:

1. What is the role of skills for innovation?
2. What is the effect of innovation on overall employment growth?
3. How does innovation affect skill demands?

8.2 The role of skills for innovation

Skills refer to productive assets of the workforce that are acquired through learning activities (Toner 2011). Thus, the key question is: what makes skills productive for innovation? The evolutionary theory has argued that innovative capabilities are a decisive factor in explaining innovation (Nelson and Winter 1982). Innovative capabilities can be defined as different degrees of knowledge accumulation and different efficiencies in the innovative search process (Dosi 1988). Hence firms' innovative capabilities are primarily determined by human capital, i.e., by the knowledge, skills, and creativity of their employees. That is, skills are necessary to identify and assess the firm-specific knowledge stock in order to generate new knowledge and innovation. But skills are also necessary to identify the value of new external information from the environment and to assimilate and apply it to commercial ends in what is called an absorptive capacity (Cohen and Levinthal 1989). It has also been argued that the higher stock of knowledge increases the speed of learning and developing higher order problem-solving skills leading to a higher functional flexibility of high-skilled workers (Toner 2011). A related argument is that individuals with high levels of education adopt new technologies and innovations faster than individuals with lower levels of education (Kim 2002). This greater functional flexibility of persons with high educational attainment in consumption and production should also be beneficial at the macro level as they are better able to cope with rapid structural change, e.g., induced by technological progress (Toner 2011).

Despite the fact that the importance of skills and skill formation is acknowledged throughout the innovation literature, there is surprisingly little empirical evidence on the role of skills and skill formation on developing innovation (Tether et al. 2005, Edquist 2005) and on (innovation-induced) productivity growth. One reason for this gap in the literature is the difficulty of operationalising and measuring the complex concept of skills.

One rather simple solution is to proxy skills by using the formal education level of the workforce like the share of workers with high levels of educational attainment (people with a tertiary degree). Empirical studies have generally confirmed that a higher share of high-skilled workers increases the likelihood of introducing new products and processes [137] or productivity (Black and Lynch 2001, Bartelsman et al. 2014). As an alternative, the number or proportion of R&D employees has been used as an indicator for innovative capabilities and skills mainly capturing engineering and science skills. A limitation of this approach is that it neglects skills of the non-R&D workforce. It furthermore neglects that R&D is not the only way for an enterprise to introduce new products and processes, and using R&D indicators tends to lead to an underestimation of innovation activities in small and medium-sized firms as well as service sector firms (Brouwer and Kleinknecht 1997). In addition, or instead, of formal education, investments in training have been used as an alternative indicator for skills (e.g., Corrado et al 2008). Peters (2009) find a positive impact of training on innovation measured both in terms of innovation input and innovation output. In terms of productivity effects, the evidence is more mixed. While Deardon et al. (2006) for the UK and Konings and Vanormelingen (2009) for Belgium find a significant productivity premium of training, Black and Lynch (1996 and 2001) find no impact of training on productivity for US firms. However, measures like training investments do not reveal what types of skills are addressed with training activities.

Against this backdrop and potential measurement limitations, the following section 2.1. aims at summarising recent trends in skills development across European countries. Section 2.2 relates different skill measures to innovation indicators at the country level while section 2.3. shows novel firm-level evidence for what types of skills are important for stimulating innovation and innovation success in European firms.

8.2.1 Skills development in Europe

This section sketches some stylised facts in the recent development of skill formation in Europe using the indicator on human resources in science and technology (HRST) [138]. The HRST indicator is a broader and better concept than the share of high-skilled workers as it combines education and occupation tasks. HRST refers to those persons who fulfil one or the other of the following conditions: (i) successfully completed education at the third level [139] or (ii) employed in a Science and Technology (S&T) occupation where the above qualifications are normally required [140].

(137) For instance, Peters (2009) found that a 1% increase in the share of highly skilled personnel raises the probability of innovating by about 0.6 percentage points for German firms.

(138) HRST data are obtained from the EU Labour Force Survey (LFS).

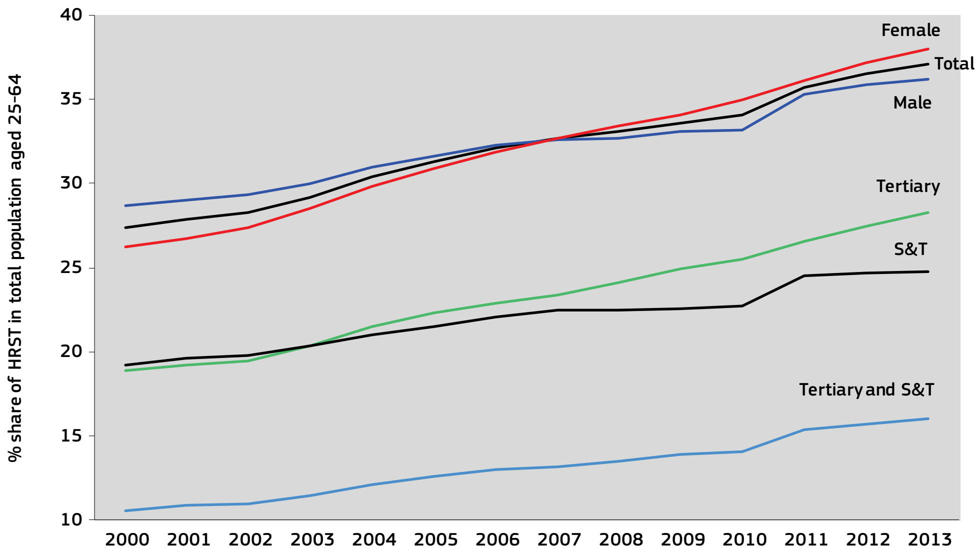
(139) People who have successfully completed a tertiary level education relates to ISCED97 — levels 5A, 5B and 6 (until 2013) and from 2014 onwards to ISCED2011- levels 5 to 8.

(140) Based on the tasks and duties undertaken in the job, the International standard classification of occupations (ISCO) organises jobs into a clearly defined set of groups. S&T occupations refer to group 2 (professionals like science and engineering professionals, health professionals, teaching professionals, business and administration professionals, information and communications technology professionals, legal, social and cultural professionals) and 3 (technicians and associate professionals like science and engineering associate professionals, health associate professionals, business and administration associate professionals, legal, social, cultural and related associate professionals, information and communications technician). Managers (group 1) are not included.

Figure II-8-1 shows the overall development of human resources in science and technology in Europe for the period 2000-2013. We observe a clear steady upskilling trend in Europe. In 2013, 37.1% of the European population aged between 25 and 64 had completed a tertiary degree or worked in an S&T occupation. The Figure shows that, in 2007, the HRST-proportion among women had surpassed the one for men but overall there are only small differences between men and women. Compared to 2010 when the Innovation Union and Agenda for New Skills and Jobs were launched, the HRST proportion demonstrates a remarkable increase by three percentage points, but the target of 40% tertiary attainment of 30-34 year olds has not yet been reached. Compared to 2000 this proportion has increased by 10 percentage points, which corresponds to a growth of 35.4%. In absolute numbers this translates to an increase from 70.8 million to 102.4 million people (+ 44.6%).

This tremendous upskilling trend is driven by both components though the formal education contributed more to this development. The labour supply of high skilled people measured by the share of population aged between 25 and 64 having a tertiary degree has grown by nearly 50% from 18.9% in 2000 to 28.3% in 2013. The increase in S&T occupations where the above qualifications are normally required is somewhat smaller with 29.2%. At the same time, the proportion of persons without a tertiary degree working in a non-S&T occupation has declined from 72.6 to 62.9%. Furthermore, while the development in both indicators is very similar for the period 2000-2007, we observe an increasing gap from 2008 onwards. While the share of the population with a tertiary degree is still steadily rising, the growth in the S&T occupation has slowed down from 8.9% in the period 2008-2011 to 1.2% from 2011-2013.

Figure II-8-1 **Human resources in science and technology (HRST)[1] in the EU[2] as % of total population aged 25-64, 2000-2013**

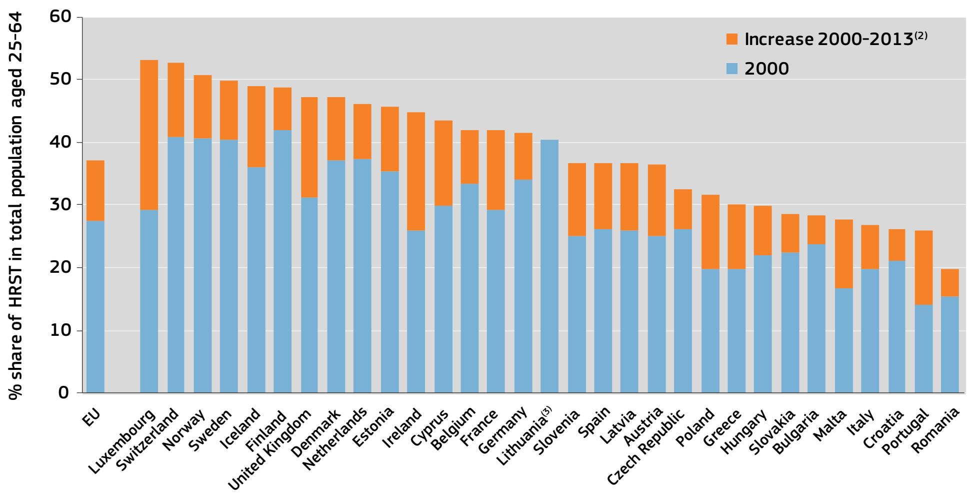


Science, Research and Innovation performance of the EU 2016

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat
Notes: [1]Total population with tertiary degree and / or employed in an S&T occupation where these qualifications are normally required (age: 25-64 years). [2]EU27: 2000-2007; EU28: 2008-2013.

European countries exhibit a relatively large heterogeneity with respect to human resources in science and technology (HRST) ranging in 2013 from 53.2% in Luxemburg and 49.9% in Sweden to 25.9% in Portugal and 19.8% in Romania (Figure II-8-2). This country heterogeneity is partly driven by differences in education systems but also by industry differences. Not surprisingly, innovation leaders like Sweden, Finland and Denmark are among the countries that demonstrate the highest share of human resources in science and technology. An exception is Germany where the education system is characterised by a well-established dual system combining general transferable skills and structured learning on the job supportive for providing technical skills. The increasing upskilling trend, however, is observed in all European countries, except for Lithuania (-2.9 pp). In particular, countries like Luxemburg (+ 24 pp), Ireland (+ 18.8 pp), the UK (+ 16.1 pp), Cyprus (+ 13.6 pp) and France (+ 12.7 pp) have substantially raised their human resources in science and technology, in particular the degree of people having a tertiary degree. Differences in the speed to upskill the workforce have furthermore reduced the heterogeneity with respect to human resources in science and technology across Europe [141].

Figure II-8-2 **Human resources in science and technology (HRST)[1] by country as % of total population aged 25-64, 2000-2013**



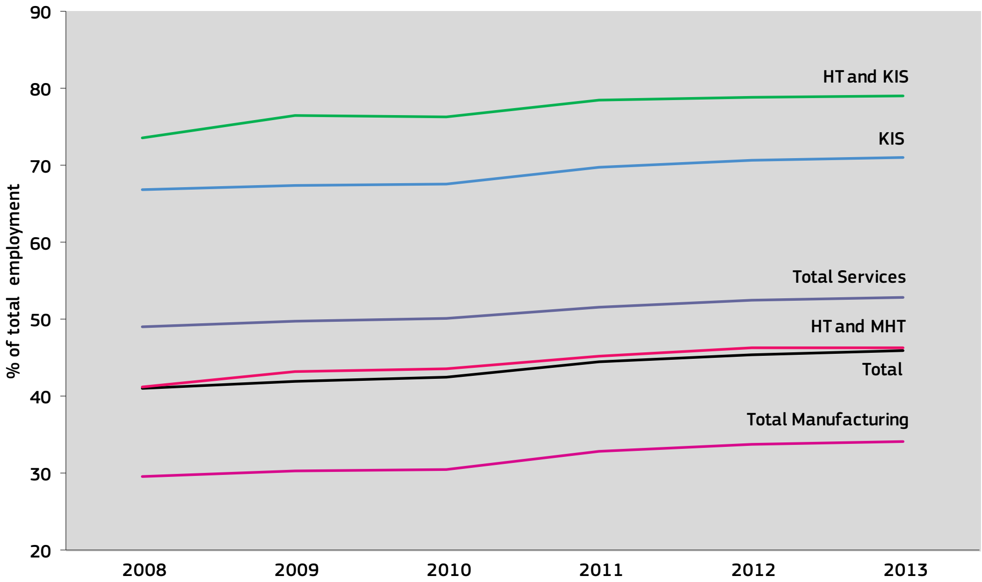
Science, Research and Innovation performance of the EU 2016

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat
Notes: [1]Total population with tertiary degree and / or employed in an S&T occupation where these qualifications are normally required (age: 25-64 years). [2]HR: 2002-2013. [3]LT: The share for Lithuania decreased from 43.2% in 2000 to 40.3% in 2013.

Manufacturing has benefitted more from the substantial skill increase in the workforce than services (Figure II-8-3). In manufacturing, the proportion of total persons employed with a tertiary degree and/or employed in an S&T occupation where the above qualifications are normally required has increased from 29.6% in 2008 to 34.1% in 2013 (+ 4.5 pp) which corresponds to a growth rate of 15.2%. Services which are characterised by a much higher input level of human resources in science and technology in general have also intensified their skill input but to a lesser extent (from 49.1% to 52.9%, i.e., growth rate: 7.7%). Despite high starting levels, we observe the strongest upskilling trend in Europe in skill-intensive sectors like high-tech manufacturing and knowledge-intensive services. In 2013, nearly four out of five employees in skill-intensive sectors have a tertiary degree or work in S&T occupations (+ 5.5 pp).

[141] Heterogeneity is measured by the coefficient of variation which has declined from 0.289 in 2000 to 0.238 in 2013.

Figure II-8-3 **Human resources in science and technology (HRST) in the EU - employment rates[1] by sector[2], 2008-2013**



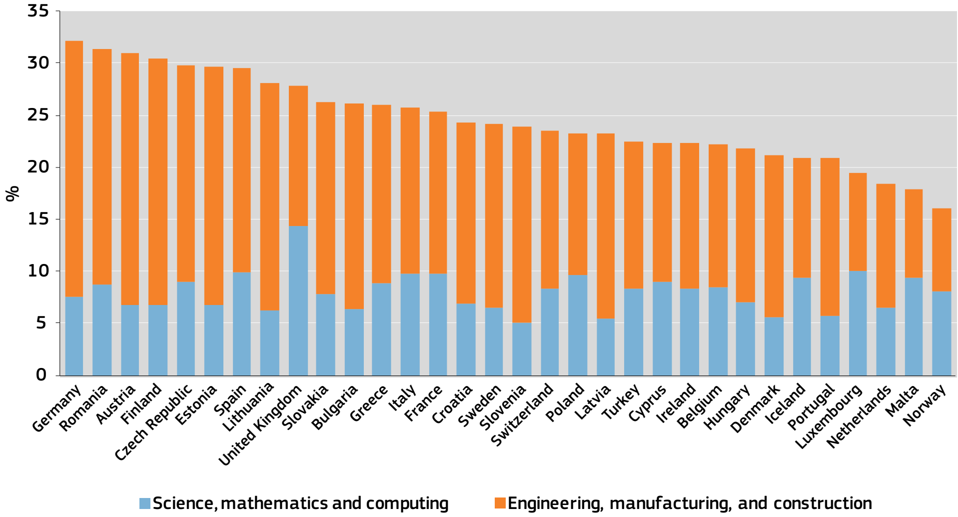
Science, Research and Innovation performance of the EU 2016

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat
Notes: [1]Percentage of total employed persons with a tertiary degree and/or employed in an S&T occupation where these qualifications are normally required (age: 25-64 years). [2]HT: High-technology manufacturing; MHT: Medium-high-technology manufacturing; KIS: Knowledge-intensive services.

European countries also exhibit a relatively large heterogeneity with respect to the education fields in which persons obtain their tertiary degree (Figure II-8-4). Education fields, which are likely to be particularly important for innovation, are science, mathematics and computing as well as engineering, manufacturing including processing and construction like architecture and building [142]. The UK has by far the largest proportion of tertiary educated persons in science, mathematics and computing (14.4%), followed by a large group of countries (Luxembourg, Spain, France, Italy, Poland, Malta, Island, Czech Republic and Cyprus) exhibiting a share between 10 and 9%. In contrast, countries like Germany, Austria, Finland, Estonia, Romania, Lithuania and the Czech Republic have a much stronger education profile in engineering, manufacturing and construction, all countries demonstrating a corresponding share of 20% and above. Taking both indicators together, Germany, Romania, Austria, and Finland are leading countries in the skill endowment of tertiary graduates as regards science, mathematics and computing as well as engineering, manufacturing and construction.

(142) The classification is based on the ISCED1997 classification. The residual group contains the following fields: education; humanities and arts; social sciences, business and law; health and social services; services; agriculture and general programmes (EF0-EF3, EF6-EF8).

Figure II-8-4 **Human resources in science and technology (HRST)[1] with a tertiary degree in science, mathematics and computing or in engineering, manufacturing and construction as % of total persons (aged 25-64) with a tertiary degree, 2013[2]**



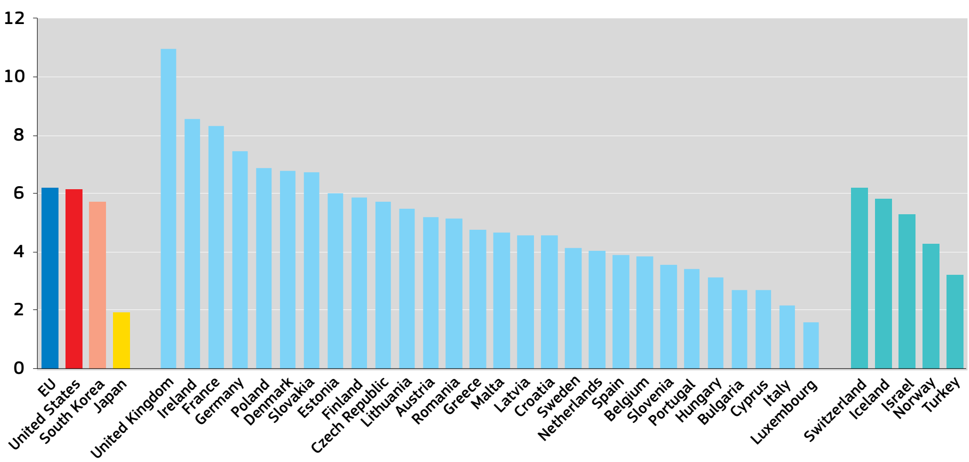
Science, Research and Innovation performance of the EU 2016

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat
Notes: [1]Total population with a tertiary degree and/or employed in an S&T occupation where these qualifications are normally required. [2]UK: 2010.

However, the fact that tertiary attainment levels strongly differ between countries has to be taken into account (see Figure II-8-5). Countries with high tertiary graduation and attainment levels hence perform relatively better at given shares of graduates in maths, science and technology.

As regards the new graduates in science, mathematics and computing or in engineering, manufacturing and construction per 1 000 population aged 25-34 the UK, Ireland and France are the leading EU countries. Romania, which performs well in the share of such graduates in the adult population, performs only at an average level as regards this indicator.

Figure II-8-5 **Graduates in science, mathematics and computing per thousand population aged 25-34, 2010[1]**

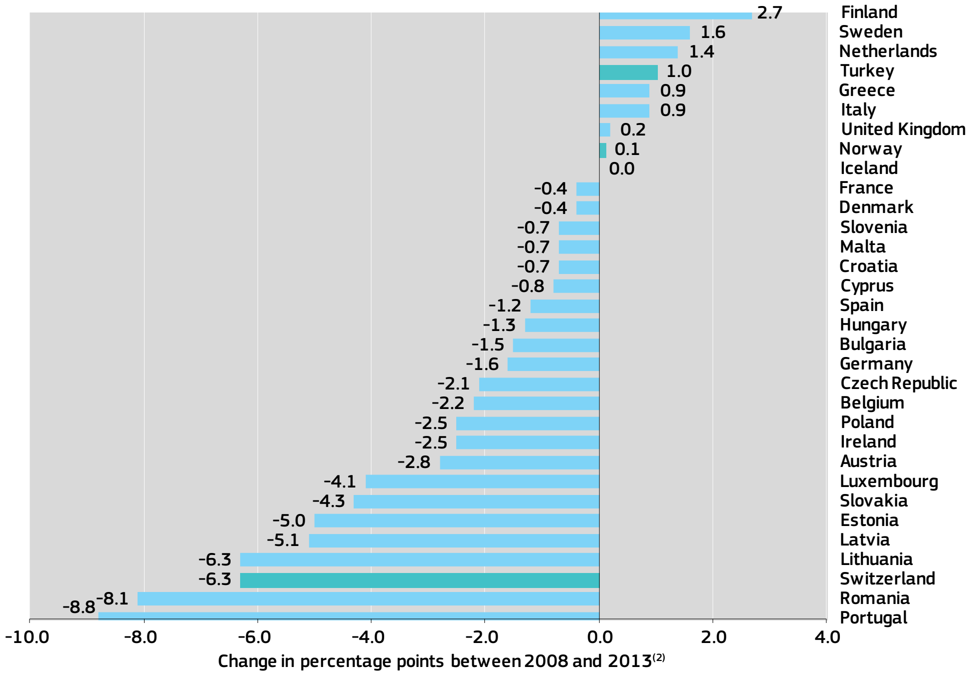


Science, Research and Innovation performance of the EU 2016

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat, OECD
Note: [1]FR: 2009; LU: 2011.

The growth in the overall number and proportion of persons with a tertiary degree over time has also led to shifts in the distribution of education fields over time (Figure II-8-6). Except for the Baltic countries and Portugal, we observe in all countries an increase in the absolute number of persons with a tertiary degree in these two areas between 2008 and 2013. However, for the majority of countries this nevertheless comes along with a decline in the relative proportion of persons with a degree in science and engineering, indicating that other education fields have benefitted more from the increased upskilling efforts than these two areas. The strongest fall is observed for Portugal and Romania with more than eight percentage points. However, in both countries this fall is mitigated by an overall increase in the number of tertiary graduates. Only Finland, Sweden, the Netherlands, Turkey, Italy and Greece have substantially expanded the proportion of persons with a degree in science and engineering.

Figure II-8-6 **Human resources in science and technology (HRST)[1] with a tertiary degree in science, mathematics and computing or in engineering, manufacturing and construction as % of total persons (aged 25-64) with a tertiary degree - change 2008-2013**



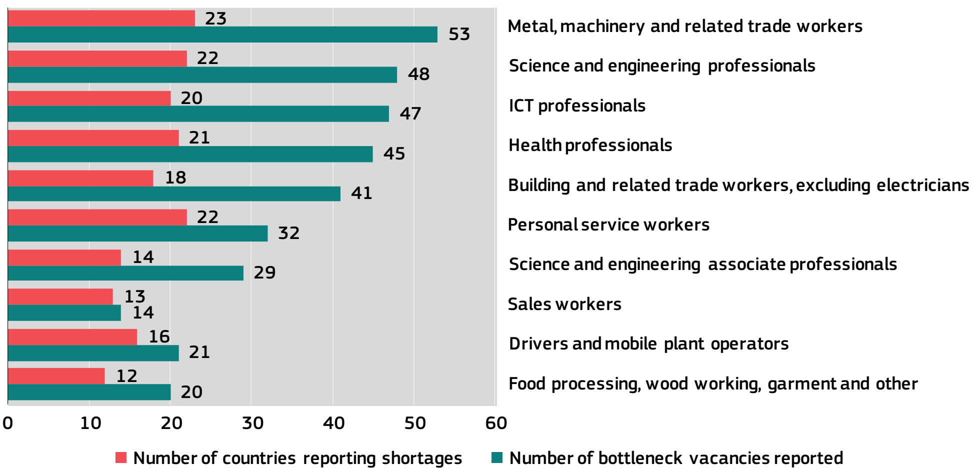
Science, Research and Innovation performance of the EU 2016

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat
Notes: [1]Total population with tertiary degree and/or employed in an S&T occupation where these qualifications are normally required. [2]UK: 2008-2010.

An important question is whether Europe has invested in the right skills or whether it is confronted with labour shortages and skill mismatch in specific areas. A recent study by Reymen et al. (2015) has investigated labour market shortages in the European Union. Their key finding is that the EU28 as a whole does not currently suffer from quantitative labour shortages. In most European countries (except for AT, BE, DE and the UK) the labour market tightness, i.e., the ratio of open vacancies to job seekers, has fallen compared to 2008, making it less likely for job seekers to find a new job. An increasing number of employees find it difficult to get a position that is adequate for their qualification level, implying that the matching process between open positions and job seekers has become less efficient. They conclude that there is currently a relative shortage of medium-level qualifications and a relative over-supply of employees with low levels of qualifications.

Although there is no evidence for European-wide skill shortages in general, specific occupations can be identified as bottleneck occupations for which employers have larger problems in recruiting persons. In a recent report by the European Commission (2014), the following Top 10 occupational groups facing bottlenecks at the EU level have been identified (Figure II-8-7). In particular, European countries suffer from a lack of supply in regard to metal, machinery and related trade workers as well as science and engineering professionals, ICT and health professionals. The report also reveals that skill mismatch is the main reason for the bottleneck occupations. Given that employers have difficulties in filling vacant jobs, far more than 90% indicate that the applicants lack relevant skills in the case of science and engineering and ICT professionals. With about 78%, this proportion is somewhat lower as regards metal, machinery and trade related workers. Only about 50% of employers indicate a lack of skills as the main reason for bottlenecks as regards health professionals. Here, working conditions and preferences of applicants play an almost equally important role and restrain job seekers from accepting job offers.

Figure II-8-7 **Top 10 occupational groups facing bottlenecks at EU level[(1)]**



Science, Research and Innovation performance of the EU 2016

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: European Commission (2014)
Note: [(1)]Data collection varies across countries and is based on surveys and / or expert interviews.

To summarise, Europe has experienced a strong upskilling trend in recent years, mainly coming from a growing proportion of persons having completed a tertiary education. This trend is observed across nearly all the countries and across all sectors. However, this upskilling trend is not unified across education fields. In most of the countries, we observe a rise in the absolute number of persons with a tertiary degree in science and engineering; however, there has been a decline in the relative importance. To what extent Europe might benefit from these changes in skills development in terms of more and better future innovations will be explored in the next two sections.

8.2.2 Skills and innovation at the country level

In order to shed light on the relationship between skills and innovation at the country level, three different sets of skills indicators are used here:

- Generic skills in numeracy, literacy and problem-solving
- Field-specific skills
- Skills employed by enterprises

Though these different skill measures are interrelated, they capture different aspects of skills and as such they have different advantages and limitations.

8.2.2.1 Generic skills and innovation

The first set of indicators measures generic numeracy, literacy and problem-solving skills within the population. Skills in numeracy, literacy and problem-solving are measured on a country level by separate indices derived from the OECD PIAAC 2012 survey. The survey assesses the proficiency of adults in the age group 16 — 65 in literacy, numeracy and problem solving in technology-rich environments (OECD, 2015, p. 1). It collects comprehensive information on reading- and numeracy-related activities of respondents, the use of information and communication technologies at work and in everyday life, and on a range of generic skills, such as collaborating with others and organising one's time, required of individuals in their work (OECD, 2015, p.1). Based on the information, indicators depicting the proficiency in literacy, numeracy and problem solving were compiled by the OECD. In addition, a general skills index was computed by taking the average over the three separate PIAAC indices. The main advantage of these four indicators is that they measure generic skills in the population which might be as important for developing innovations as field-specific knowledge. Furthermore, this indicator is comparable across different OECD countries, among others the US, Japan and South Korea, though is not available for all European countries [143]. Innovation is measured by the number of patent applications per 100 000 population [144].

Figure II-8-8 depicts three striking results:

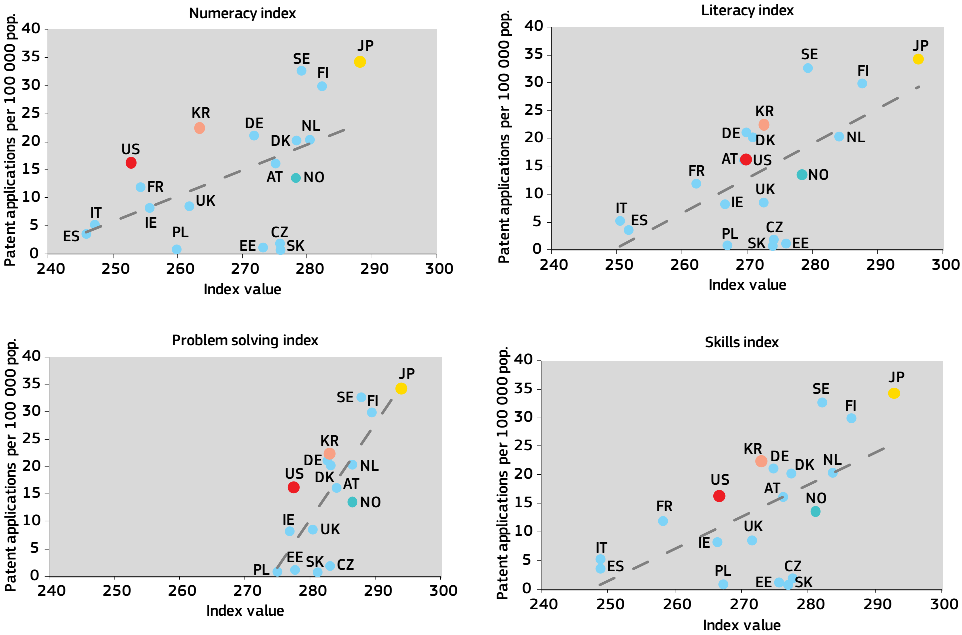
- In general, skills in numeracy and literacy are more dispersed across countries than problem-solving skills.
- All three generic skill measures are positively correlated to the number of patent applications.
- This relationship is particularly strong between problem-solving skills and innovation and weakest for numeracy skills and innovation.
- The performance of Japan, Sweden and Finland is outstanding. All three countries show the highest values in all three types of generic skills and innovation. These three countries are followed by Germany, Denmark, the Netherlands and South Korea which perform similarly in terms of generic skills and patent applications.

Unfortunately, information on generic skills in the population is only available for the 2012 cross-section and hence developments over time cannot be assessed yet.

[143] PIIAC surveyed approximately 166 000 adults in 24 countries.

[144] Data on population was downloaded from https://stats.oecd.org/Index.aspx?DataSetCode=POP_FIVE_HIST on May 18th 2015. Data on patent applications was downloaded from http://stats.oecd.org/Index.aspx?DataSetCode=MSTI_PUB on May 18th 2015.

Figure II-8-8 **Relationship between generic skills and patent applications[1], 2012**



Science, Research and Innovation performance of the EU 2016

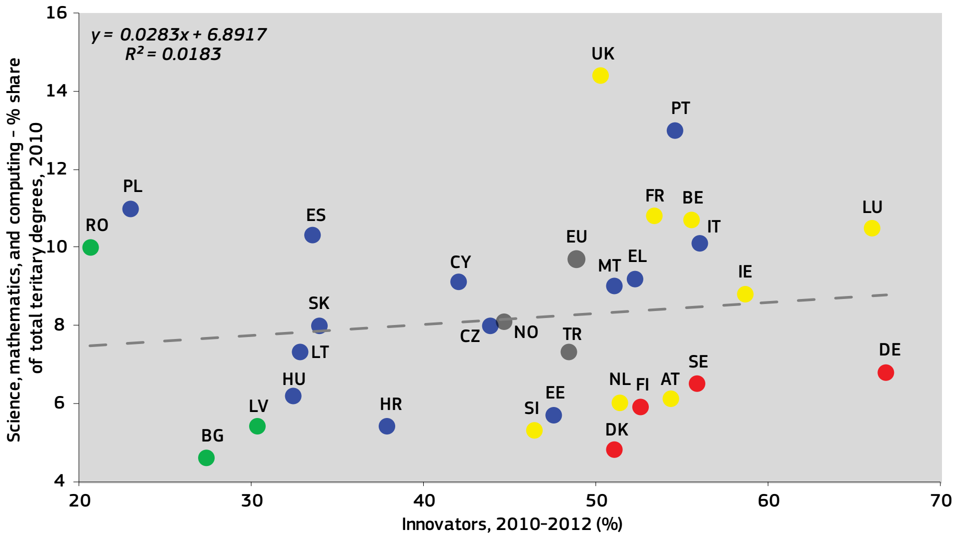
Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: OECD: PIAAC 2012 and patent database; own calculation
Note: [1]Patent applications filed under the PCT with priority year 2012 per 100 000 inhabitants.

8.2.2.2 Field-specific skills and innovation

In contrast to generic skills, Figure II-8-9 assesses the role of field-specific knowledge for innovation. The focus is on tertiary-educated persons in science, mathematics and computing –education fields likely to be particularly important for innovation. Since both figures only concentrate on European countries, we use the proportion of innovative firms instead of patent applications as a measure for innovation. A virtue of this approach is that the innovation indicator measures innovations along different dimensions, i.e., both technological (product and process) innovations as well as non-technological (organisational and marketing) innovations are included [145]. Both skill indicators relate to the year 2010 whereas the proportion of innovative firms refers to the period 2010-2012 in order to mitigate endogeneity problems.

[145] Patents have been criticized as being a poor yardstick for innovative outcome (Scherer 1965, Griliches 1990) as not all inventions are patented and not all patented inventions lead to marketable innovations. Additionally, patents not only represent the outcome of the innovation process but also serve as an instrument to protect the returns of innovation and hence are subject to strategic considerations of firms. Nevertheless, patents have been used in section 2.2.1 since no comparable Figure on the proportion of innovative firms is available for the US.

Figure II-8-9 **Persons with a tertiary degree in science, mathematics, and computing as % of total persons (aged 25-64) with a tertiary degree, 2010 versus share of innovative firms in total firms (%)[1], 2010-2012**



Science, Research and Innovation performance of the EU 2016

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat (HRST and CIS 2012)
Note: [1]Red: innovation leaders; Yellow: innovation followers; Blue: moderate innovators; Green: modest innovators; Grey: no classification in Innovation Union Scoreboard.

Figure II-8-9 confirms that there is a positive, though not very strong, relationship between countries' endowment with human capital in science, mathematics and computing and the introduction of innovations. This relationship, however, turns out to be rather weak at the country level. Surprisingly, all innovation leaders according to the Innovation Union Scoreboard 2015 (Finland, Sweden, Denmark and Germany) show high scores on innovation but disproportionate low shares in persons with a tertiary degree in science, mathematics and computing. No clear picture emerges for innovation follower countries. While the UK, France, Luxemburg and Belgium have a very strong profile in sciences that exceeds innovation leader countries by far, Austria, Slovenia and the Netherlands are comparable to the innovation leaders in terms of the proportion of tertiary-educated persons in science but turn out to be less innovative.

8.2.2.3 Skills usage and innovation

Important new insights into the relative importance of different types of skills for innovation can furthermore be gauged from the Community Innovation Surveys in 2010 (CIS 2010). In addition to various innovation indicators, the CIS 2010 included a special question on creativity and skills. All — and not only innovative — firms were asked whether they have employed in-house or contracted from external sources skills related to eight different areas or whether these skills were not relevant. These eight skill indicators can be broadly classified into five skill groups: First, technical and scientific skills which capture skills in engineering and applied sciences as well as in mathematics, statistics and database management; second, design skills which refer to activities like designing objects and services but which also include graphical arts, layout, advertising; third, multimedia skills which combine skills in multimedia and web design, fourth, skills in software development and, finally, market-related skills like market research. Figure II-8-10 provides an overview on the skills indicators in CIS.

Figure II-8-10 **Classification of skill usage in the Community Innovation Survey, 2010 (CIS 2010)**

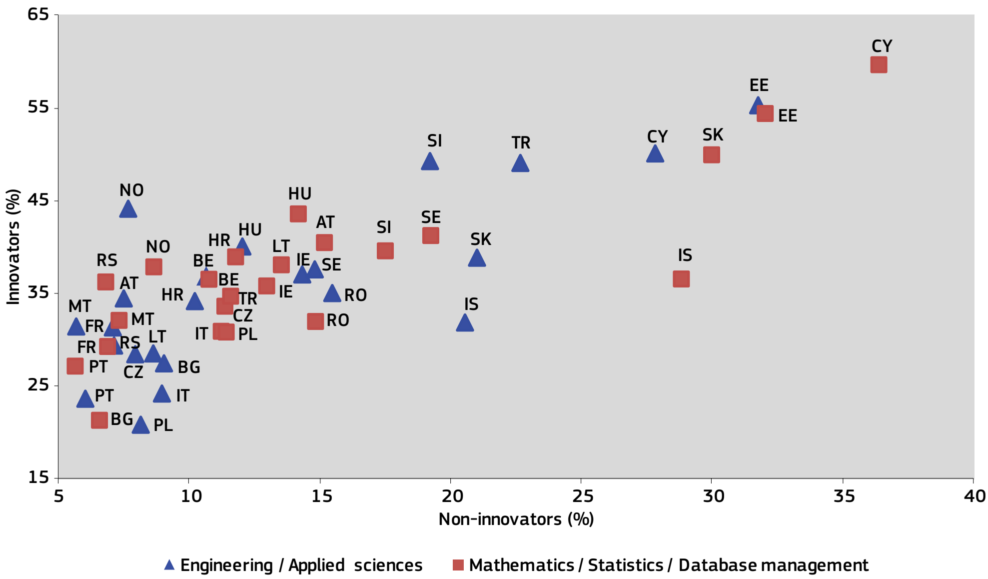
Skill group	Skill indicators
Technical and scientific skills	Engineering and applied sciences Mathematics, statistics and database management
Design skills	Design of objects and services Graphical arts, layout, advertising
Multimedia skills	Multimedia Web design
Software skills	Software development
Market skills	Market research

Science, Research and Innovation performance of the EU 2016
Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat (CIS 2010)

The merit of CIS skill indicators is that they allow for a much more fine-grained analysis of the relationship between skills and innovation than the education-related skills data in the previous section. In particular, more detailed information is available for different types of modern IT and computing skills like multimedia, web design, database management or software development which will be particularly important for exploiting the potential of big data and industry 4.0 applications. One limitation of the CIS data is that the question on skills was not mandatory and is only available for a subset of 20 European countries (plus Norway, Iceland, Serbia and Turkey) in particular, countries like Germany, the UK, Finland and the Netherlands have not collected this type of information.

Figure II-8-11 depicts the proportion of enterprises that have used technical and scientific skills separately for innovators and non-innovators in each country. Most strikingly, we find that in all observed European countries innovators employed workers having skills in engineering and applied sciences as well as in mathematics, statistics and database management more often than non-innovators. This confirms the positive finding from the last subsection on science and mathematics but also highlight a positive relationship between engineering and innovation. Furthermore, the Figure reveals no clear pattern with respect to the relative importance of both types of skills across European countries. Whereas innovative enterprises in France, Ireland, Romania, Slovenia, Bulgaria, Estonia (and Norway and Turkey) have a stronger focus on engineering and applied sciences, mathematics, statistics and database management are more often employed in the other countries.

Figure II-8-11 **% shares of innovators and of non-innovators making use of technical and scientific skills(1), 2008-2010**



Science, Research and Innovation performance of the EU 2016

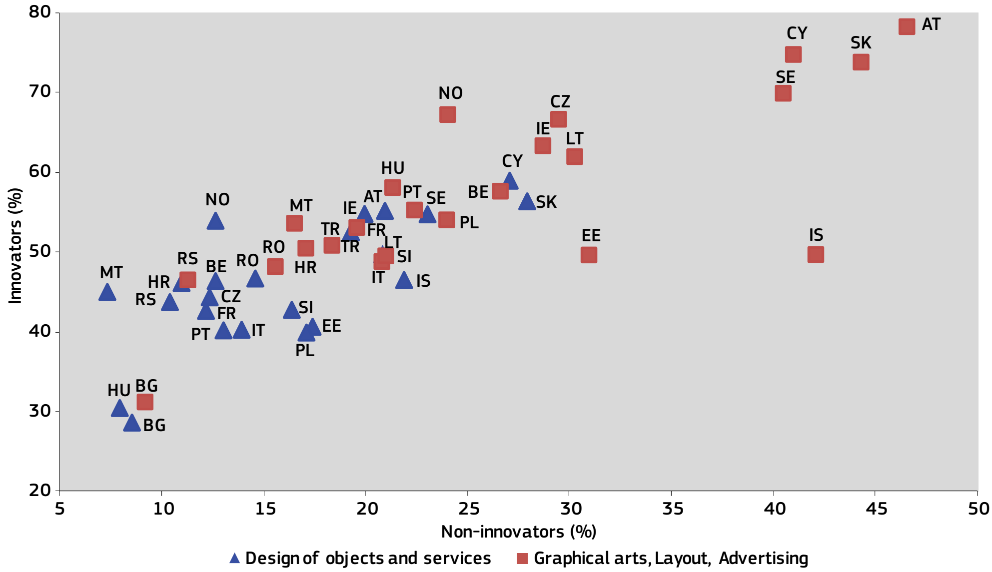
Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat (CIS 2010)
Notes: (1)Blue triangle: % shares of innovators and non-innovators that have used skills in engineering and applied sciences in the period 2008-2010. (2)Red square: % shares of innovators and non-innovators that have used skills in mathematics, statistics and database management in the period 2008-2010.

Relating the proportion of innovators that have employed engineers and applied scientists to the innovation performance rating of the country (4: innovation leader, 3: innovation follower, 2: moderate innovator, 1: modest innovator) we furthermore corroborate a positive correlation of about 0.220 (Figure II-8-16). That is, in countries with a higher innovation performance ranking firms have used technical and scientific skills more frequently (and probably also more efficiently). This correlation is also positive but smaller at about 0.181 between the usage of mathematics, statistics and database management and a country's innovation performance.

Similarly, Figure II-8-12 highlights a positive relationship between the usage of design skills and innovation. In all countries innovators have employed workers having skills in designing objects and in graphical arts and layout more frequently than non-innovators. Furthermore, Figure II-8-17 reveals that, in all countries (except Turkey), skills in graphical arts, layout and advertising, i.e., skills which are mainly important for the commercialisation of (new) products, are more often employed by innovators than skills needed for designing (new) products. But both types of design skills are more frequently used by innovators than technical and scientific skills. One might think that this is mainly driven by services; however, the same pattern emerges for manufacturing firms.

In addition, the figures reveal a strong correlation between the country's innovation performance index and its design-related skill usage. With correlation coefficients of about 0.484 (design of objects and services) and 0.446 (graphical arts, layout and advertising), the correlations between design and innovation performance index turn out to be more than twice as large as between the usage of technical and scientific skills and the innovation performance index.

Figure II-8-12 **% shares of innovators and of non-innovators making use of design skills[1], 2008-2010**



Science, Research and Innovation performance of the EU 2016

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

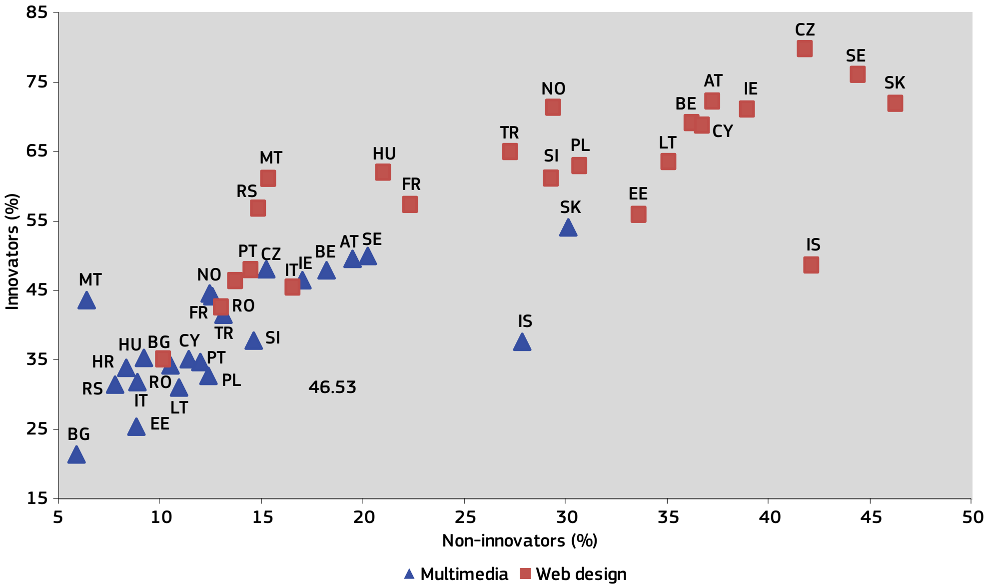
Data: Eurostat (CIS 2010)

Notes: [1]Blue triangle: % shares of innovators and non-innovators that have used skills related to the design of objects and services in the period 2008-2010. [2]Red square: % shares of innovators and non-innovators that have used graphical arts, layout and advertising skills in the period 2008-2010.

As already mentioned, CIS data allow for a fine-grained analysis of different modern IT skills like multimedia, web design and software development as well. Figure II-8-13 and Figure II-8-14 take a detailed look on the usage of multimedia, web design and software development by innovators and non-innovators. Like for the other skills, we find innovators to employ all three types of skills much more frequently than non-innovators.

Furthermore, Figure II-8-17 depicts that web design is the most often used skill type among innovators in 10 out of the 23 countries, e.g., in Sweden, France, Ireland and Czech Republic. In seven countries like in Italy, Belgium, Estonia, Slovenia and Cyprus, innovative enterprises put the strongest focus on software development. Compared to web design and software development, firms have employed workers with multimedia skills less frequently. However, at the country level we find the strongest positive correlation between multimedia skill usage and the innovation performance ranking (0.639). That is, countries with a high proportion of multimedia-using firms have a disproportionately high innovation performance ranking. The correlation is almost equally high between the usage of web design and innovation performance (0.631). The correlation between the proportion of enterprises developing software and the innovation performance ranking is somewhat lower (0.403) and thus similar to design.

Figure II-8-13 **% shares of innovators and of non-innovators making use of multimedia skills[1], 2008-2010**

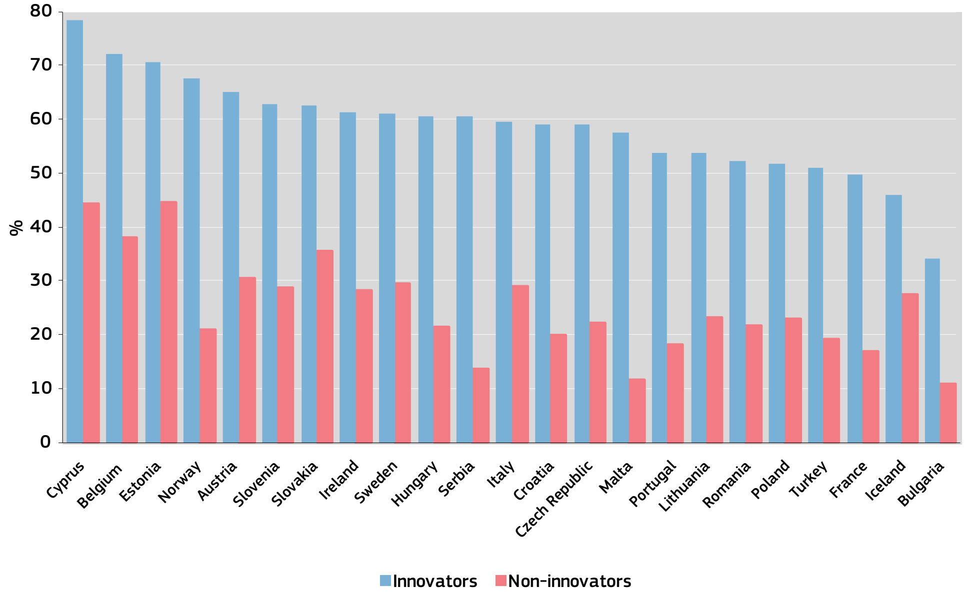


Science, Research and Innovation performance of the EU 2016

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat (CIS 2010)
Notes: [1]Blue triangle: % shares of innovators and non-innovators that have used multimedia skills in the period 2008-2010.
[2]Red square: % shares of innovators and non-innovators that have employed web design skills in the period 2008-2010.

Finally, Figure II-8-15 examines the importance of skills related to market research. These skills refer, e.g., to the ability of developing a strategic vision of marketing as a way to tackle business problems, the mastery of marketing knowledge and tools to business opportunities, the ability to plan, design and implement strategies or the ability to collect, organise, and interpret data at a regional, national, or global scale to determine potential sales of a product, service, or retail facilities. The results clearly demonstrate that innovative enterprises have a stronger focus on the use of market research related skills than non-innovative firms. In most of the countries, market-related skills are more often used by enterprises than technical and scientific skills. However, they are less frequently employed than skills related to multimedia, web design or software development. Only in two of the moderate innovator countries, Bulgaria and Romania, do market-related skills represent the dominant skill mode.

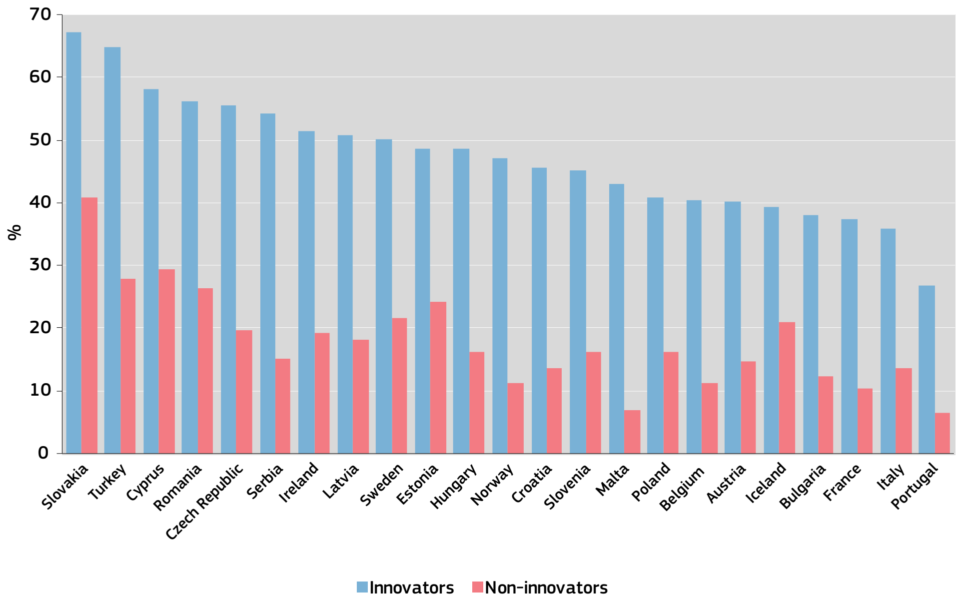
Figure II-8-14 **% shares of innovators and of non-innovators making use of software skills, 2008-2010**



Science, Research and Innovation performance of the EU 2016

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat (CIS 2010)

Figure II-8-15 **% shares of innovators and of non-innovators making use of market research skills, 2008-2010**

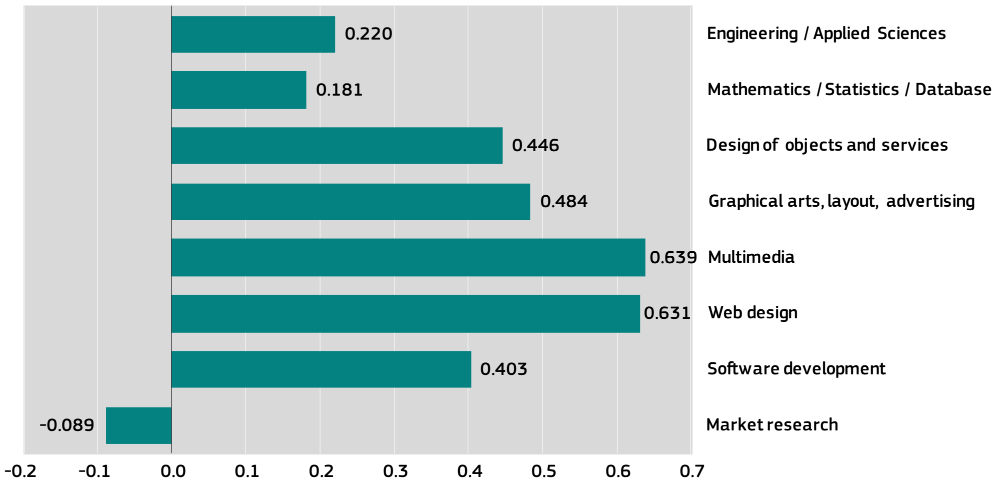


Science, Research and Innovation performance of the EU 2016

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat (CIS 2010)

In contrast to the findings for the other skill types, it turns out that the usage of market research skills is negatively correlated with the innovation performance ranking (-0.089). This result is not only driven by the modest innovators Bulgaria and Romania. The correlation remains negative when taking them out. However, this negative pairwise correlation does not necessarily imply that skills in market research negatively impact innovations since the calculation neglects the use of other skills. Another drawback of these simple cross-country correlations between the share of different skills used by firms and the innovation performance ranking is that such an analysis does not control for other firm- or industry-specific variables which might drive both indicators. The following section will hence continue with an econometric approach.

Figure II-8-16 **Correlation between countries' skill usage and innovation performance ranking[1]**



Science, Research and Innovation performance of the EU 2016

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat (CIS 2010), Innovation Union Scoreboard 2015
Note: [1]Correlation coefficient between the proportion of innovators that have used a specific skill type and the innovation performance ranking based on the Innovation Union Scoreboard 2015. Innovation performance ranking: 4: Innovation leader, 3: Innovation follower, 2: Moderate innovator, 1: Modest innovator.

Figure II-8-17 **Skill usage of innovators - % shares of innovators that have used a specific skill type[(1)], 2008-2010**

	Engineering / Applied Sciences	Mathematics / Statistics / Database management	Design of objects and services	Graphical arts, layout, advertising	Multimedia	Web design	Software development	Market research
Belgium	36.8	36.6	46.4	57.7	48.0	69.3	72.0	40.5
Bulgaria	27.5	21.3	28.7	31.3	21.5	35.3	34.3	38.1
Czech Republic	28.5	33.7	44.4	66.7	48.2	80.0	59.1	55.6
Estonia	55.4	54.5	40.7	49.7	25.5	56.1	70.7	48.7
Ireland	37.1	35.8	54.8	63.4	46.6	71.3	61.2	51.5
France	31.4	29.3	42.7	53.1	44.3	57.5	49.8	37.3
Croatia	34.2	39.0	46.2	50.5	34.0	46.5	59.2	45.5
Italy	24.2	30.9	40.3	48.9	31.9	45.6	59.6	35.9
Cyprus	50.2	59.7	59.0	74.8	35.2	68.9	78.3	58.2
Lithuania	28.6	38.1	49.9	62.0	31.1	63.7	53.8	50.9
Hungary	40.1	43.6	30.5	58.1	35.4	62.2	60.6	48.7
Malta	31.5	32.1	45.0	53.6	43.7	61.3	57.6	43.1
Austria	34.5	40.5	55.2	78.3	49.7	72.4	65.1	40.2
Poland	20.9	30.9	40.0	54.1	32.8	63.1	51.7	40.8
Portugal	23.7	27.2	40.2	55.3	34.8	48.1	53.8	26.9
Romania	35.1	32.0	46.7	48.2	34.3	42.7	52.3	56.2
Slovenia	49.3	39.6	42.8	49.6	37.9	61.3	62.8	45.2
Slovakia	38.9	50.0	56.4	73.8	54.2	72.1	62.7	67.2
Sweden	37.6	41.3	54.8	69.9	50.1	76.2	61.0	50.2
Iceland	31.9	36.6	46.5	49.7	37.7	48.8	46.0	39.4
Norway	44.2	37.9	54.0	67.3	44.7	71.5	67.5	47.2
Switzerland	29.4	36.3	43.8	46.6	31.5	57.0	60.4	54.2
Turkey	49.1	34.7	52.5	50.9	41.6	65.1	50.9	64.8

Science, Research and Innovation performance of the EU 2016
Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat (CIS 2010)
Note: [(1)]Red: most often used skill type; grey: second most used skill type; blue: third most used skill type.

8.2.3 Skills as drivers of innovation and innovation success

This section makes use of firm-level CIS data in order to provide novel empirical insights into the role of different types of skills for innovation. The CIS is a survey that is based on a common questionnaire administered by Eurostat and national statistical offices in all EU Member States. The methodology of CIS is based on the definition laid down in the OECD/Eurostat Oslo Manual (latest edition: OECD, 2005). CIS collects information at the firm level. The target population covers all legally independent enterprises with at least 10 employees in manufacturing, mining, energy and water supply and selected services. Original firm-level data have been accessed at Eurostat's safecenter. In total, the following analyses comprises information for about 78 741 firms from 16 countries (BG, CY, CZ, EE, FR, HR, HU, IT, LT, LV, NO, PT, RO, SE, SI, SK); slightly more than half of the observations stem from West European enterprises (40 942) and 37 799 observations stem from East Europe.

In order to better understand the role of specific skills for the innovation process, we adopt an econometric approach. This helps to identify those skills that are necessary to reap the benefits that innovation can bring alone, as well as to enable a smooth transition of the workforce to new and more productive activities. As a result, it also allows for deriving more targeted guidelines for policy regarding how to foster innovation by improving relevant skills.

In the first step, we estimate the propensity to innovate

$$inno_i^* = \beta_0 + \sum_{k=1}^{8} \beta_k * skilltype_{ik} + \sum_j \beta_j * x_{ij} + u_i$$

$inno^*$ is the latent innovation propensity that is not directly observed. Instead we only observe in the data whether the firm has innovated or not ($inno$). Hence, we estimate the likelihood of being an innovator by using a probit model. In order to capture the skill effect on different types of innovation, we use five different innovation indicators:

- *Product innovation* (PD) which refers to the introduction of new or significantly improved products or services in the period 2008-2010;
- *Market novelties* (PD-Market) which denote product innovations that are new to the market;
- *Firm novelties* (PD-Firm) which describe product innovations that are new to the firm but not to the market as a whole, i.e., firm novelties describe adoption or imitation activities;
- *Process innovation* (PC) which refers to the introduction of new or significantly improved production process, distribution method or supporting activity in the period 2008-2010;
- *Organisational innovation* (Orga) which denote a new organisational method, business practice (including knowledge management), workplace organisation or new external relations in the period 2008-2010 that have not been previously used by the enterprise.

$skilltype$ denotes the eight different skill types explored in subsection 2.2.3. As control variable x, we included the initial firm size in 2008 (log number of employees), two dummies for whether the firm belongs to a domestic or foreign group (reference: domestic unaffiliated firms), the innovation intensity (innovation expenditure per sales), a dummy for whether the enterprise has co-operations and a set of industry and country dummies.

Figure II-8-18 depicts the marginal effects of the eight different skill variables on the likelihood of innovating. Most strikingly, nearly all skill types significantly foster innovation, though there is a large heterogeneity in the marginal effects across skill types and innovation types.

Engineering skills are particularly important for developing new products. Employing workers with engineering and applied scientific skills increases the likelihood of introducing new products by 5.8 percentage points [146]. With a marginal effect of 3.5 and 3.8 pp. engineering skills are equally important for firm and market novelties. Engineering skills are less important for boosting process innovation (+ 1.8 pp) and show no significant association with introducing organisational innovation. In contrast, after controlling for firm-, country and industry-specific characteristics, skills in mathematics, statistics and database management only weakly stimulate innovation. The findings suggest no significant impact on the introduction

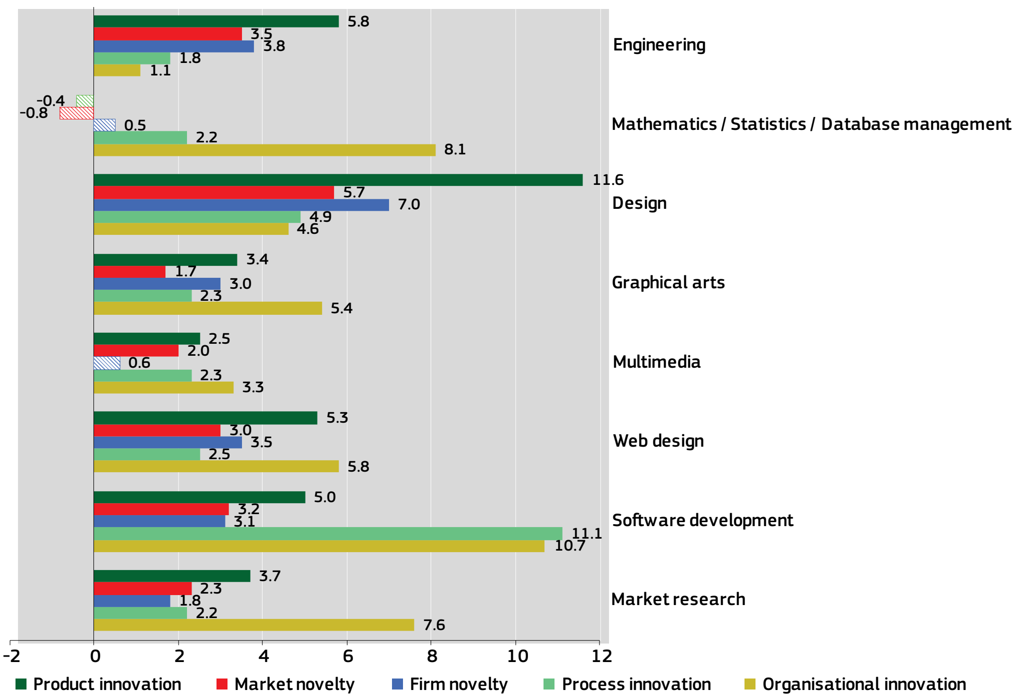
[146] We cannot rule out reverse causality, i.e., firms that want to innovate employ more engineers. In order to deal with this type of endogeneity, an instrumental variable approach would be appropriate. However, the data does not include appropriate instruments for the skill measures. Hence, results should be interpreted as correlations rather than as a causal effect.

of new products. However, the use of these skills is associated with a large rise in organisational innovation and likewise in process innovation.

Not surprisingly, design skills have a large impact on the introduction of new products. Employing workers with skills in designing objects and services increases the likelihood of introducing new products by 11.6 percentage points. The marginal effect is slightly larger for firm novelties than for market novelties. This marginal effect is even larger than for engineering and applied science. Somewhat surprising is its relatively large impact on process and organisational innovation, however, this might reflect that design activities lead to the introduction of new products which in turn involve major changes in the production technology or in the way of organising workplaces or businesses practices. In contrast to design skills, skills in graphical art, layout or advertising have a much smaller impact on the likelihood of introducing new products or processes.

While multimedia, web design and software development belong to the group of skills most often employed by enterprises, their marginal impact on product innovation is smaller than the one of engineering and design. Among the three types, web design and software development abilities foster product innovation to a similar extent. The stimulating effect of multimedia skills, however, turns out to be much smaller. Outstanding is the large impact software skills exert on the introduction of new production technologies and organisational methods. Employing workers with software skills increases the likelihood of getting a process and organisational innovation by 11.1 and 10.7 percentage points, respectively.

Figure II-8-18 **Marginal effect of skill usage on the likelihood of innovating[1]**



Science, Research and Innovation performance of the EU 2016

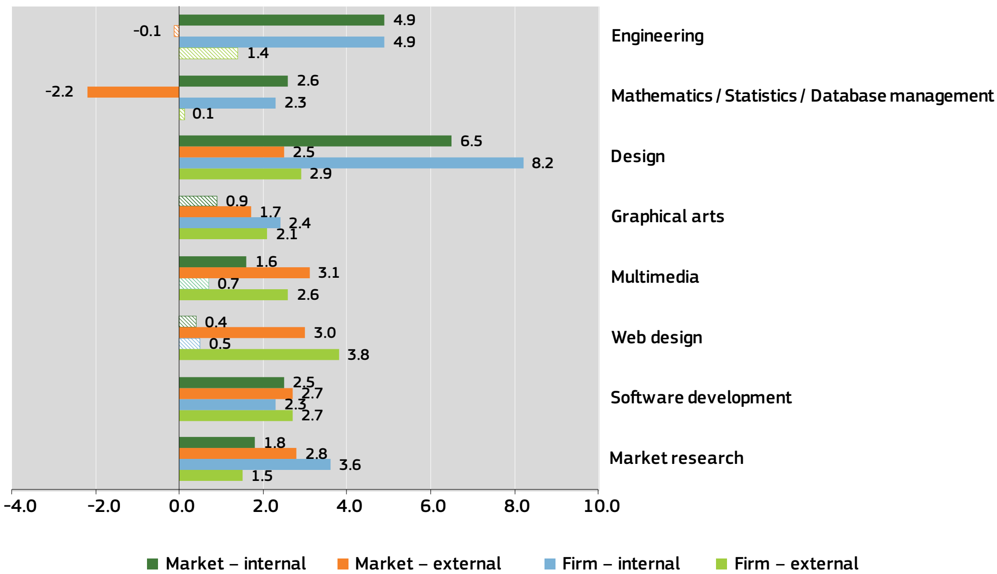
Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat (CIS 2010)
Note: [1]The graph shows the marginal effects at mean values of the eight different skill variables (and all other explanatory variables). The marginal denotes e.g. the change in the predicted probability of getting a product innovation (PD) when a firm uses engineering skills compared to when it does not use them (in percentage points). All effects are significant at least at the 5% significance level except for the effect of engineering on process innovation which is significant only at the 10% level and striped bars denote insignificant marginal effects. Results for control variables have been omitted for presentation.

Market research skills also increase the likelihood of introducing new products, processes and organisational methods. The size of the effect is similar to the effect of graphical arts, layout and advertising. For instance, employing workers with skills in market research raises the propensity to develop and launch new products by 3.7 percentage points. Surprisingly, market research skills are also associated with a large stimulating effect on organisational innovation. One potential explanation could be that market research activities allow firms to identify new business opportunities in more distant places. In order to exploit these new opportunities firms might set up new external relationships which count as organisational innovations.

Market novelties, as a measure for more radical innovation, are particularly fostered by employing design skills, followed by engineering skills and abilities in software development and web design. For process innovation, we find a very similar effect in magnitude of about 2-2.5 percentage points for all skill types with the exception of the outstanding effect of software skills. Skills in software development, mathematics, statistics and database management as well as in market research are main drivers of organisational innovation.

Is it important for innovation whether firms employ workers with certain skills in-house or are they equally innovative when they lack these skills internally and buy in such skills from external sources? Figure II-8-19 shows the change in the likelihood of getting a market or firm novelty when we split the skill usage in internal and external use. Four key findings can be summarised: First, in terms of fostering innovation it is important that firms employ workers with engineering skills and abilities in mathematics, statistics and database management in-house. Firms that have employed these skills from external sources do not show a higher likelihood of introducing new products. This is consistent with the finding that firms need absorptive capacities in order to benefit from external knowledge and transfer it to new applications (Cohen and Levinthal 1989). Second, both internal and external skills in designing objects increase the likelihood of innovating; however, firms that have employed these skills in-house are much more innovative. Surprisingly, we find the opposite result for skills in multimedia and web design. Firms that are short of these modern IT skills and that have decided to buy in these skills from external specialists are able to benefit from this strategy by increasing their propensity to innovate by 2.5-4 percentage points. Fourth, concerning the use of software skills there are hardly any differences between employing these skills internally or externally.

Figure II-8-19 **Marginal effect of internal and external skill usage on the likelihood of market and firm novelties**[1]



Science, Research and Innovation performance of the EU 2016

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat (CIS 2010)
Note: [1]The graph contains the marginal effects at mean values of the eight different skill variables when they are used in-house and sourced externally. Striped bars denote insignificant marginal effects. Results for control variables have been omitted for presentation.

To what extent do skills also affect innovation performance and hence the benefits firms can reap from innovation activities? To answer this question, we use a Tobit model which investigates the impact of skill usage on the share of sales with new products, market novelties or firm novelties. We use the same control variables as for the probit models. Figure II-8-20 reports the impact of skill on innovation performance. The empirical evidence shows strong positive effects of all skill types on innovation performance. In contrast to the findings at the country level, the largest effect on the share of sales due to new products by far stems from design activities, followed by software development, engineering, market research and web design [147]. The latter four skill types exert a similar effect on the share of sale with new products ranging between 0.75 and 0.55. The effect is still positive but smaller for skills related to multimedia or arts and layout. Only skills in mathematics, statistics and database management have not (yet) boosted innovation performance. This is consistent with the finding that so far these skills have been mainly used for process and organisational innovation.

[147] Note that the innovation performance indicator that we use at the country level was different. It was the ranking of countries in terms of their innovation performance which is based on a wide range of different innovation indicators.

Figure II-8-20 Impact of skills on innovation performance[1]

Impact on sales share by skills type:	PD	PD-Market	PD-Firm
Engineering	0.064*** (0.006)	0.050*** (0.006)	0.060*** (0.007)
Mathematics / Statistics / Database management	-0.007 (0.006)	-0.007 (0.006)	-0.005 (0.006)
Design	0.150*** (0.006)	0.121*** (0.006)	0.127*** (0.006)
Graphical arts	0.035*** (0.006)	0.022*** (0.006)	0.048*** (0.007)
Multimedia	0.029*** (0.006)	0.040*** (0.006)	0.011* (0.007)
Web design	0.055*** (0.006)	0.048*** (0.006)	0.037*** (0.007)
Software development	0.074*** (0.006)	0.068*** (0.006)	0.058*** (0.006)
Market research	0.063*** (0.006)	0.056*** (0.006)	0.053*** (0.006)

Science, Research and Innovation performance of the EU 2016
Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat (CIS 2010)
Note: [1]Tobit regression. ***, **, * indicate significance at the 1%, 5% and 10% level respectively. Control variable not reported.

To summarise, this section has impressively shown that skills in general have a positive impact on innovation activities. Skills increase both the likelihood of innovating but also innovation performance. However, we find a non-negligible heterogeneity across different types of skills as well as on different types of innovation activities.

8.3 Effects of innovation on employment growth

The last section has demonstrated that Europe has experienced a strong upskilling trend in recent years and that skills in general have a positive impact on innovation activities. Innovations, however, are not an end in themselves but are aimed at improving firms' competitiveness and performance. Since employment is key to business and overall economic development, this section investigates to what extent innovations are conducive to overall employment growth.

8.3.1 Employment trends in sectors differing in technology intensity

In this subsection we aim at investigating whether sectors that differ in their technology and knowledge intensity demonstrate different employment trends. Figure II-8-21 depicts the employment growth rate for EU28, the US and Japan for knowledge-intensive activities in business industries (KIABI[148]). Knowledge-intensive activities are identified based on a level of tertiary educated persons in business industries. An activity is classified as knowledge intensive if employed tertiary educated persons (according to ISCED97, levels 5+6) represent more than 33% of the total employment in that activity [149].

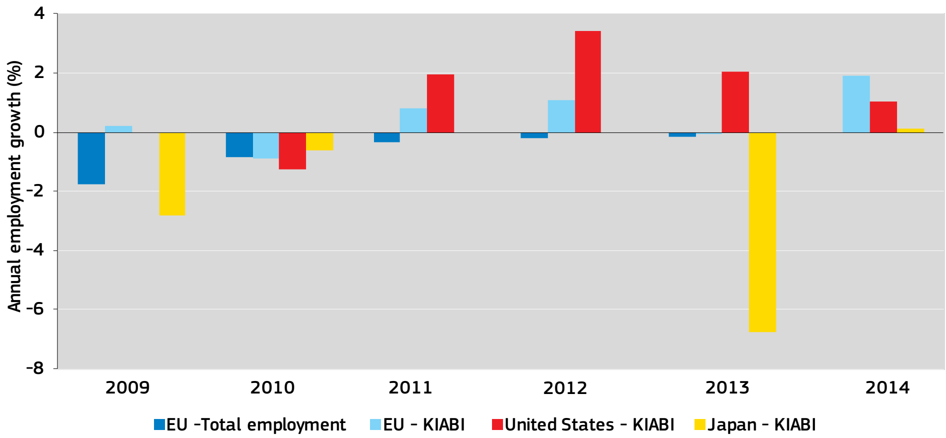
[148] For the economic activities included in knowledge intensive activities in business industries see: Eurostat: http://ec.europa.eu/eurostat/cache/metadata/Annexes/htec_esms_an8.pdf

[149] The definition is built based on the average number of employed persons aged 25-64 at aggregated EU27 level in 2008 and 2009 according to NACE Rev. 2 at 2-digit, using EU Labour Force Survey data. This includes the following 2-digit NACE codes: 09, 19, 21, 26, 51, 58-66, 69-75, 78-79, 90.

Even during the recent economic crisis, employment growth has been positive in knowledge-intensive activities in Europe in most of the years, except for 2010 and 2013. Absolute employment has grown in these sectors from 28.9 million in 2008 to 29.3 million in 2013. This corresponds to an overall growth of 1.7% over the six-year period (see Figure II-8-22). At the same time, overall employment has suffered from the severe economic crisis and has declined in EU28 by 2.7% from 222.9 million in 2008 to 216.9 million in 2013. The fact that employment growth is higher in knowledge-intensive activities indirectly indicates that innovation stimulates employment in Europe.

However, Figure II-8-22 also reveals a large heterogeneity in employment growth in knowledge-intensive activities across Europe since 2008. In 18 out of 28 European countries absolute employment figures have grown over the period 2008-2013 whereas 10 countries exhibit negative growth rates. Growth ranges from +20% in Luxemburg to -12.2% in Spain. For the three largest economies in Europe, we observe a positive employment growth of about 2.2% in Germany, 3.1% in France and 6.7% in the UK.

Figure II-8-21 **Growth (%) in total employment in the EU and in employment in knowledge-intensive activities in business industries (KIABI), 2008-2014[(1)]**

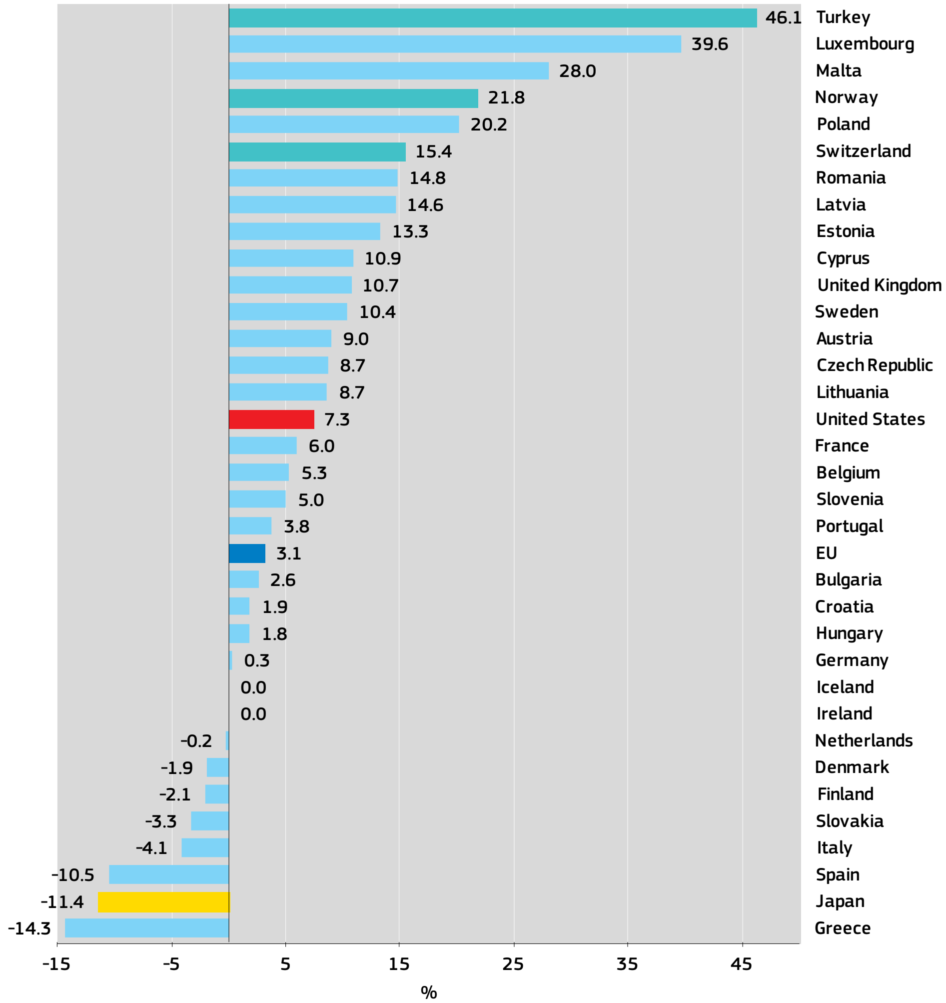


Science, Research and Innovation performance of the EU 2016
Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat
Note: [(1)]US: KIABI not available for 2008-2009; JP: KIABI not available for 2010-2011 and 2011-2012; EU: Total employment not available for 2013-2014.

How does Europe perform in knowledge-intensive activities compared to major competitors? Compared to the US and Japan, Europe demonstrates a lower employment proportion in knowledge-intensive activities (2013: 13.8%) than the US (2013: 17.2%) and Japan (2013: 16.1%). Furthermore, compared to the US employment growth has been lower in knowledge-intensive activities (US: +6.2% for the period 2009-2013). However, Europe's development in knowledge-intensive activities is much better than in Japan which has suffered great employment losses in these areas (-11.5%) [(150)].

[(150)] Data sources: Labour Force Survey (LFS) for JP and Current Population Survey (CPS) for the US. Data refer to the number of persons employed in economic sectors according to JSIC Rev.12 and aged 15-64 years old in JP and to age group 16 years old using US NAICS 2007 classification of economic activities. A 1-to-1 correspondence between classification systems is not always possible and might affect results. However, this should not affect growth rates over time.

Figure II-8-22 **Growth (%) in employment in knowledge-intensive activities in business industries (KIABI) between 2008 and 2014[(1)]**



Science, Research and Innovation performance of the EU 2016

Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat
Note: [(1)]TR, US: 2009-2014.

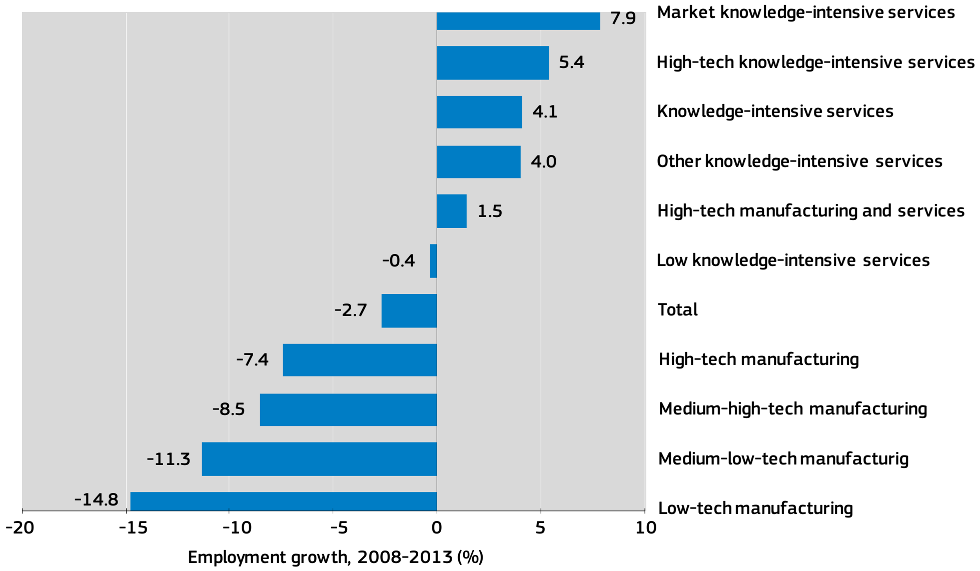
The KIA definition is solely based on the share of tertiary educated persons within sectors. In order to take the technology intensity of sectors more directly into account, the traditional sectoral approach can be used. This approach classifies manufacturing industries according to their technological intensity (R&D expenditure/value added) into high-technology (M_HTC), medium high-technology (M_M-HTC), medium low-technology (M_M-LTC) and low-technology (M_LTC) industries. Services are aggregated into knowledge-intensive services (S_KIS) and less knowledge-intensive services (S_LKIS) based on the share of tertiary educated persons at NACE 2-digit level. Knowledge-intensive services are further split into high-technology knowledge-intensive services (S_KIS_HTC), market knowledge-intensive services (S_KIS_MKT) and other knowledge-intensive services (S_KIS_OTH) [(151)].

Figure II-8-23 depicts employment trends over the period 2008-2013. For the aggregate

[(151)] For more details, see http://ec.europa.eu/eurostat/cache/metadata/Annexes/htec_esms_an3.pdf.

of high-technology sectors in manufacturing and services in Europe, we observe a similar total growth in employment over the period 2008-2013 (+ 1.5%) as for the KIA definition. Figure II-8-23, however, additionally reveals that only high-technology service industries benefitted in terms of employment growth (+ 5.4%). High-technology manufacturing industries on the contrary follow a diverging trend and suffered great losses in employment during the period (-7.4). This result, however, does not necessarily imply that innovation harms employment in high-technology manufacturing. Positive employment effects of innovation might also be outweighed by other factors driving employment, like differences in demand or general productivity trends across sectors. The fact that this diverging pattern generally emerges for manufacturing and service industries speaks in favour of this interpretation. High tech manufacturing employment might also be affected by a general shift from manufacturing to services and by outsourcing functions in manufacturing to the service sector so that innovation induces more employment in services than in manufacturing.

Figure II-8-23 **Growth (%) in employment in the EU by technology intensity sector between 2008 and 2013**

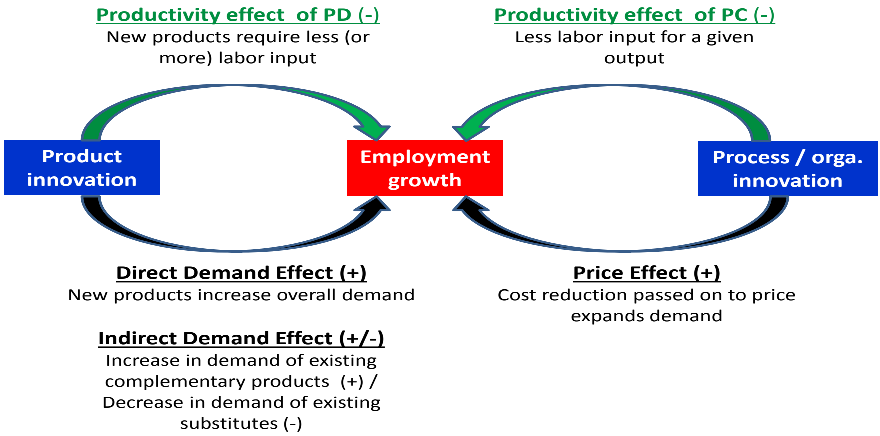


Science, Research and Innovation performance of the EU 2016
Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat

8.3.2 Potential transmission channels of product, process and organisational innovation

In order to identify the effects of innovation on employment, this section takes a more direct and structural approach. The question how innovation affects overall employment growth is non-trivial since various channels exist through which different kinds of innovation may destroy existing jobs (displacement effects) or may create new jobs (compensation effects) (see e.g., Katsoulacos 1986). In addition, different types of innovation such as product, process or organisational innovation influence employment via different channels. Figure II-8-24 sketches the main channels.

Figure II-8-24 Effects of product, process and organisational innovation on employment



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Source: Own representation.

Product innovation boosts employment growth mainly via increasing demand. Demand for the new product can either be the result of an overall market expansion, or it may come at the expense of displacing products of competing firms [152]. But on the other side, indirect demand effects on the innovative firm's existing products have to be taken into account as well as the possibility that the new products might (partially or totally) replace the existing ones (cannibalisation effect). In the case of complementary demand relationships, however, the new product will cause demand for existing products to rise as well, and an additional employment effect occurs. Finally, the same amount of output of the new product may be produced at higher or lower productivity levels compared to the existing product. That is, the new product may imply a change in production methods and input mix, which could either reduce or increase labour input. This effect is called productivity effect of product innovation (Harrison et al., 2008). At the industry level, additional employment effects are likely to take place in competing firms or in upstream and downstream firms.

Employment effects of process innovation are closely related to productivity changes. New production processes most often lead to labour productivity improvements since they allow firms to produce the same amount of output with less labour input. The size of this effect depends on the specific production technology and direction of the technological change. While technology advances of this type foster job destruction, they reduce marginal production costs and open up possibilities for price reductions. In a dynamic perspective, lower prices enable the innovator to gain from increasing product demand while alleviating the employment losses or even reversing them. The magnitude of this compensating indirect price effect is determined by the amount of price reduction, the price elasticity of demand and the competitive environment. An inelastic product demand, for instance, does not cause a price reduction to be sufficiently demand-inducing. Thus, the direct effect's negative employment impact cannot be outweighed. Only the demand of price elastic products can sufficiently increase as a response to price reductions. Price elastic goods are primarily traded on competitive markets. The transmission channels of organisational innovation are similar to those for process innovation.

(152) Therefore, the size of this effect depends on the demand elasticity, the existence of substitutes and the reactions of competitors (see Garcia et al., 2004).

8.3.3 Evidence on employment effects of innovation

One of the very early firm-level studies finds product innovations to boost employment in Germany (Entorf and Pohlmeier 1990). This positive relationship has been confirmed afterwards by many studies using different indicators, covering different time periods and countries (see e.g., Brouwer et al. 1993, König et al. 1995, Van Reenen 1997, Smolny 1998, Garcia et al. 2004, Hall et al. 2008, Peters 2008, Lachenmaier and Rottmann 2011, Leitner et al. 2011, Dachs and Peters, 2014, Damijan et al. 2014, Harrison et al., 2014). In a nutshell, the econometric evidence impressively highlights that product innovating firms create more jobs than non-product innovating firms. This means that the employment-inducing effects outweigh the labour displacement effects for product innovations.

However, no such conclusion can be drawn for process innovations as the empirical evidence for the effect of process innovations is ambiguous. Entorf and Pohlmeier (1990), Van Reenen (1997), Jaumandreu (2003) and Hall et al. (2008) find no significant effect of process innovations on employment. In contrast, the results of Peters (2008), Dachs and Peters (2014), Harrison et al. (2014) and Damijan et al. (2014) disclose a negative relationship between process innovations and employment [153]. Moreover, König et al. (1995), Leitner et al. (2011), Greenan and Guellec (2000) and Lachenmaier and Rottmann (2011) report a significant positive employment impact of process innovations. In addition, the latter two analyses find process innovations to create more jobs than product innovations.

The majority of empirical studies have focused on technological innovations. Non-technological innovations such as organisational innovations have rather been neglected, which is partially due to measurement problems (Lam 2005, Armbruster et al. 2008). In the last decade, however, organisational innovations have received significant attention in the literature on ICT investments and productivity. It was shown that ICT investments and organisational innovations are complementary and increase productivity (see e.g., Brynjolfsson and Hitt 2000, 2003, Bresnahan et al. 2002, Bertschek and Kaiser, 2004, Gera and Gu 2004), not only in the ICT sector (Ichinowski et al. 1997, Black and Lynch 1996, 2004, Polder et al. 2010). Empirical evidence has also shown that organisational and technological innovations are complementary (Schmidt and Rammer 2007, Polder et al., 2010) though the direction of that relationship is not precisely identifiable. Technological innovations either pave the way for organisational changes (Henderson and Clark 1990; Deneels 2002) or organisational innovations act as a driver for the implementation of technological innovations (Lokshin et al. 2009). Only a few empirical studies have actually examined potential employment effects of organisational innovations (Evangelista and Vezzani 2011, Vivarelli 2012). The results are inconclusive and seem to depend on the type of organisational change and the sector (Peters et al. 2013). Organisational changes like shifts towards more flexible organisations or transfers of responsibilities significantly decrease net employment growth rates (Greenan 2003, Bauer and Bender 2004). In contrast to these negative employment impacts, team work induces employment to increase (Bauer and Bender 2004).

In a recent study, Peters et al. (2014) examined the impact of product, process and organisational innovation on employment growth at the firm level for 26 European countries over the period 1998-2010. In order to better understand the role that business cycles play in generating employment growth from innovation, they separately estimated the relationship between innovation and employment growth for four phases of the business cycle. They decomposed average employment

(153) Damijan et al. (2014) find a negative impact of process innovation in manufacturing but no effect in services.

growth into the contribution of five different sources which are depicted in Figure II-8-25:

- The contribution of *general trends in productivity* in the production of *old products* not attributable to a firm's own process, product or organisational innovation, which captures employment effects of training, improvements in the human capital endowment, corporate restructuring, acquisitions of firms, productivity effects from spillovers, etc.;

- The contribution of *process innovation* such as the introduction of new production technologies, new technologies in logistics, etc., applied in the production of old products;

- The contribution of *organisational innovation* such as new ways of workplace organisation, quality standards for suppliers;

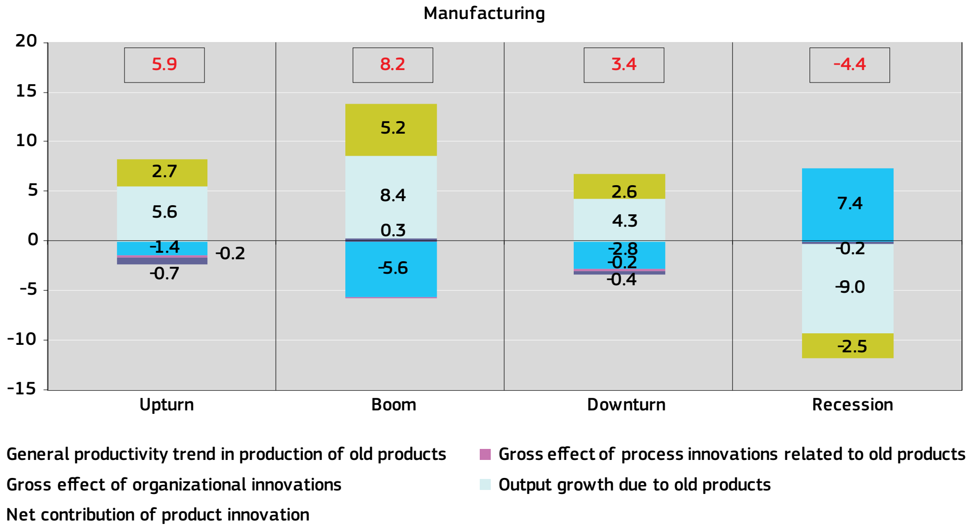
- The contribution from the *real growth of output (demand) in old products* for firms that do *not* introduce any new products;

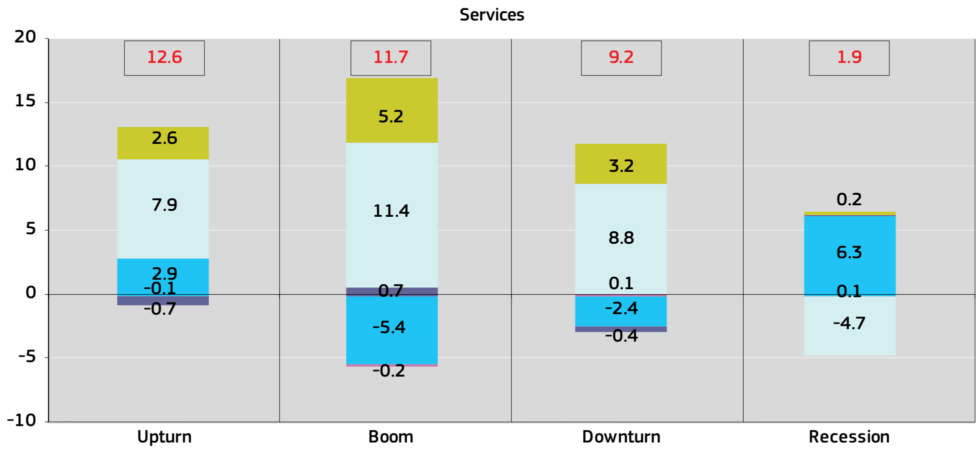
- The net contribution of *product innovation*. This effect includes increases in the demand for new products, but also increases or decreases in the demand for the old product depending on whether old and new products within the same firm substitute or complement each other. [154]

Their findings corroborate that product innovation fosters employment growth in European countries, i.e., product innovation creates much more employment due to the demand effect than it destroys due to the productivity effect and substitution effects between old and new products. This positive impact has been found in all phases of the business cycle except for the recession period in manufacturing. This positive employment effect of product innovation is strongest in boom periods which confirms the assumption that market acceptance for new products and the potential for demand expansion and extra-normal profits is higher during upswings and booms of the business cycle, leading to a stronger demand effect and larger employment creation from product innovation during upturn and booms than during downturn or recessions.

[154] The employment effect that stems from an increase in demand for new products depends on three factors: the share of firms engaged in innovation, the innovation success measured as sales growth due to new products, and the way innovation success is translated into employment growth which means whether there is a potential productivity effect associated with new products.

Figure II-8-25 **Contribution of innovation to employment growth over four phases of the business cycle in Europe[(1)], 1998-2010[(2)]**





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Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat, Peters et al (2014)
Notes: [(1)]Europe includes IS and NO and all EU Member States with the exceptions of IE, AT, PL and UK. [(2)]The number on top of each bar is the overall employment growth rate. The calculations are based on CIS 3, CIS 4, CIS 2006, CIS 2008 and CIS 2010.

In upturns, booms and downturns, however, the largest contribution to employment growth does not stem from product innovation but from the demand for old products. This completely changes in the recession where old products are the largest burden for employment growth. Indeed in manufacturing the contribution of product innovation has also become negative because output from new products does not grow fast enough to compensate demand losses in old products. However, the loss in demand and, as a result, in employment (-2.5%) is much smaller than for non-product innovators (-9%). In this sense product innovation has an employment stabilising effect and keeps employment losses limited in a recession. In services, the product innovation even fosters employment in the recession period. These detailed findings mostly explain the overall employment trend in manufacturing and services in Europe shown in the previous section.

Results further show that process and organisational innovation lead to job losses. However, compared to other factors, displacement effects of process and organisational innovation are small and of minor importance for employment growth. This confirms findings of Peters et al. (2013) who only find weak evidence of organisational innovation to impact employment growth in European service firms. [155]

8.4 Innovations as source for skill upgrading and job polarisation in Europe

8.4.1 Evidence on skill upgrading and job polarisation in Europe

Maybe even more important than the total employment effect of innovation is the impact of technological change on the demand for heterogeneous labour and skills. It is often argued that new and more complex technologies and, in particular, the use of new information and communication technologies have raised the demand for highly skilled labour but has deteriorated the position of low skilled workers as these workers are increasingly substituted by higher qualified workers or more capital-intensive production technologies. This is known as skill-biased technological change (Piva et al. 2005). In addition, skill-biased organisational change might take place as an increasing number of firms transform from rigid organisations towards more flexible structures with less hierarchy. These flexible organisational forms lead to employees having to perform a wider range of tasks and being awarded more responsibility which requires high-skilled workers in order to perform the more demanding tasks efficiently (Bresnahan et al. 2001, Caroli and Van Reenen 2001).

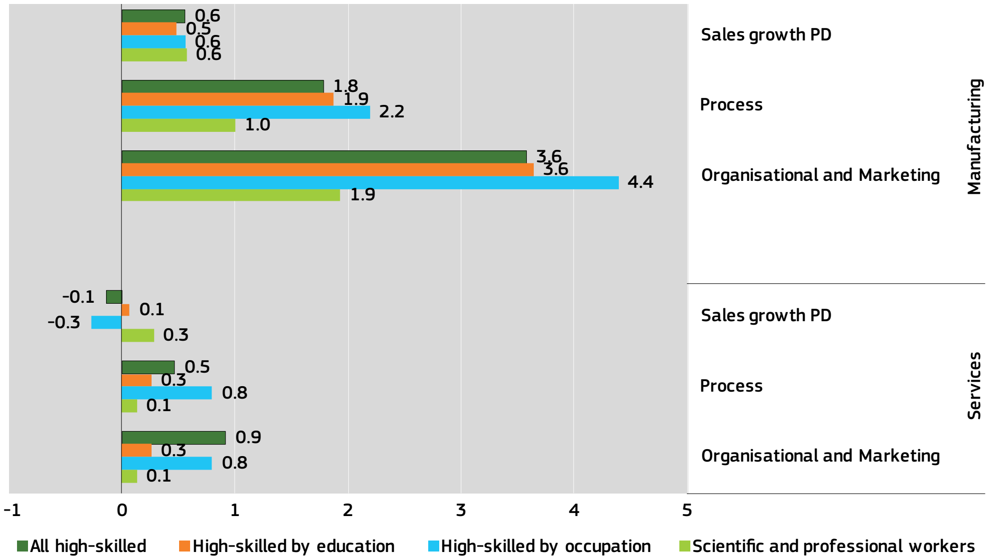
Indeed it has been observed in Europe and in many other industrialised countries that the share of highly educated persons has grown over time. Despite a large increase in the supply of highly educated workers, real wages of highly educated workers have increased relatively more than those of low-educated workers. This implies that the increase in the demand for high skills was even larger than the increase in their supply which has led to increasing returns to skills over time (Acemoglu and Autor 2011).

As an alternative to the skill-bias technological and organisational change explanation, the rise in demand for high-skilled workers has been attributed to the increasing globalisation. The latter has led to a growing specialisation in human capital intensive goods in developed countries. With increasing volumes of world trade, the demand for low-skilled workers has therefore declined in developed countries like Europe (Piva and Vivarelli 2002).

In order to test the skill-biased technological change hypothesis two routes have been taken. On the one hand, dynamic factor demand systems have been estimated. In these models, the optimal demand for different skill groups (either in terms of the change in labour demand or in terms of employment shares) depends on investments in new technologies. A recent example for 28 European countries is the study by Damijan et al. (2014). As the dependent variable they employ different measures for the share of high-skilled labour at the industry level: either HRST, HRST by education, HRST by occupation or the share of scientific and professional workers. As the main explanatory variables they use the lagged sales growth due to new products, the share of process innovators and the share of organisational and marketing innovators (at the industry level). They lagged these variables by one period (2006-2008) in order to mitigate potential endogeneity problems. They additionally control for the initial employment in 2008 and Chinese import share. The results of the study by Damijan et al. (2014) are depicted in Figure II-8-26.

[155] The positive findings of Damijan et al (2014) are not directly comparable as they group organizational and marketing innovations together.

Figure II-8-26 **Impact of innovation on upskilling[(1)] in the EU, 2008-2010**



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Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat (LFS), Damijan et al (2014)
Note: [(1)]Effects of the sales growth due to new products, the share of process innovators and the share of organisational and marketing innovators in the period 2006-2008 on the share of high-skilled workers in the period 2008-2010 (at the industry level). Based on a fixed effects regression for 28 European countries. Additional control variables: initial employment in 2008 and Chinese import share. Reading: A 10% increase in sales due to new products at the industry level leads to an increase in the proportion of high-skilled workers by 0.6%. A 10% increase in the share of process innovators at the industry level leads to an increase in the proportion of high-skilled persons by 1.8%. Similarly for the share of organizational and marketing innovators.

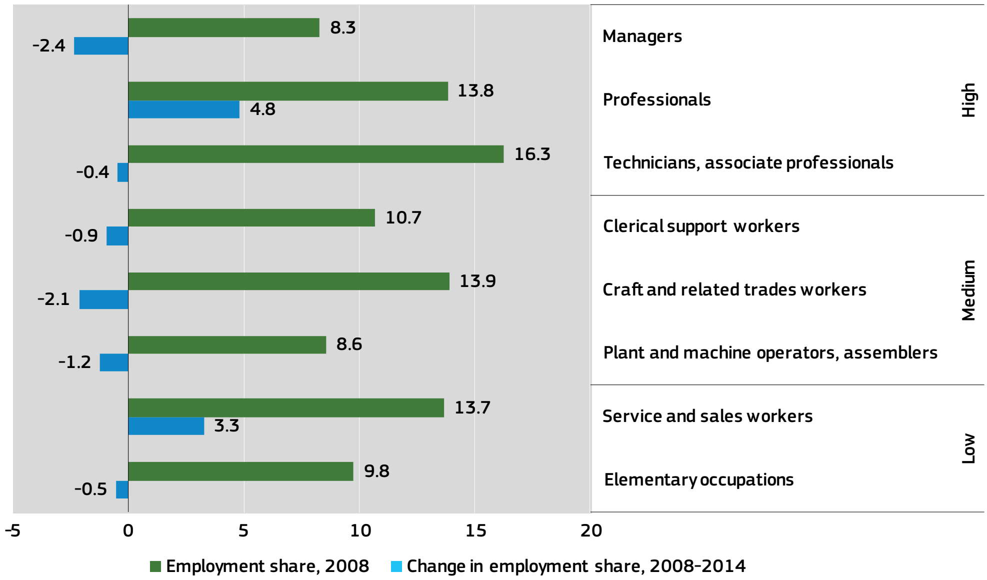
The results confirm a strong upskilling impact of product and process innovation in European manufacturing and thus confirm the skill-biased technological skill hypothesis. For instance, a 10% increase in sales due to new products at the industry level leads to an increase in the proportion of high-skilled workers by 0.6% in manufacturing. And according to the study a 10% increase in the share of process innovators at the industry level leads to an increase in the proportion of high-skilled persons by 1.8%. The results further indicate that the upskilling impact of innovation is stronger in manufacturing than in services. These findings at the European level corroborate the substantial and consistent evidence in favour of the skill-bias technological change hypothesis found in prior studies. Most of these studies refer to the nineties and first decade of this century. The evidence was found for different technology measures (e.g., R&D intensity, R&D investments, innovation indicators or ICT investment) and for different countries, e.g., the US (Berman et al. 1994, Dunne et al. 1996, Doms et al. 1997, Adams 1999), Canada (Gera et al. 2001), the UK (Machin 1996), Germany (Kaiser 2000, 2001, Falk and Seim 2000, 2001), Spain (Aguierregabiria and Alsonso-Borrego 2001) or Italy (Piva et al. 2005).

The study by Damijan et al. (2014) also shows that organisational and marketing innovations strongly contribute to the upskilling trend in Europe. This effect is even larger than for process innovation. This supports the skill-bias organisational change hypothesis. This finding is again in line with prior findings from the literature for single countries. Though, in general, fewer studies have focussed on skill-biased organisational change, there is also substantial evidence in favour of this hypothesis in the literature. Bresnahan et al. (2001) showed that both IT investment and new workplace organisation are associated with an increase in human capital in the US. Their results furthermore point towards complementary, i.e., the effect of IT on high skilled labour demand is larger when combined with changes in the workplace organisation. Similarly, Caroli and Van Reenen (2001) found for British and French firms that past organisational changes lead to a significant decline in the wage bill share of unskilled manual workers and to a corresponding rise for skilled manual workers, clerical workers and professionals. Piva and Vivarelli (2002) also found evidence that the upskilling trend of employment is a result of organisational changes in Italy. Like Damijan et al. (2014) they find this effect to be stronger than the one for technological change and globalisation. Piva et al. (2005) corroborated this finding and also showed that organisational changes, in particular to shop floor functions, and R&D investments jointly affect the demand for high skilled labour.

The second approach to test for skill-biased technological change uses the so-called canonical model which includes two skill groups performing two distinct and imperfectly substitutable tasks. Technology is assumed to take a factor-augmenting form which, by complementing either high or low skilled workers, can generate skill-biased demand shifts (Acemoglu and Autor 2011). This model has successfully explained several salient changes in the earnings distribution between high- and low-skilled workers in the past (e.g., Katz et al 1995, Fitzenberger and Kohn 2006 and Chennells and van Reenen 2002, Katz and Autor 1999, Goldin and Katz 2009 or Acemoglu and Autor 2011 for surveys).

The skill-biased technological change, however, cannot explain the recent phenomenon of what is called job polarisation (Autor et al. 2006, 2008, Goos and Manning 2007, Spitz-Oener 2006, Goos et al. 2014). Job polarisation describes the phenomenon that actually the demand for both high and low skilled and paid occupations has increased whereas the demand for middling occupations has decreased. This phenomenon has first been reported for the US (Autor et al. 2006, 2008). In a recent study Goos et al. (2014) confirmed this finding for 16 European countries for the period 1993-2010. Figure II-8-27 shows that the trend towards job polarisation is still ongoing in Europe. Depicted are the employment shares of eight different occupation classes in 2008 as well as their change between 2008 and 2014. Based on the average European wage within each occupation class, the eight occupation classes are classified into three high-paid, three medium-paid and two low-paid occupation classes (see Goos et al. 2014). The results show that among the high-paid occupations professionals like scientists and engineers, health, teaching, business and administration, IT and law professionals have substantially raised their employment share over the six-year period by +4.8 percentage points. In contrast, even high-paid occupations like technicians and associate professionals (-0.4 pp) and managers (-2.4 pp) have suffered losses in employment shares. But as the hypothesis of job polarisation states low-paid occupations like service and sales workers have experienced a substantial increase in the employment share over this period of about 3.3 percentage points. This is not the case for low-paid workers in elementary occupations though their employment share has only slightly decreased — at least compared to medium-paid workers. The Figure impressively shows that (relative) job losses are strongest for this occupational group. Clerical support workers, craft and related trade workers as well as plant and machines operators and assemblers have experienced a decline in employment shares by 1 to 2 percentage points. This corresponds to a decline of about 10 to 14% with respect to their employment share in 2008.

Figure II-8-27 **Employment by occupation[1] as % of total employment in the EU, 2008 and change in percentage points between 2008 and 2014**



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Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Eurostat (LFS), Damijan et al (2014)
Note: [1]High, medium and low classifies occupations based on their average European wage (see Goos, Mannings and Salomons 2014). Residual occupation class not reported: Armed forces occupations.

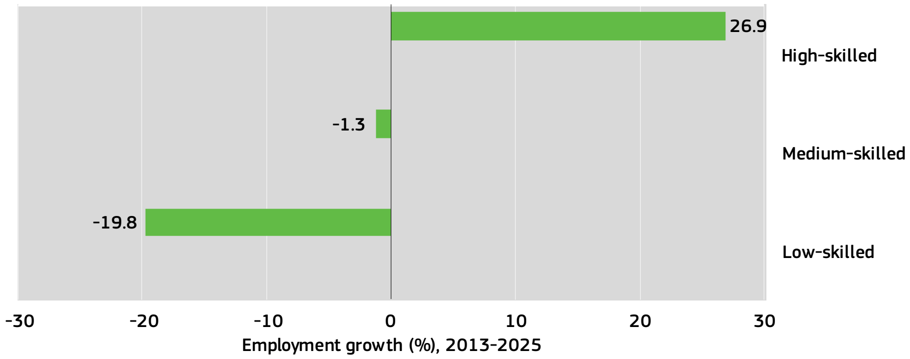
How can this job polarisation be explained? Research has tried to explain this with the task approach. The basic idea is that in order to produce a good or service certain tasks have to be performed and whether capital or (different types of) labour perform a specific task can vary over time. That is, the boundary between labour tasks and capital tasks in production is permeable and shifting (Autor 2013). The introduction of a new product or service and the implementation of new production technologies often involve novel tasks. These novel tasks are often first assigned to high-educated workers as they are more flexible and adaptable if problems arise. Often, these tasks become more formalised and codified, i.e., routinised, over time and allow for automation as machines are typically more cost efficient in performing routine tasks. This is why technological change is biased towards replacing labour in routine tasks. Using a Routine task intensity and offshorability indicator for each occupation category, Goos et al. (2014) provided empirical evidence that this shift in the labour demand between high-, medium- and low-paid occupations in Europe is mainly driven by routine-biased technological change. The offshoring of tasks as a result of increasing globalisation also contributes to this development but to a much lesser extent.

8.4.2 Skills development outlook

Recent forecasts show that the trend towards upskilling and job polarisation in the European labour market is likely to continue in the next decade (Cedefop 2015). Overall, forecasts by Cedefop show that in a baseline scenario employment will grow by about 9 million jobs or 4.1% between 2013 and 2025 [156]. But employment will not rise equally across qualification levels. Due to an increasing demand for high-skilled employees, and a simultaneous rise in the supply of persons having a tertiary education, employment of high-skilled persons is estimated to increase by about 27%. At the same time, employment of medium-skilled and low-skilled persons will decline by -1.3% and -19.8% (Figure II-8-28).

[156] Forecasts of the development of skills supply and demand are based on a modular approach. It includes a multi-sectoral macroeconomic model by country to estimate employment forecasts and additional modules to estimate the expansion and replacement demand by occupation and qualification levels. Additional modules are used to estimate skills supply (see Cedefop 2012).

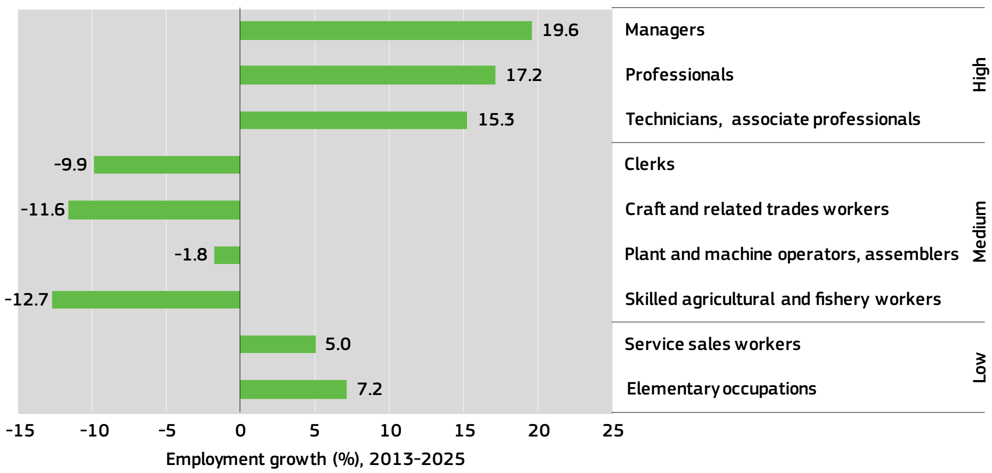
Figure II-8-28 **Forecast of employment growth (%) in the EU by qualification, 2013-2025**



Science, Research and Innovation performance of the EU 2016
Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Cedefop: Skills Forecast for 2015

Employment growth by occupations, however, depicts a more nuanced pattern. According to the forecasts employment of all three high-paid occupations will substantially rise (Figure II-8-29). As in the period 2008-2013 jobs of professionals like scientists and engineers, health, teaching, business and administration, IT and law professionals are predicted to grow by 17% between 2013-2025. This development is forecasted for all European countries despite a large cross-country heterogeneity (Figure II-8-30). Likewise, employment of technicians and associate professionals as well as managers is supposed to increase by 15.3% and 19.6%, respectively. For both occupations, however, country-level data reveals that this development is not unified across Europe with 4 and 11 countries showing a diverging negative trend for these high-paid occupational groups.

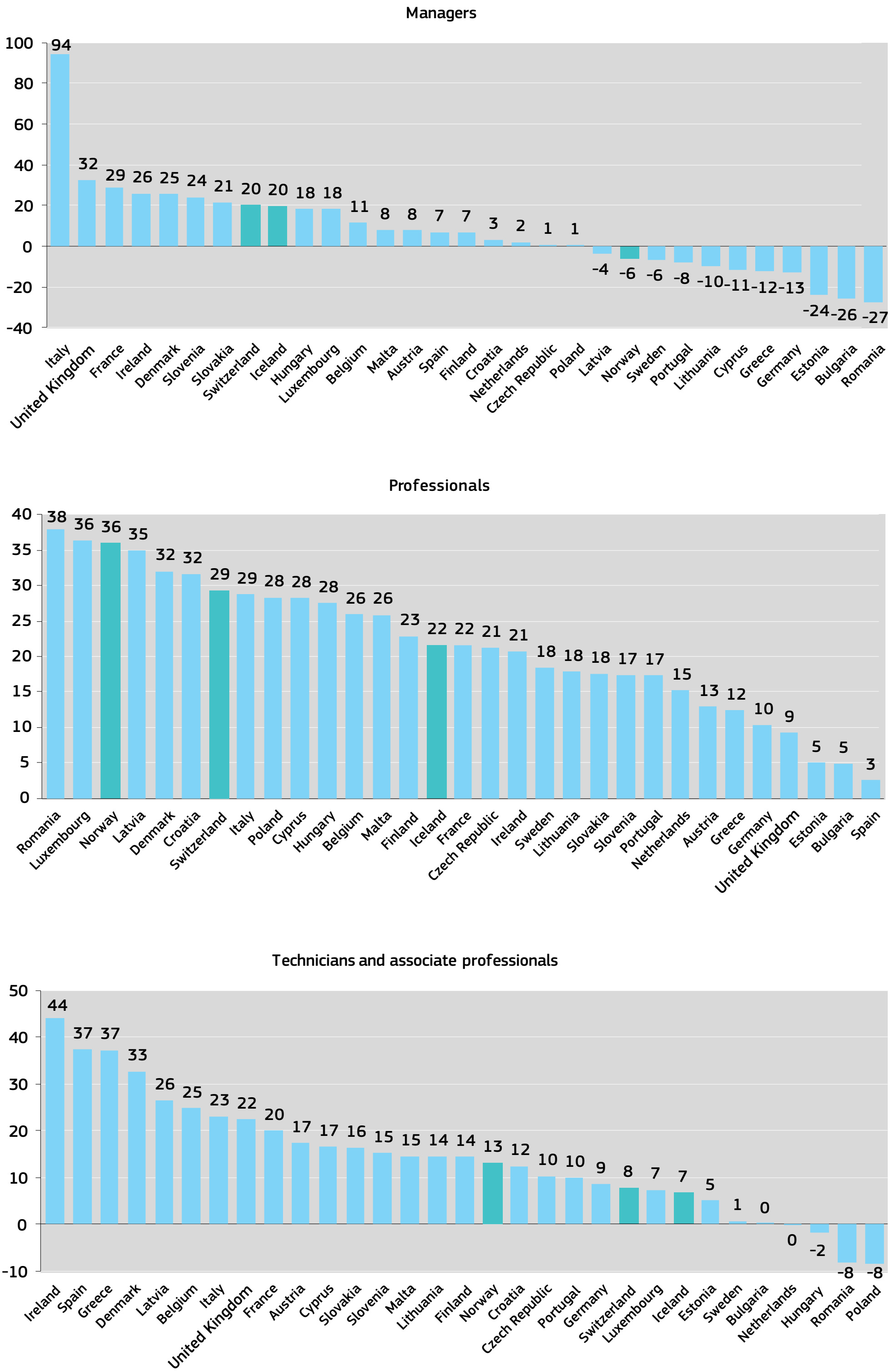
Figure II-8-29 **Forecast of employment growth (%) in the EU by occupation[1], 2013-2025**



Science, Research and Innovation performance of the EU 2016
Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Cedefop: Skills Forecast for 2015
Note: [1]High, medium and low classifies occupations based on their average European wage (see Goos, Mannings and Salomons 2014).

The development that mainly routinised-cognitive and routinised-manual tasks — typical for medium-paid occupations — are destroyed by technological progress and globalisation is supposed to continue in the next decade. Forecasts show that the prospects of medium-paid occupations will further deteriorate predicting a job destruction rate that is of similar range for clerks (- 10%), craft and related trade workers (- 11.6%) and agricultural and fishery workers (- 12.7%). Only plant and machine operators and assemblers are supposed to be less affected by job destruction (-1.8%).

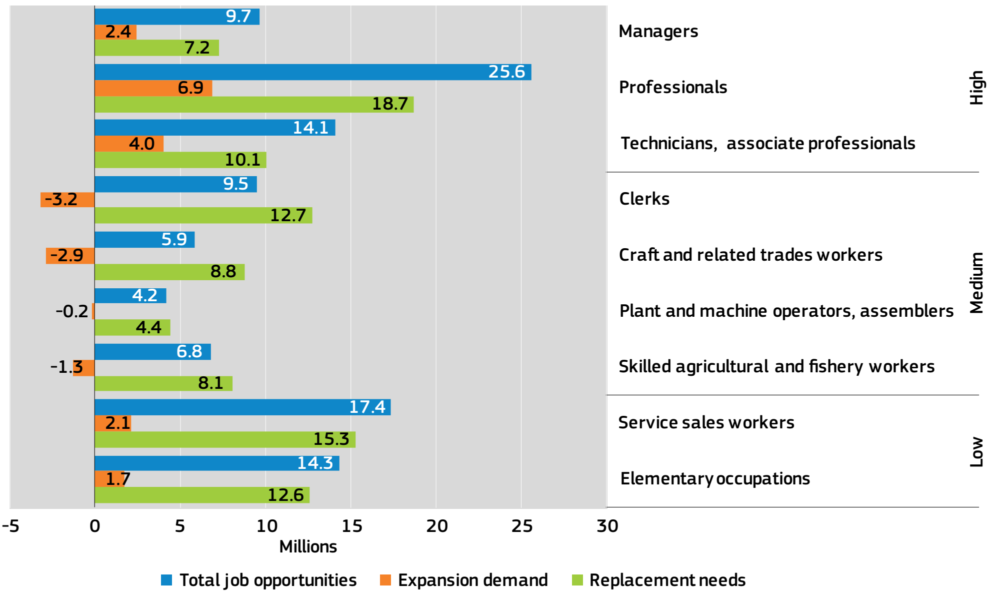
Figure II-8-30 **Forecast of employment growth (%) for high-paid occupations, 2013-2025**



Science, Research and Innovation performance of the EU 2016
Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies
Data: Cedefop: Skills Forecast for 2015

In contrast to medium-paid occupations but in line with job polarisation, employment of low-paid service and sales workers and workers in elementary occupations are predicted to increase by 5% and 7.2%, respectively. This sharply contrasts with the finding that employment of low-skilled persons is supposed to fall. Hence, the forecasts on the employment growth by qualification and occupation point towards an important future risk of skill mismatch through over-qualification. In particular, in times of weak labour demand persons might be more willing to accept jobs below their qualification level. A similar conclusion can be drawn for the high-skilled employees as the growth in employment of high-skilled persons is stronger than the job of high-paid occupations [157].

Figure II-8-31 **Forecast of job opportunities (millions of jobs) in the EU by occupation[1], 2013-2025**



Science, Research and Innovation performance of the EU 2016

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

Data: Cedefop: Skills Forecast for 2015

Note: [1]High, medium and low classifies occupations based on their average European wage (see Goos, Mannings and Salomons 2014).

As a final piece of evidence related to the future skills development, Figure II-8-31 shows the estimated growth in job opportunities between 2013 and 2025. Job opportunities represent the sum of net employment changes and replacement demand. Replacement demand is based on the fact that some jobs become available due to people leaving work places for different reasons (retirement, migration, etc.) and these vacant positions need to be filled. As Figure II-8-31 shows there will be more than 107 million jobs opportunities between 2013 and 2025. Job opportunities will also arise mainly for higher- and lower-paid occupations. More than 90% of them are forecasted to be a result of the need to replace people leaving the labour market, mainly to retire (Cedefop 2015). In particular for medium-paid occupations future job opportunities mainly relate to replacement demand.

(157) This line of reasoning neglects that wage differentials between different occupation groups might change as a result of higher qualification levels.

8.5 Conclusions

The relationship between skills, innovation and employment growth has, for several reasons, gained attention among researchers and policy-makers in recent years. On the one hand, there is rising educational attainment and supply of high-skilled labour. On the other hand, the demand for high-skilled labour has grown strongly as a result of the increased complexity of technologies and IT-enabled organisational innovations. At the same time, the overall unemployment rates have been growing in many European countries in recent years affecting, in particular, young people in southern Europe and leading to a situation in which a large proportion of young people have no opportunities to accumulate skills by training on the job. This comes while Europe is facing a multitude of grand challenges like increasing competition from Asian countries.

This chapter of the Report has summarised and analysed the complex interrelationship between skills, innovation and employment growth in Europe. The evidence shows a substantial and cumulative relation between the supply of higher level education and skills, the generation of new products, process and organisational procedures and employment growth, in particular for high-skilled occupations but also for some low-skilled occupations. The key findings can be summarised as follows:

- There has been an *ongoing upskilling trend* in Europe in recent years, mainly coming from a growing proportion of persons having completed tertiary education. This increase in supply is observed across nearly all countries and across all sectors but it is not unified across education fields. In most countries the absolute number of persons with a tertiary degree in science and engineering has grown, but less than in other fields.
- *Higher skill levels foster the likelihood of introducing an innovation and they improve innovation performance in European firms*. This confirms that skills are necessary to identify and assess firm-specific knowledge in order to generate new knowledge and innovation but also in order to identify the value of new external information from the environment and to assimilate and apply it to commercial ends. This positive relationship has been found for both generic skills and field-specific skills.
- However, the results point towards a non-negligible *effect heterogeneity* across different types of skills as well as on different types of innovation activities:
  - With respect to generic skills, the innovation impact is particularly strong for problem-solving skills, followed by literacy and numeracy skills.
  - Engineering skills are particularly important for developing new products, less so for process innovation and not conducive to organisational innovation.
  - In contrast, skills in mathematics, statistics and database management significantly stimulate organisational and process innovation but not product innovation as of yet.
  - Design skills are conducive to all three types of innovation.
  - While multimedia, web design and software development belong to the group of skills most often employed by enterprises, their marginal impact on product innovation is smaller than that of engineering and design.
  - The large impact software skills exert on the introduction of new production technologies and organisational methods is outstanding.
  - Market novelties, as a measure for radical innovation, are particularly fostered by employing design skills, followed by engineering skills and abilities in software development and web design.
  - Process innovations are particularly driven by software skills.
  - Skills in software development, mathematics, statistics and database management as well

as in market research are main drivers of organisational innovation.

- The innovation-inducing effect of skills depends on whether skills are employed in-house or whether they are bought in from external sources. Engineering and design skills are more effective in-house whereas the lack of in-house multimedia and web design capacity can be more than compensated by hiring external specialists.

  Policy should take this heterogeneity effect into account when designing educational, training or innovation programmes.

- *Product innovation fosters employment growth.* Empirical evidence for process and organisational innovation is mixed and also rather limited.

- *Europe undergoes an ongoing job polarisation trend* which describes the phenomenon that the demand for both high- and low-skilled and paid occupations has increased whereas the demand for middling occupations has decreased. Evidence shows that technological change is biased towards replacing labour in routine tasks mainly performed by medium-paid occupations. The extent to which this replacement takes place depends on the relative costs of labour to capital. Policy should avoid needless increases in labour costs for this group of workers in order to not stimulate labour displacement in this segment in the first place. For those workers which have been laid off, it will be necessary for policy to offer them programmes in order to improve their skill level and thus increase their chances to participate in the labour market.

Currently, there is no evidence for a European-wide skill shortage. However, certain occupations and related skills — in particular in the area of science and engineering, ICT and health professionals but also metal and machinery workers — already present a bottleneck for firms in Europe and impair their competitiveness. These shortages do not only reflect short-term developments on the labour market but forecasts indicate that these occupations are also associated with higher growth potentials and job opportunities at least in the next decade. As shown above, skills in these areas are also drivers of innovation and employment growth. Hence, policy should strive for reducing skills shortages in these areas while taking into account that reasons for skill mismatches are quite different across occupations. Improving the working environment could be, for instance, a rather short-term policy instrument to increase the labour supply of health professionals. On the other hand, stimulating young people to take up study or apprenticeship in current and future shortage occupations is more of a long-term oriented policy measure.

In addition, major upcoming technological changes like the transition to a low-carbon economy, the fourth industrial revolution (industry 4.0) and Big data applications but also the aging population and associated potential skill shortages will be challenges for managing skills, innovation and employment in the future. For instance, in order to successfully manage the transition to a low-carbon economy, green skills will be crucial. Green skills are skills needed by the workforce in all sectors in order to help the adaptation of the products, services and processes to the changes due to climate change and to environmental requirements and regulations (OECD 2014). Here, Europe is still at the beginning. Changes in curricula and competences have mainly taken place for explicit green jobs but not at a large scale. But skill shortages in this area may result in increased costs to climate change mitigation and adaptions (OECD 2014). Based on the evidence on skill-biased organisational change, we can also expect that, in particular, the changes in industrial production due to industry 4.0 which are associated with a stronger customisation of products using intelligent automated methods of self-optimisation, self-diagnosis and cognition, will further change skill requirements of workers. Exploiting the potential of Big data analysis, data has to be processed with advanced analytical and algorithm tools to generate useful information in order to improve the factory floor or to better address customer needs. Skills in these areas are thus likely to become more important for innovation in the future. Hence, policy should set the course for stimulating skill development in these areas as these skills will turn out to be a major future competitive advantage for European firms.

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Methodological Annex

SYMBOLS AND ABBREVIATIONS

Country codes

BE	Belgium	**FI**	Finland
BG	Bulgaria	**SE**	Sweden
CZ	Czech Republic	**UK**	United Kingdom
DK	Denmark	**EU**	European Union
DE	Germany	**IS**	Iceland
EE	Estonia	**LI**	Liechtenstein
IE	Ireland	**NO**	Norway
EL	Greece	**CH**	Switzerland
ES	Spain	**MK**	The former Yugoslav Republic of Macedonia
FR	France	**RS**	Serbia
HR	Croatia	**TR**	Turkey
IT	Italy	**IL**	Israel
CY	Cyprus	**ERA**	European Research Area
LV	Latvia	**US**	United States
LT	Lithuania	**JP**	Japan
LU	Luxembourg	**CN**	China
HU	Hungary	**KR**	South Korea
MT	Malta	**IN**	India
NL	Netherlands	**TW**	Chinese Taipei
AT	Austria	**SG**	Singapore
PL	Poland	**RU**	Russian Federation
PT	Portugal	**ZA**	South Africa
RO	Romania	**BR**	Brazil
SI	Slovenia	**RoW**	Rest of the world
SK	Slovakia		

Other abbreviations

: 'not available'

- 'not applicable' or 'real zero' or 'zero by default'

SCIENCE, RESEARCH AND INNOVATION PERFORMANCE OF THE EU

R&D intensity

Definition: Gross domestic expenditure on R&D (GERD) as % of Gross domestic product (GDP)
Sources: Eurostat, OECD

Gross domestic product (GDP)

Definition: Gross domestic product (GDP) data have been compiled in accordance with the European System of National and Regional Accounts (ESA 2010).
Source: Eurostat

Gross domestic expenditure on R&D (GERD)

Definition: Gross domestic expenditure on R&D (GERD) is defined according to the OECD Frascati Manual (2002) definition. GERD can be broken down by four sectors of performance:

(i) Business enterprise expenditure on R&D (BERD);
(ii) Government intramural expenditure on R&D (GOVERD);
(iii) Higher education expenditure on R&D (HERD);
(iv) Private non-profit expenditure on R&D (PNPRD).

GERD can also be broken down by four sources of funding:

(i) Business enterprise;
(ii) Government;
(iii) Other national sources;
(iv) Abroad.

Sources: Eurostat, OECD

Public expenditure on R&D

Definition: For the purposes of this publication, public expenditure on R&D is defined as Government intramural expenditure on R&D (GOVERD) plus Higher education expenditure on R&D (HERD).
Sources: Eurostat, OECD

Business R&D intensity (BERD intensity)

Definition: Business enterprise expenditure on R&D (BERD) as % of Gross domestic product (GDP)
Sources: Eurostat, OECD

Public R&D intensity

Definition: Public expenditure on R&D (GOVERD plus HERD) as % of Gross domestic product (GDP).
Sources: Eurostat, OECD

Government budget appropriations or outlays for R&D (GBAORD)

Definition: Government budget appropriations or outlays for R&D (GBAORD) is defined according to the OECD Frascati Manual (2002) definition. The data are based on information obtained from central government statistics and are broken down by socio-economic objectives in accordance with the nomenclature for the analysis and comparison of scientific programmes and budgets (NABS).
Source: Eurostat

Framework Programme

Definition: The Framework Programmes for Research and Technological Development are the EU's main instruments for supporting collaborative research, development and innovation in science, engineering and technology. Participation is on an internationally collaborative basis and must involve European partners. The first Framework Programme was launched in 1984. The seventh Framework Programme (FP7) covers the period 2007-2013.
Source: DG Research and Innovation

Structural Funds

Definition: Structural Funds are funds intended to facilitate structural adjustment of specific sectors, regions, or combinations of both, in the European Union. Structural Funds for RTDI include data from sectors involving research and development, technological innovation, entrepreneurship, and human capital.

Source: DG Regional and Urban policy

Purchasing Power Standards (PPS)

Definition: Financial aggregates are sometimes expressed in Purchasing Power Standards (PPS), rather than in euro based on exchange rates. PPS are based on comparisons of the prices of representative and comparable goods or services in different countries in different currencies on a specific date. The calculations on R&D investments in real terms are based on constant 2005 PPS.

Source: Eurostat

Value Added

Definition: Value added is current gross value added measured at producer prices or at basic prices, depending on the valuation used in the national accounts. It represents the contribution of each industry to GDP.

Sources: Eurostat, OECD

Venture Capital

Definition: Venture Capital investment is defined as private equity being raised for investment in companies. Venture Capital includes seed, start-up and later stage capital.

Sources: Eurostat, NVCA

Small and medium-size enterprises (SMEs)

Definition: Small and medium-size enterprises (SMEs) are defined as enterprises having fewer than 250 employees.

Sources: Eurostat, OECD

Multifactor productivity (MFP)

Definition: Multi-factor productivity (MFP) relates a change in output to several types of inputs. MFP is often measured residually, as that change in output that cannot be accounted for by the change in combined inputs.

Source: OECD

Capital deepening

Capital deepening refers to the annual rate of change in capital intensity. Capital intensity is defined as the ratio of capital services per hour worked.

Source: OECD

Unemployment rate

The number of people unemployed as a % of the labour force.

Sources: Eurostat (LFS), DG Economic and Social Affairs, OECD

Employment rate

The number of persons employed aged 15-64 years as % of total population aged 15-64 years based on resident population concept.

Sources: Eurostat (LFS), OECD

Higher Education

Data on education up to and including 2012 are based on ISCED [158] 1997. Data from 2013 onwards are based on ISCED 2011. The table below shows the correspondence between ISCED 1997 and ISCED 2011 levels (at 1-digit ISCED 1997):

ISCED 1997 *(data up to 2012)*	ISCED 2011 *(data from 2013 onwards)*
ISCED 5: Tertiary education (first stage) not leading directly to an advanced research qualification	ISCED 5: Short-cycle tertiary education ISCED 6: Bachelor's or equivalent level ISCED 7: Master's or equivalent level
ISCED 6: Tertiary education (second stage) leading to an advanced research qualification (PhD or doctorate)	ISCED 8: Doctoral or equivalent level

Source: Eurostat

Human Resources for Science and Technology (HRST), sR&D personnel and researchers

The Canberra Manual proposes a definition of HRST as people who either have higher education or are employed in positions that normally require such education. HRST applies to people who fulfil one or other of the following conditions:

a) Have successfully completed education at the tertiary level in an S&T field of study (HRSTE - Education);
b) Not formally qualified as above, but employed in an S&T occupation where the above qualifications are normally required (HRSTO - Occupation).

HRST Core (HRSTC) refers to people with both tertiary-level education and an S&T occupation. Scientists and engineers are defined as ISCO [159] categories 21 (physical, mathematical and engineering science professionals) and 22 (life science and health professionals).

The Frascati Manual (2002) proposes the following definitions of R&D personnel and researchers:

- R&D personnel: "All persons employed directly on R&D should be counted, as well as those providing direct services such as R&D managers, administrators, and clerical staff." ;
- Researchers: "Researchers are professionals engaged in the conception or creation of new knowledge, products, processes, methods and systems and also in the management of the projects concerned". R&D may be either the primary function or a secondary function. It may also be a significant part-time activity.

Therefore, the measurement of personnel employed in R&D involves two exercises:

- Measuring their number in headcounts (HC) whereby the total number of people who are mainly or partially employed in R&D are counted;
- Measuring their R&D activities in full-time equivalence (FTE): the number of people engaged in R&D is expressed in full-time equivalents on R&D activities.

Source: Eurostat

Job-to-job mobility

Definition: Mobility (job-to-job mobility) of employed HRST is built up by considering the number of HRST employed in the years T-1 and T, that have changed jobs during the twelve month period. It is expressed as a proportion of the total number of HRST employed in year T.

Source: Eurostat

[158] International Standard Classification of Education
[159] International Standard Classification of Occupations

Patent Cooperation Treaty (PCT) – International Patents

Definitions: The Patent Cooperation Treaty (PCT) is an international treaty, administered by the World Intellectual Property Organization (WIPO), signed by 133 Paris Convention countries. The PCT makes it possible to seek patent protection for an invention simultaneously in each of a large number of countries by filing a single "international" patent application instead of filing several separate national or regional applications. Indicators based on PCT applications are relatively free from the "home advantage" bias (proportionate to their inventive activity, domestic applicants tend to file more patents in their home country than non-resident applicants). The granting of patents remains under the control of the national or regional patent offices. The PCT patents considered are 'PCT patents, at international phase, designating the European Patent Office'. The country of origin is defined as the country of the inventor. If one application has more than one inventor, the application is divided equally among all of them and subsequently among their countries of residence, thus avoiding double counting.

"PCT is an option for possible future patenting, that provides the applicant with a further delay before deciding to apply or not. The delay can be 6 to 12 months. The relation between the PCT option and patent value is not predictable (Grupp and Schmoch, 1999). The PCT process provides the advantage of a longer investigation of the technological potential of the invention, and in case of a negative assessment, the application can be withdrawn before entering into the expensive regional (EPO) phase. Having passed this test, the PCT applications that are continued towards entering the regional phase are likely the ones of higher value. However, the argument can be reversed in the way that inventions with unclear market potential are passed through the PCT route, whereas those with an unquestionable potential are directly applied at the regional phase, since the direct path is cheaper." (Guellec & van Pottelsberghe, 2000).

Source: OECD

Scientific Publications

Definition: Publications are research articles, reviews, notes and letters published in referenced journals which are included in the Scopus database of Elsevier. Bibliometric indicators were calculated using either full counting (i.e. each paper was counted once for each entity listed in the address field) or fractional counting (i.e. each author / entity is attributed a fraction of the paper, so that the total across entities adds up to the total number of papers), as specified. In the case of the full counting method, for the EU aggregate, double counts of multiple occurrences of EU Member States in the same record were excluded.

Source: Scopus (Elsevier); treatments and calculations: Science Metrix

Average of Relative Citations (ARC)

The ARC is an indicator of the scientific impact of papers produced by a given entity (e.g. the world, a country, a NUTS2 region, an institution) relative to the world average (i.e. the expected number of citations). The number of citations received by each publication is counted for the year in which it was published and for the three subsequent years. For papers published in 2010, for example, citations received in 2010, 2011, 2012 and 2013 are counted.

To account for different citation patterns across fields and subfields of science (e.g. there are more citations in biomedical research than in mathematics), each publication's citation count is divided by the average citation count of all publications of the corresponding document type (i.e. a review would be compared to other reviews, whereas an article would be compared to other articles) that were published the same year in the same subfield to obtain a Relative Citation count (RC). The ARC of a given entity is the average of the RCs of the papers belonging to it. An ARC value above one means that a given entity is cited more frequently than the world average, while a value below one means the reverse.

Methodology of co-publication analysis

The methodology used for the co-publication analysis involved three types of analysis:

a) Single country publications cover co-publications that involve domestic partners only; this is the sum of all papers written by one or more authors from a given country (and non-nationals resident in that country). Although the literature usually distinguishes between domestic single publications (including one or more authors belonging to the same institution) and domestic co-publications (i.e. authors within the same country but from different main organisations), for the aim of the current analysis the sum of the two categories have been treated as single country publications.
b) EU transnational co-publications refer to international co-publications which involve at least one author from an EU country. This category includes both co-publications by authors from at least two different EU Member States (as defined by research papers containing at least two authors' addresses in different countries) and co-publications between one or several authors from the EU together with at least one author from a country outside the EU.
c) Extra-EU co-publications is a sub-category of the broader EU transnational co-publications. It refers exclusively to international co-publications involving at least one EU author and at least one non-EU author, as defined by the authors' addresses in different countries.

An important methodological issue is the way in which a co-publication is quantified. The full counting method has been used in this report, meaning that a single international co-published paper is assigned to more than one country of scientific origin. If, for example, the authors' addresses signal three different countries in the EU, the publication is counted three times – once for each country mentioned. Therefore, in a matrix of co-publications between countries, the number of publications mentioned is not a completely accurate indicator of the number of publications being co-authored, but rather how often a country or region is involved in co-publications.

Public-Private co-publications

Definition: Number of public-private co-authored research publications. The private sector excludes the private medical and health sector.

Source: DG Research and Innovation, based on Scopus database (SciVal)

Matching scientific subfields to FP7 thematic priorities

The matching process was undertaken using expert decisions supported by different statistics. The first step was to delineate the breadth of each thematic priority by reading the Work Programmes (http://cordis.europa.eu/fp7/find-doc_en.html) for all themes. The documents were also used to extract relevant keywords that were searched in Scopus. Statistics were produced to identify the association between the thematic priorities (through keywords) and the fields and subfields (through the classification of the articles retrieved).

The resulting matching scheme matches S&T field(s) and/or subfield(s) to each thematic priority. All themes have been matched to at least one relevant field/subfield. No S&T field or subfield has been matched with more than one theme, with the exception of Aerospace & Aeronautics, which has been matched to both Space and Aeronautics. It is impossible to split Aerospace & Aeronautics into two subfields, even when using a match based on journals, because many journals present research on both aerospace science and aeronautics (e.g. Aircraft Engineering and Aerospace Technology, Transactions of the Japan Society for Aeronautical and Space Sciences, Canadian Aeronautics and Space Journal). However, it should be noted that this subfield includes many more articles on space science than on aeronautics.

It should also be noted that this solution contains missing links between thematic priorities and scientific papers that are not classified under the suggested matching S&T field/subfield (false negatives), as well as spurious links between thematic priorities and scientific papers that are classified under the suggested match but are not relevant to the theme. Nevertheless, this matching scheme is believed to be highly appropriate for linking the FP7 priorities with scientific output (through bibliometric data).

FP7 Thematic Priorities	Science-Metrix Field	Science-Metrix SubField
1. Health	Biomedical Research	All subfields
	Clinical Medicine	All subfields
	Psychology & Cognitive Sciences	All subfields
	Public Health & Health Services	All subfields
2a. Food, Agriculture and Fisheries	Food, Agriculture and Fisheries	All subfields
2b. Biotechnology	Enabling & Strategic Technologies	Biotechnology
	Enabling & Strategic Technologies	Bioinformatics
3. Information and Communication Technologies	Information and Communication Technologies	All subfields
4a. Nanosciences and Nanotechnologies	Enabling & Strategic Technologies	Nanoscience & Nanotechnology
4b. Materials (excluding nanotechnologies)	Enabling & Strategic Technologies	Materials
	Chemistry	Polymers
4c. New Production Technologies	Engineering	Industrial Engineering & Automation
	Engineering	Operations Research
4d. Construction and Construction Technologies	Built Environment & Design	All subfields
5. Energy	Enabling & Strategic Technologies	Energy
6. Environment (including Climate Change)	Earth & Environmental Sciences	Environmental Sciences
	Engineering	Environmental Engineering
	Earth & Environmental Sciences	Meteorology & Atmospheric Sciences
	Earth & Environmental Sciences	Oceanography
	Biology	Ecology
7a. Aeronautics	Engineering	Aerospace & Aeronautics
7b. Automobiles	Engineering	Automobile Design & Engineering
7c. Other Transport Technologies	Economics & Business	Logistics & Transportation
	Engineering	Mechanical Engineering & Transports
	Engineering	Civil Engineering
8a. Socio-Economic Sciences	Communication & Textual Studies	Communication & Media Studies
	Economics & Business	All subfields except Logistics & Transportation
	Social Sciences	All subfields
8b. Humanities	Anthropology, Archeology & History	All subfields
	Communication & Textual Studies	Languages & Linguistics
	Communication & Textual Studies	Literary Studies
	Philosophy & Theology	All subfields
	Visual & Performing Arts	All subfields
9. Space	Engineering	Aerospace & Aeronautics
10. Security	Enabling & Strategic Technologies	Strategic, Defence & Security Studies

Source: Science-Metrix

High-tech (HT) manufacturing

Definition: High-tech manufacturing includes the following sectors (NACE Rev.2 codes are given in brackets): basic pharmaceutical products and pharmaceutical preparations (21), computer, electronic and optical products (26).

Sources: Eurostat, OECD.

Medium-high-tech (MHT) manufacturing

Definition: Medium-high-tech manufacturing includes the following sectors (NACE Rev.2 codes are given in brackets): chemicals and chemical products (20), electrical equipment (27), machinery and equipment (28), motor vehicles, trailers and semi-trailers (29), other transport equipment (30).

Sources: Eurostat, OECD

Knowledge-intensive services (KIS)

Definition: Knowledge-intensive services (KIS) include the following sectors (NACE Rev.2 codes are given in brackets): water transport (50), air transport (51), publishing activities (58), 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), financial service activities, except insurance and pension funding (64), insurance, reinsurance and pension funding, except compulsory social security (65), activities auxiliary to financial services and insurance activities (66), legal and accounting activities (69), activities of head offices, management, consultancy activities (70), architectural and engineering activities, technical testing and analysis (71), scientific research and development (72), advertising and market research (73), other professional, scientific and technical activities (74), veterinary activities (75), employment activities (78), security and investigation activities (80), public administration and defence; compulsory social security (84), education (85), human health activities (86), residential care activities (87), social work activities without accommodation (88), creative arts and entertainment activities (90), libraries, archives, museums and other cultural activities (91), gambling and betting activities (92), sports activities and amusement and recreation activities (93).

Sources: Eurostat, OECD

Knowledge-intensive activities (KIAs)

Definition: Knowledge-intensive activities (KIAs) are defined as economic sectors in which more than 33% of the employed labour force has completed academic-oriented tertiary education. They cover all sectors in the economy, including manufacturing and services sectors, and can be defined at two and three-digit levels of the statistical classification of economic activities.

Source: Eurostat

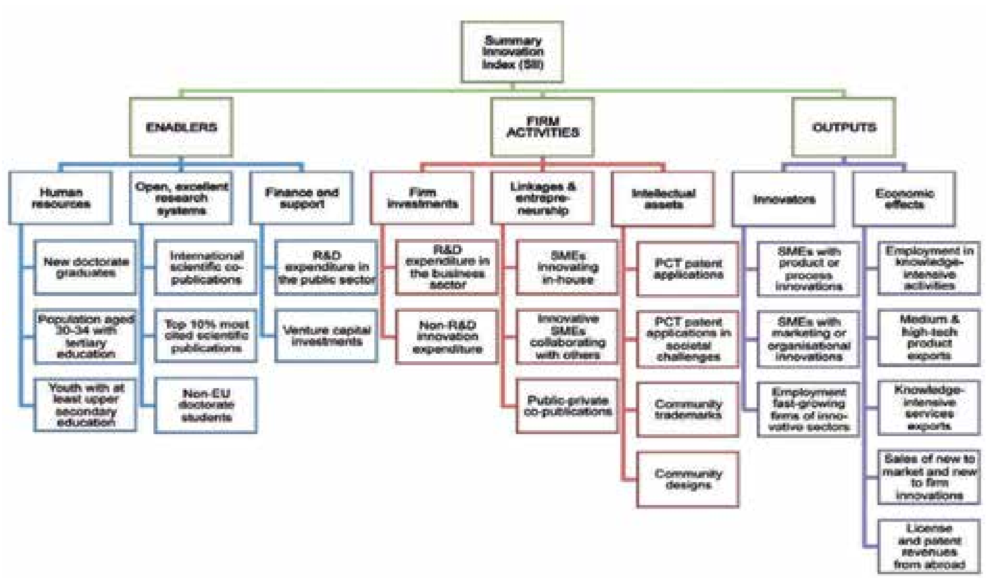
Knowledge-intensive activities – business industries (KIABI)

Definition: KIABI corresponds to the economic sectors defined as KIA with the exception of the following sectors (NACE Rev.2 codes in brackets): public administration and defence; compulsory social security (84), education (85), human health activities (86), libraries, archives, museums and other cultural activities (91), activities of membership organisations (94) and activities of extraterritorial organisations and bodies (99).

Source: Eurostat

Innovation Union Scoreboard (IUS) index

Definition: The IUS index measures innovation performance using a composite indicator (the Summary Innovation Index – SII), which summarizes the performance of a range of different indicators. The Innovation Union Scoreboard distinguishes between three main types of indicators – Enablers, Firm activities and Outputs – and eight innovation dimensions, capturing in total 25 indicators.



Source: DG Internal Market, Industry, Entrepreneurship and SMEs (Innovation Union Scoreboard 2015)

Innovation Output Indicator

$$I = w_1 \times PCT + w_2 \times KIABI + w_3 \times COMP + w_4 \times DYN$$

where

PCT = Number of patent applications filed under the Patent Cooperation Treaty per billion GDP;
Patent counts are based on the priority date, the inventor's country of residence and fractional counts (Eurostat/OECD).

KIABI = Employment in knowledge-intensive activities in business industries (including financial services) as % of total employment;
Knowledge-intensive activities are defined, based on EU Labour Force Survey data, as all NACE Rev.2 industries at 2-digit level where at least 33 % of employment has a higher education degree (Eurostat).

COMP = 0.5 × *GOOD* + 0.5 × *SERV*

GOOD = High-tech and medium- tech products exports as % of total exports
Sum of product exports in Standard International Trade Classification (SITC) Rev.3 classes: 266, 267, 512, 513, 525, 533, 54, 553, 554, 562, 57, 58, 591, 593, 597, 598, 629, 653, 671, 672, 679, 71, 72, 731, 733, 737, 74, 751, 752, 759, 76, 77, 78, 79, 812, 87, 88 and 891 (Eurostat (COMEXP)/UN (Comtrade)).

SERV = Knowledge-intensive services exports as % of total service exports
(exports of knowledge-intensive services are measured by the sum of credits in EBOPS 2010 (Extended Balance of Payments Services Classification)
items SC1, SC2, SC3A, SF, SG, SI, SJ, SK1 (UN/Eurostat)).

DYN = Employment in fast-growing firms in innovative business industries, including financial services (NACE Rev. 2 sections B-N & S95).

$$\sum_s (CIS^{score} \times KIA^{score})_s \frac{E_{sC}^{HG}}{E_C^{HG}}$$

where

$(CIS^{score} \times KIA^{score})_s$	=	Innovativeness coefficient of sector s, resulting from the product of Community Innovation Survey and Labour Force Survey scores for each sector at EU level. Innovativeness coefficients have been updated from (CIS*KIA) 2008 to (CIS*KIA) 2010.
E_{sC}^{HG}	=	The employment in fast-growing firms in sector *s* and country *C*.
E_C^{HG}	=	The employment in fast-growing firms in country *C*.
W_1, W_2, W_3, W_4	=	The weights of the component indicators, fixed over time, and statistically computed in such a way that the component indicators are equally balanced. The current values are (27, 19, 33, 21).

Source: DG Research and Innovation (*Commission Staff Working Document - Developing an indicator of innovation output*) – Unit for the Analysis and Monitoring of National Research Policies

Community Design System (CD)

Definition: A design is the outward appearance of a product or part of it, resulting from the lines, contours, colours, shape, texture, materials and/or its ornamentation. The design or shape of a product can be synonymous with the branding and image of a company and can become an asset with increasing monetary value. A registered Community design (RCD) is an exclusive right that covers the outward appearance of a product or part of it. Community Trademarks and Design refer to trade mark and design protections throughout the European Union, which covers 28 countries. The Office for Harmonization in the Internal Market (OHIM) is the official office of the European Union for the registration of Community Trademarks and Designs.
Source: OHIM

Innovative enterprises

Definition: These are enterprises that introduce new or significantly improved products (goods or services) to the market or those that implement new or significantly improved processes. Innovations are based on the results of new technological developments, new combinations of existing technology, or the use of other knowledge acquired by the enterprise.

Product innovative enterprises are those which introduced new or significantly improved goods and/or services with respect to their capabilities, user friendliness, components or sub-systems. Changes of a solely aesthetic nature and the simple resale of new goods and services purchased from other enterprises are not considered as innovation.

Process innovative enterprises implemented new or significantly improved production process, distribution method or supplying activity.

Organisational innovative enterprises implemented a new organisational method in the enterprise's business practices, workplace organisation or external relations.

Marketing innovative enterprises implemented a new marketing concept or strategy that differs significantly from enterprises' existing marketing methods and which has not been used before. It requires significant changes in product design or packaging, product placement, product promotion or pricing and excludes seasonal, regular and other routine changes in marketing methods.
Source: Eurostat

Fast-growing enterprises / High-Growth Enterprises

Definition: High-Growth Enterprises (HGEs) are defined as enterprises with an average annual growth in employees greater than 10 % a year, over a three-year period, and with 10 or more employees at the beginning of the observation period.

Source: Eurostat

Ease of doing business

Definition: Doing Business measures regulations affecting 11 areas of the life of a business. Ten of these areas are included in this year's ranking on the ease of doing business: starting a business, dealing with construction permits, getting electricity, registering property, getting credit, protecting minority investors, paying taxes, trading across borders, enforcing contracts and resolving insolvency. Doing Business also measures labour market regulation, which is not included in this year's ranking.

The indicators are used to analyse economic outcomes and identify what reforms of business regulation have worked, where and why.

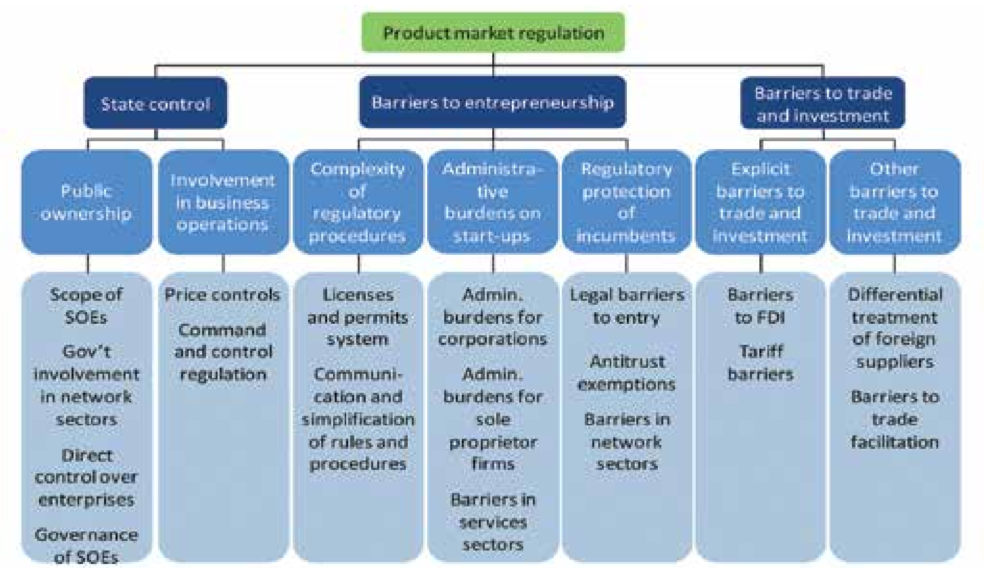
The Starting a business indicator measures the number of procedures, time and cost for a small and medium-size limited liability company to start up and formally operate.

The ***Enforcing contracts indicator*** assesses the efficiency of the judicial system by following the evolution of a commercial sale dispute over the quality of goods and tracking the time, cost and number of procedures involved from the moment the plaintiff files the lawsuit until payment is received.

Source: World Bank

Product Market Regulation

Definition: The OECD Indicators of Product Market Regulation (PMR) are a comprehensive and internationally-comparable set of indicators that measure the degree to which policies promote or inhibit competition in areas of the product market where competition is viable. They measure the economy-wide regulatory and market environments in 34 OECD countries in (or around) 1998, 2003, 2008 and 2013, and in another set of non-OECD countries in 2013. They are consistent across time and countries. Users of the data must be aware that they may no longer fully reflect the current situation in fast reforming countries. The indicators cover formal regulations in the following areas: state control of business enterprises; legal and administrative barriers to entrepreneurship; barriers to international trade and investment.



Source: OECD

Employment protection indicators

Definition: The OECD indicators of employment protection legislation measure the procedures and costs involved in dismissing individuals or groups of workers and the procedures involved in hiring workers on fixed-term or temporary work agency contracts.

Source: OECD

Employment protection

The OECD indicators of employment protection are synthetic indicators of the strictness of regulation on dismissals and the use of temporary contracts. For each year, indicators refer to regulations in force on the 1st of January.

Source: OECD

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Carlos Moedas
European Commissioner for Research, Science and Innovation

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