



THE ECONOMIC RATIONALE FOR PUBLIC R&I FUNDING AND ITS IMPACT



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THE ECONOMIC RATIONALE FOR PUBLIC R&I FUNDING AND ITS IMPACT

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KEY TAKE-AWAYS

Research and Innovation (R&I) are key drivers of productivity and economic growth as demonstrated by ample empirical evidence. Firms and economies achieve large and significant returns on these investments, which also create new and better jobs. The importance of R&I increases even further as our economies become more knowledge-based and intensive in intangible assets.

R&I investments are also crucial to address key societal challenges and improve well-being. They contribute to improving health outcomes, fight against climate change, and build more inclusive and resilient societies. Therefore, a full understanding of the impacts of R&I needs to consider both the economic impacts and the social impacts that support higher levels of well-being¹.

A number of market failures are directly linked to investment decisions in R&I. High risks, sunk costs, market uncertainty, lack of full appropriability of results, or unavailability of funding, all induce underinvestment in R&I below what is socially desirable. To maximise the spillovers that the creation and diffusion of knowledge generates, public R&I funding, for both public and private investment, is needed.

At the same time, we should not lose sight of the fact that the rationale for public R&I funding is evolving as innovation dynamics rapidly change. Digitisation, artificial intelligence and robotics grow exponentially, big data analytics changes our approach to business, science is increasingly more open and interdisciplinary, and "winner takes most" competition can make a small number of highly profitable firms capture market shares to a considerable extent and create jobs.

The celerity of change, increased complexity of innovations and higher concentration of benefits in key innovators radically influence the ability of innovation to be absorbed and diffused across firms, sectors and countries and thus, the impacts of R&I investments. Changes in innovation can build enhanced barriers for R&I investment throughout the research and innovation cycles. This is particularly true for market creating innovations, where timing and scale are crucial to reap the expected private and social benefits, and where Europe currently lags behind.

As a result, the role for public R&I funding seems more important than ever before and should address the needs of fundamental research while equally support market-creating innovation, and strike a balance between cooperation and competition.

The benefits of public R&I funding have been extensively researched and are generally positive according to a number of meta-analyses. Nonetheless, capturing the whole breadth of R&I benefits is a complex operation and significant challenges to that measurement are linked to the intangible and changing nature of innovation. More robust evidence is therefore needed. In addition, maximising the impacts of public R&I funding will increasingly depend on the existence or setting up of well-functioning markets and smart regulations that avoid market fragmentation and the production of skilled human capital and appropriate access to financing.

As regards EU public R&I funding, the economic impacts of the EU's Seventh Framework Programme for Research and Technological Development 2007-2013 have been estimated to be very large and significant. Further work is needed to measure the impact of public supranational R&I investments. The interim evaluation of Horizon 2020, the EU R&I funding programme 2014-2020, and the ex-ante evaluation of the successor to Horizon 2020, will shed additional light on this issue.

To sum up, the economic impacts of public R&I funding are large and significant. Public R&I policy is justified by market failures resulting from positive spill-overs and negative externalities. These impacts are directly affected by: (1) Adequate investments from fundamental research to market-creating innovation, (2) Improved framework conditions in support of innovation, and (3) Responsive public R&I policy that adapts to the changing landscape of innovation creation and diffusion through the necessary reforms.

¹ This paper focuses on assessing the economic impacts of research and innovation (R&I) investments. This analysis is therefore partial and does not manage to capture the full breadth of the impacts of R&I, and public R&I funding. This is particularly important as much public R&D does not focus on obtaining a direct economic return.

EXECUTIVE SUMMARY

Research and Innovation (R&I) are crucial to address Europe's economic and societal challenges. They contribute to reaping the new growth opportunities generated from knowledge, technological breakthroughs, process and product innovations, and new business models that support economic performance and help tackling societal challenges by, for instance, improving health outcomes, fighting climate change and building inclusive and resilient societies².

Our societies face multiple, complex and urgent challenges that affect the quality of life of our citizens: from energy efficiency to security, climate change or an ageing population. R&I plays a crucial role to anticipate and respond to these needs, in addition to boosting economic growth and new and better job opportunities, and support social prosperity and well-being. Economic growth needs to go hand-in-hand with societal progress in order to ensure a harmonious development. Therefore, a complete understanding the full impacts of R&I needs to take into account both economic impacts as well as the social impacts that support higher levels of well-being.

This paper focuses solely on assessing the economic impacts of R&I. Such analysis is partial and does not take into account the full breadth of the impacts of R&I, and public R&I funding. This is particularly important as much **public R&D does not focus on obtaining a direct economic return.**

From a policy perspective, assessing the rationale and economic impacts of R&I and public R&I funding is important to ensure public accountability and to nurture better evidence-based policy action.

Overall, ample empirical evidence demonstrates that R&I is a key driver of productivity and economic growth. While the estimated impacts vary depending on the methodology used and the period, countries and industries analysed, some *typical findings* of the estimates of R&I impacts on productivity and economic growth are:

- **Two-thirds of economic growth in Europe** from 1995 to 2007 derives from R&I, broadly defined (Bravo-Biosca et al, 2013). The most restrictive definition of R&I estimates its impacts on labour productivity growth³, between 2000 and 2013, at 17% in countries such as Finland, Germany or the United Kingdom and at near 30% in Ireland (INTAN-INVEST and EIB, 2016)
- Among all investment categories that drive labour productivity growth, including investment in tangible capital, or economic competences⁴, **R&I accounted for 15% of all productivity gains in Europe**, with large differences across Member States in the period between 2000 and 2013. **In Finland or the United Kingdom, R&I accounted for 50% and 40% of productivity gains respectively**, while in Hungary, Greece, Czech Republic or Slovenia, it accounted for less than 10%. In the United States, it accounted for one third of all gains (INTAN-INVEST and EIB, 2016)
- An increase in 10% of R&D investment is associated with gains in productivity between 1.1% and 1.4% (Donselaar and Koopmans, 2016). It should be noted that in absolute terms, an increase in 1.1%-1.4% in labour productivity is much higher than an increase in 10% of R&D investment. In the European case, for example, if there is no change in the amount of hours worked, an increase of 1.1% in labour productivity would represent an increase of 1.1% in GDP. In other words, an increase in R&D investment of 0.2% of GDP⁵ would result in an increase of 1.1% of GDP, **i.e. an increase five times bigger in absolute terms.**

These impacts on productivity and economic growth are mainly driven by positive and significant rates of return to R&I investment for firms investing in R&I:

- While there is a large heterogeneity of results depending of the particular study, the rate of return to investment, or the economic benefits that a firm gets when investing in R&D, in

² European Commission Communication (2014) 339 final, "Research and innovation as sources of renewed growth".

³ Labour productivity is in general defined as the total output produced in an economy divided by the total number of hours worked.

⁴ Investment in economic competences would include aspects such as training, organisation capacity through management and branding

⁵ The R&D intensity at the EU was 2.03% in 2015. Therefore, a 10% increase in R&D would represent 0.2% of GDP.

advanced economies is estimated to be in the 10% to 30% bracket. In other words, for every 100 euros a company invests in R&D, the *net* benefit it obtains is between 10 and 30 euros for every year the R&D investment is considered not to have become obsolete (Hall et al, 2010)

Regarding the impact of R&I on jobs, the empirical evidence is still inconclusive. R&I-enabled new technologies such as ICT, robotisation or Artificial Intelligence are expected to automate a large number of existing jobs and deeply transform others, potentially resulting in job losses (Frey and Osborne, 2017). At the same time, they will also create new job opportunities, as evidenced by **the creation of 400000 net jobs in technology and knowledge intensive sectors in Europe from 2008 to 2013** (European Commission, 2016d). This hints to the fact that R&I are supporting the creation of better, higher-quality jobs.

The impact of R&I depends on a broad set of place specific factors. Overall, reported economic impacts are average results presented in meta-data analyses, i.e. studies that compile and analyse a large set of specific empirical studies on the relation between R&D investments and economic growth. However, these can vary based on different specific factors: (1) **macroeconomic stability**; (2) **business environment, including the functioning of markets and the impact of a fragmented single market in the European case**; (3) **financial conditions**, (4) **availability of human capital**, (5) **economic structure and degree of international openness**; or (6) **distance to the technological frontier**, have all proven to affect both the levels of R&I investment and its productivity and thus, impact, on the economy.

As a result, the impact of R&I varies across countries and type of companies/sectors:

- The rates of return are estimated to be higher in the United States than in the EU 15, notably due to higher business sector investments in R&D and stronger public-private sector linkages in the US (Kokko et al, 2015) or because in larger countries R&D spillovers tend to remain within national boundaries (Donselaar and Kooopmans, 2016)
- The rates of return are estimated to be higher for those companies that proportionally invest more in R&D. For these companies in Europe, the rate of return is estimated to be 54%, i.e. for every 100 euros invested in R&D, the company obtains a net economic benefit of 54 euros (Hervás and Amoroso, 2016). Innovation at firm level is also considered to lead to better performance in terms of productivity with elasticities of the order of 0.25. In other words, if the sales of new products per employee raise by 10%, labour productivity rises by 2.5% (Mohnen and Hall, 2013)

The impact of R&I can also evolve over time. Recent data on the lack of progress in Total Factor Productivity growth in Europe suggest that the ability of R&I to impact on productivity growth may have temporarily changes giving rise to a "productivity paradox". In other words, for Europe there is evidence that the positive R&I-Productivity relationship has been broken and that the "Knowledge-Innovation" and diffusion machine has become dysfunctional (OECD, 2015).

This phenomenon can be explained by obstacles to the diffusion of innovation from productivity-leading companies, sectors and countries to laggards, which have led to a sharp slow-down in diffusion; barriers to the creation, entry and post-entry growth of new firms in productivity thriving sectors and a potential increase in negative R&I externalities. The celerity of change in the innovation process, the increasing complexity of innovations that require mastering several technologies and competencies, and the concentration of innovation benefits on a compact set of global leaders, all explain this slow-down in the diffusion of innovation. And all these factors affect negatively the productivity and impact of R&I investments.

Removing barriers to the faster diffusion of innovation brings forward a number of implications for the formulation of public R&I policies, both in terms of improving business conditions to enhance R&I investment and for the development and uptake of innovations, and in relation to public R&I investments. Traditionally, businesses aiming at engaging in R&I activities many times face four types of barriers: (1) *high risks and sunk costs*; (2) scientific, technological and market *uncertainty*; (3) *inability to fully appropriate* the results of R&I investment; and (4) unavailability of appropriate *financing*. **These barriers lead to the presence of significant market failures that result in R&I underinvestment** with regards to the socially desirable level due to the presence of significant **positive spillover effects** towards other firms that accrue from these investments. As a result, public R&I funding is justified. More precisely, due to positive spillover effects, the rate of return for an economy, also known as **the social rate of return, has been estimated to be much larger than the return a company achieves. This can be up to two to three times higher** (Frontier Economics 2014, Coe-Helpman 1995, Kao et al 1999).

In the current economic context and in view of the deep changes in today's innovation dynamics, the barriers to the creation and diffusion of R&I seem to be more pronounced and affect the whole research and innovation cycle, ranging from fundamental research to market-creating innovation. As a result, the role of public R&I seems more important than ever before, including in support of market-creating innovations, where Europe is particularly lagging behind. Traditionally, spillover effects were considered to be larger in terms of fundamental research. However, the increase of the network and scale effects brought about by the changing nature of innovation, together with increasingly rapid "creative destruction", can lead to important bottlenecks in R&I investments, notably in relation to the time and scale that are needed to ensure that market-creating innovations lead to the highest possible economic impacts for society.

The benefits of public R&I funding have been well documented, even if results are not at all times fully robust. Public R&I creates new knowledge, methodologies or enhanced skills that are crucial to facilitate innovation creation and the diffusion of innovations. Measuring the full impact of public R&I is complex given the nature, timing and multiplicity of its transmission channels- many of them indirect- through which the benefits accrue. In addition, existing methodologies continue to face a number of challenges to accomplish this task. Among the studies that have found positive effects using a variety of methodologies:

- Public R&D drives productivity growth. **An increase of 10% in public R&D results in an increase of 1.7% in Total Factor Productivity⁶** which in turn results in higher economic growth (Guellec and van Pottelsberghe de la Potterie, 2004). Some other studies, however, have not been able to find such a positive relationship using macro-econometric models.
- Some studies have calculated **the economic returns to public R&D to be around 20%**, i.e. for every 100 euros of public R&D invested, an economy expands by 120 euro, providing a *net* benefit of 20 euros, for every year the R&D investment is considered not to have become obsolete. (Sveikaucas 2012, Georghious 2015)
- Public funding of private R&D, via tax incentives, grants or financial schemes, seems to have a **positive leverage impact to increase business R&D investment**, although its role and impact are different and depend on the design and implementation (IMF, 2016).

In the EU context, in particular, the economic impact of EU funded research through the EU Framework Programmes, and notably of the 7th Framework Programme (FP7)⁷, reveal important positive economic impacts in sustaining economic growth and job creation. They also reveal the contribution of FP7 to building better conditions for private R&D activities across the EU. More precisely, FP7 has been estimated to contribute to an increase of 500 billion euros to GDP in a period of 25 years, the creation of 130000 research jobs in a period of 10 years and 160000 additional jobs in the broader economy in a period of 25 years.

Against this backdrop, **this paper concludes** that:

1. **The impact of public R&I funding is large and significant** as it acts as a catalyser to boost the productivity growth needed to accelerate economic growth and the creation of more and better job opportunities.
2. **Maximising the impact of public R&I funding will require the adoption of holistic strategies that enable faster and deeper innovation development and diffusion** across companies, sectors and countries that have been holding back the positive impacts of R&I in recent years. More precisely, improving the business environment in terms of market functioning,

6 -Total Factor Productivity measures the efficiency of an economy to combine all the different production inputs, e.g. labour and capital investment, in order to achieve a certain production level. It can include factors such as efficient functioning of the markets, effective regulation, technological development, sound business strategies, effective and transparent public institutions, that are many times difficult to capture by statistics.

7-This analysis of EU funded research through FP7 is intended as an illustration of the economic impacts of the European R&I funding scheme. Additional research on the impacts of public R&I funding at supranational level needs to be carried out. A more thorough analysis of the European Value Added of EU R&I funding programmes is under preparation as part of the Interim Evaluation of the Horizon 2020 programme and the preparation of the ex-ante Impact Assessment of the new R&I Framework Programme. It shall provide a wealth of data and analysis.

including measures to overcome the persistent fragmentation of the single market in Europe and make the R&I system increasingly open will be crucial. In addition, investing in human capital and ensuring appropriate financing are also important.

- 3. The implementation of public R&I funding should be well targeted to cover the whole research-innovation spectrum, including market creating innovations;** and channelled through the appropriate R&I instruments that need to be properly designed and implemented based on the local conditions that affect their effectiveness.

THE ECONOMIC RATIONALE FOR PUBLIC R&I FUNDING AND ITS IMPACT

1. Introduction

Research and Innovation (R&I) are crucial to address Europe's economic and societal challenges. They contribute to reaping the new growth opportunities generated from knowledge, technological breakthroughs, process and product innovations, and new business models that support economic performance and help tackling societal challenges by, for instance, improving health outcomes, fighting climate change and building inclusive and resilient societies⁸.

Our societies face multiple, complex and urgent challenges that affect the quality of life of our citizens: from energy efficiency to security, climate change or an ageing population. R&I plays a crucial role to anticipate and respond to these needs, in addition to boosting economic growth and new and better job opportunities, and support social prosperity and well-being. Economic growth needs to go hand-in-hand with societal progress in order to ensure a harmonious development. Therefore, a full understanding of the impacts of R&I needs to take into account both economic as well as societal impacts that support higher levels of well-being.

This paper focuses solely on assessing the economic impacts of R&I. Such analysis is partial and does not take into account the full breadth of the impacts of R&I, and public R&I funding. This is particularly important as much **public R&D does not focus on obtaining a direct economic return.**

From a policy perspective, assessing the economic impacts of R&I investments and the role that public R&I funding plays in supporting higher levels of innovation and economic returns has always been high in the agenda. Such assessment ensures public accountability and helps develop better evidence based policy action. This is particularly important in a context where public research and innovation policy is called to rapidly change as the opportunities that digital technologies bring about make science and innovation increasingly and swiftly more open, more collaborative, more inclusive, more interdisciplinary and more global. This is why the EU's research and innovation policy agenda focuses on supporting more Open Innovation, Open Science and more science and innovation that is Open to the World⁹.

In recent years, the need to get a better handle on the economic impacts of R&I and its determinants, including the role of public policies and R&I policy instruments for knowledge creation and diffusion has become even more important. This is due to the emergence in advanced economies and notably in Europe of the "productivity paradox": a period where the rise of several new and emerging technologies promising to revolutionise our economies and offer large productivity gains are confronted by stagnant or even negative rates in productivity growth.

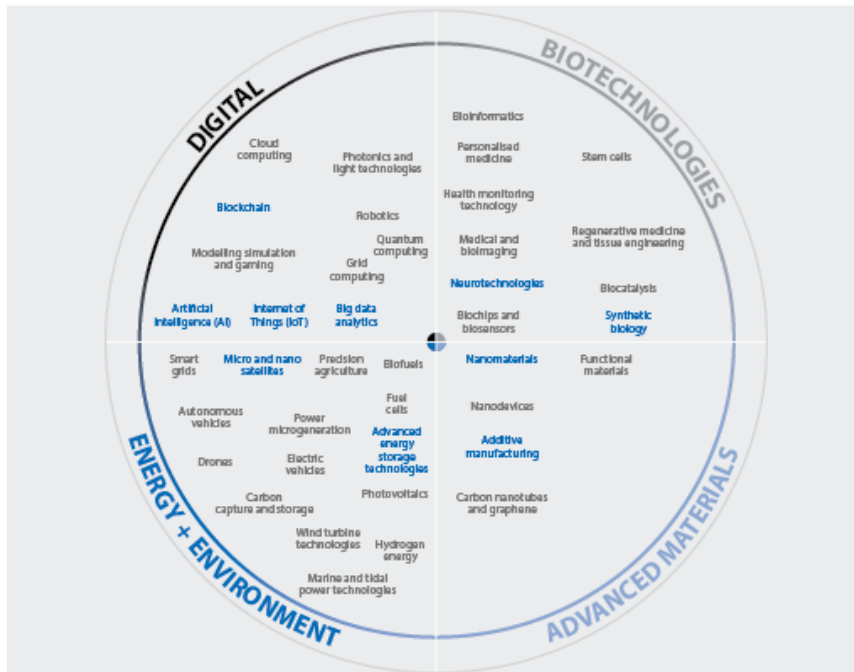
More precisely, since a few years, we are experiencing the rise of some key and emerging technologies such as the Internet of Things; Big Data Analytics; Artificial Intelligence; Neurotechnologies; Nano/Microsatellites; Nanomaterials; Additive Manufacturing; Advanced Energy Storage Technologies; Synthetic Biology or Blockchain¹⁰. These technologies are regarded as enabling or "general purpose technologies" that can generate significant disruptive innovations across different sectors and be mapped into four quadrants that represent broad technological areas: biotechnologies, advanced materials, digital technologies and energy and environment technologies.

⁸ European Commission Communication (2014) 339 final, "Research and innovation as sources of renewed growth".

⁹ For more information, please visit <https://ec.europa.eu/digital-single-market/en/news/open-innovation-open-science-open-world-vision-europe>

¹⁰ For a review of each of this key and emerging technologies, please see OECD (2016): "Science, Technology and Innovation Outlook, 2016) (p79-ff)

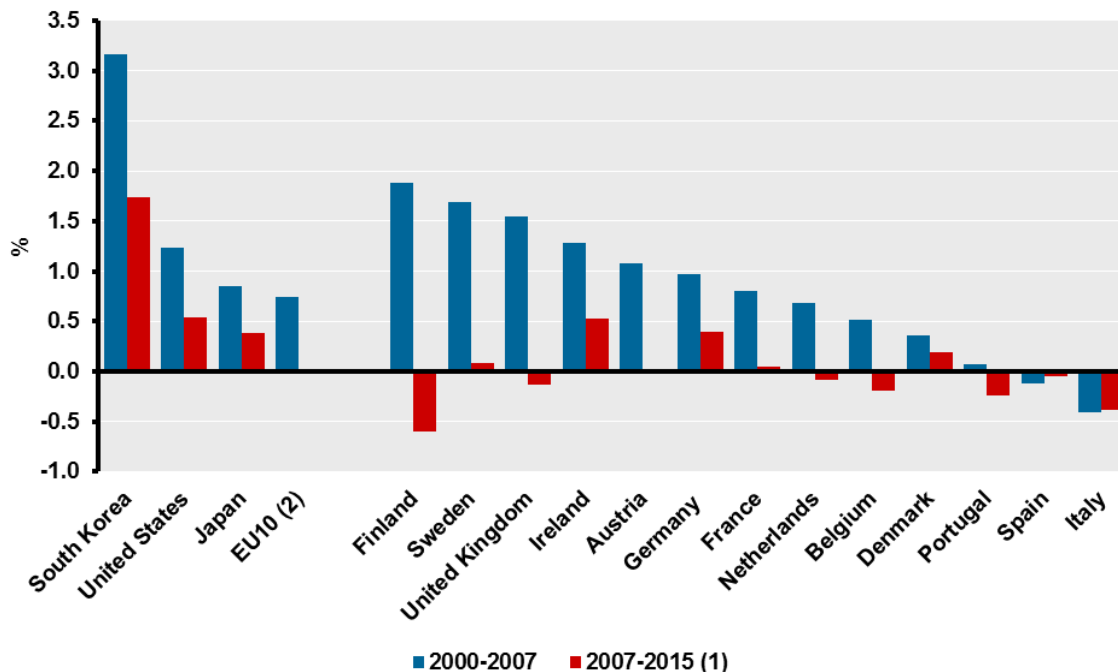
Figure 1: 40 key and emerging technologies for the future



Source: OECD, Science, Technology and Innovation Outlook 2016

However, at the same time, productivity growth, notably Total Factor Productivity, that has traditionally been associated with technological and innovation development, has been squeezed out, with very low growth rates that and in some cases has turned out to become negative. This process has been observed in several countries, including countries such as Finland, United Kingdom or Belgium, that have been significant investors in R&I.

Figure 2: Multifactor productivity - average annual growth (%), 2000-2007 and 2007-2015



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

Notes: ⁽¹⁾IE, ES, PT, JP: 2007-14. ⁽²⁾EU10: Multifactor productivity was estimated by DG RTD and includes BE, DK, DE, FR, IT, NL, AT, FI, SE, UK.

As a result of this "Productivity Paradox", some doubts have been casted about the role and impacts of R&I to support economic growth, and whether we are experiencing a period when the machine, many times categorised as a black box, that transformed R&D and knowledge creation into innovation and economic growth has been broken or become dysfunctional to achieve the positive economic returns of R&I investment of the past; and if so, what should be the role of public policy and notably of public R&I funding to fix this.

Against this backdrop and based on the existing empirical literature, this paper aims at (1) shedding some light into the relationship between R&I, economic growth and job creation; (2) the determinants of this relationship and its possible evolution; and (3) identifying the role and impacts of public policies, and notably of public R&I funding in this process, notably in the European context.

In doing so, the paper seeks to provide an answer to the following policy questions:

1. Is R&I investment important to sustain economic growth and job creation?
2. How important is R&I in the current economic context? What are the determinants of the impacts of R&I?
3. What are the impacts of R&I on jobs?
4. Do we need public R&I funding?
5. How should public R&I investment evolve in order to shape the emerging changes in innovation dynamics and ensure higher economic impacts?
6. How much public R&I funding do we need? What are the impacts of public R&I funding?
7. Is there a case for EU R&I funding? If so, how impactful is it?

The paper structures around these seven policy questions and in providing an answer, even if sometimes imperfectly, it aims at getting a better handle about the role of public R&I funding to support economic growth, the efficiency of public spending and its contribution in meeting socio-economic objectives.

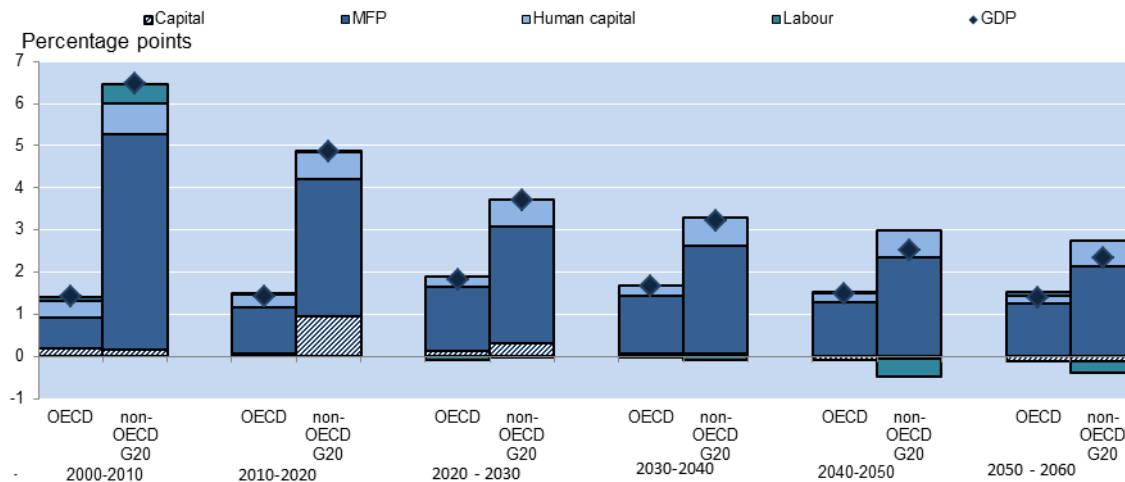
2. Is R&I investment important to sustain economic growth and job creation?

Economic and social prosperity has relied on the ability of countries to spur economic growth and job opportunities. Increasingly for Europe, this depends on its ability to raise productivity levels.

Economic and social prosperity in any given economy depends on its ability to grow and create new and better job opportunities. In order to grow, countries must mobilise increasing production resources, e.g. more labour, more land or more capital, and/or improve the efficiency of how these resources are combined and used in the production process, i.e. increase their productivity. In other words, in order to foster economic growth, economies must combine working more and doing it better or more smartly. In the EU, mobilising more production resources, for example by increasing activity and employment rates, while possible in some cases as Europe has not reached its Europe 2020 participation rate target¹¹, it may become increasingly difficult going forward, given demographic trends. In addition, the EU lacks access to abundant reserves of commodities, such as oil or mineral resources. As a result, economic growth in Europe increasingly relies on its ability to boost productivity growth.

Figure 3 presents long term economic forecasts produced by the OECD (2014). The calculations present a decomposition of economic growth by main drivers for both OECD and large emerging economies. The results show that for OECD countries, i.e. advanced economies, many of them in Europe, economic growth relies on the ability to boost productivity levels. Productivity accounted for more than half of the growth in the 2000-2010 decade, and is expected to account for about 80% by 2050. The contribution of other drivers, such as increased labour or capital investment is expected to remain very low, and sometimes even negative.

Figure 3: Contribution to growth in GDP per capita, 2000-2060 (annual average)



Note: The non-OECD G20 countries are Argentina, Brazil, China, India, Indonesia, Russian Federation, Saudi Arabia and South Africa.

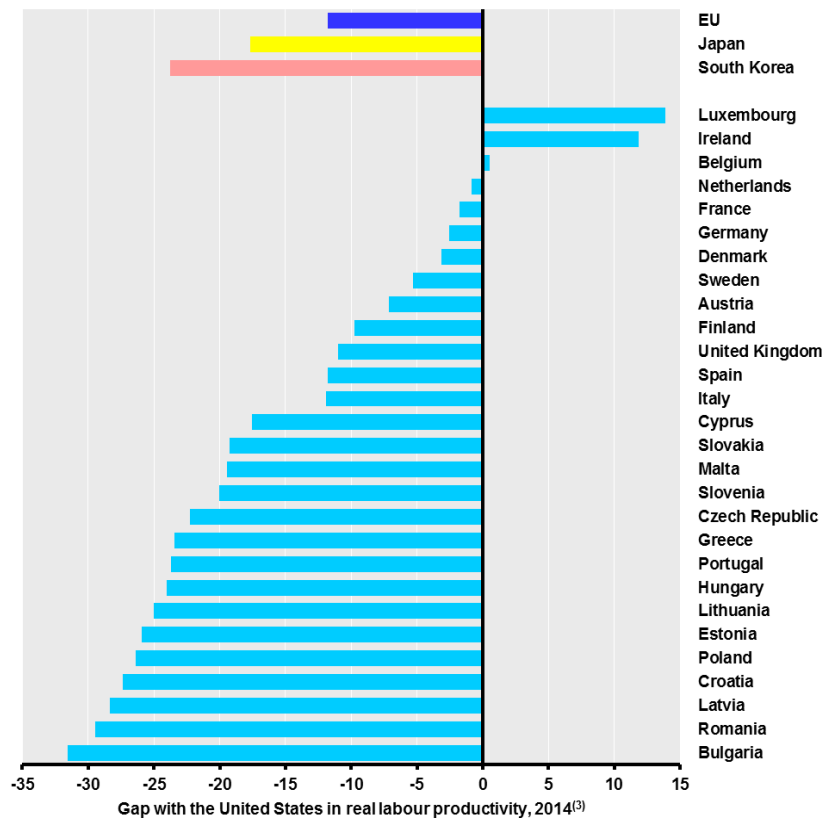
Source: Braconier H, Nicoletti G and Westmore b (2014), OECD.

¹¹ The employment rate is of 75% of the 20-64 years old to be employed by 2020. In 2015, this rate was of 70.1%

In recent years, labour productivity growth in the EU has stagnated and in some cases even turned negative, leading to an increased productivity gap vis-à-vis the United States. Raising labour productivity to boost economic growth remains a challenge

Despite the importance of productivity in boosting economic growth, labour productivity, i.e. the amount of economic output produced by an employee, remains lower for most EU Member States in comparison to the United States and the gap has been rising during the economic and financial crisis. More precisely, Figures 4 and 5 show that labour productivity in the EU is around 15% lower than in the United States and this gap overall has widened in the past years, despite some significant improvements for some countries.

Figure 4: The gap in real labour productivity (GDP per hour worked) between each country and the United States, 2015

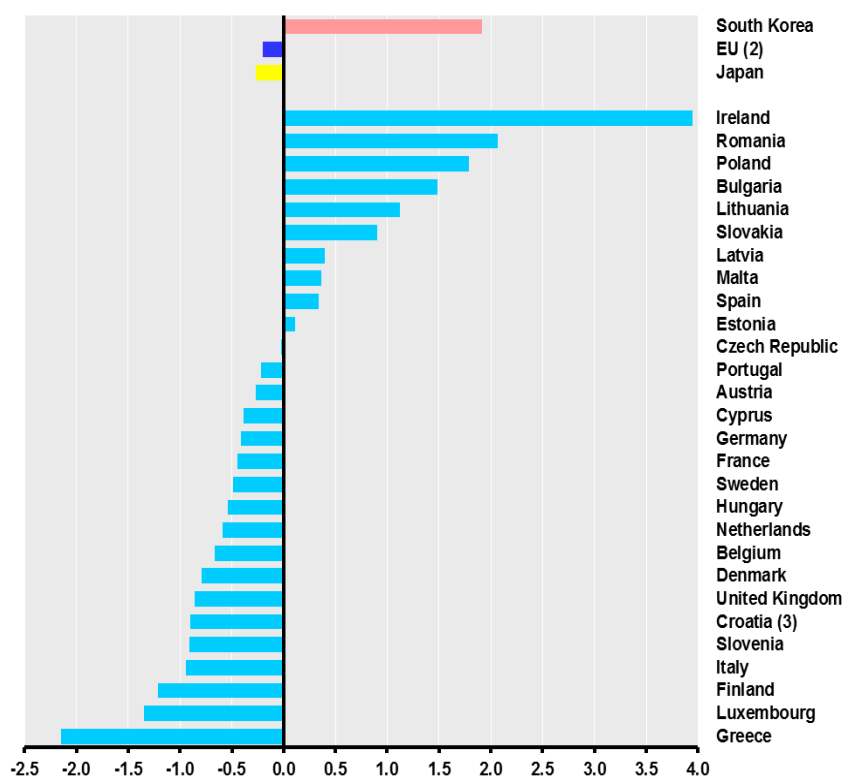


Source: DG Research and Innovation - Unit for the Analysis and Monitoring of National Research Policies

Data: Eurostat, DG Economic and Financial Affairs, OECD

Notes: ⁽¹⁾GDP per hour worked in PPS€ at 2010 prices and exchange rates.

Figure 5: The gap in compound annual real growth in labour productivity (GDP per hour worked), 2007-2015, between each country and the United States



Gap with the United States in compound annual real growth (%) in labour productivity, 2007-2015

Data: Eurostat, DG Economic and Financial Affairs, OECD

Notes: ⁽¹⁾GDP per hour worked in PPSC at 2010 prices and exchange rates. ⁽²⁾EU: Croatia is not included.

⁽³⁾Croatia: the gap between Croatia and the United States refers to 2008-2015.

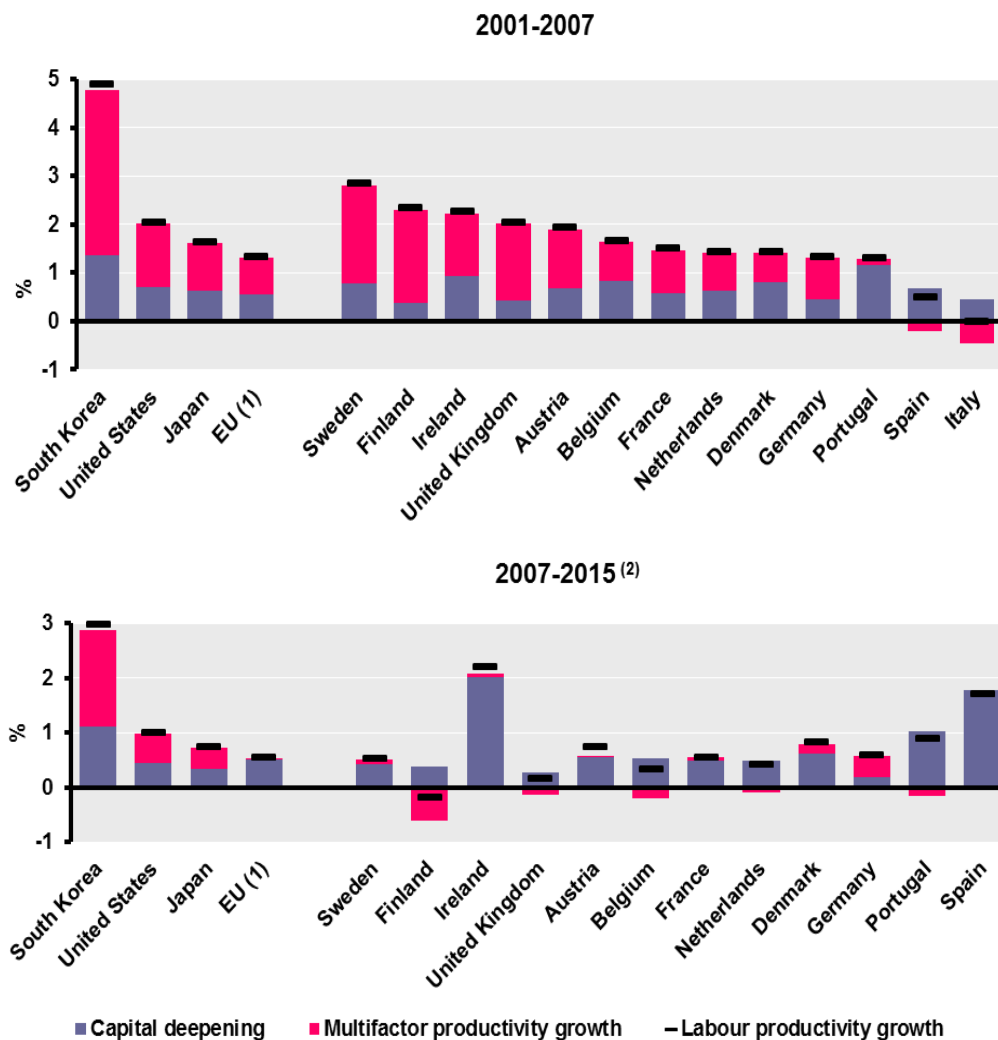
Low labour productivity growth is driven by low investment, notably in productivity enhancing assets, such as R&I.

Boosting labour productivity depends on the ability of an economy to increase the amount of capital available per worker, i.e. capital deepening, and on efficiency in the combination of production factors, i.e. multifactor productivity. Since the crisis, the levels of capital investment in Europe have been sluggish¹², and this has affected the ability of European economies to substantially increase the levels of available capital per worker¹³. In addition, multifactor productivity growth has sharply decreased, and even turned negative in many countries, such as Finland, United Kingdom, The Netherlands and Portugal, despite being one of the main drivers of economic growth from the beginning of the millennium until the crisis.

¹² Please, see EIB (2016) for a recent review of capital investment trends in Europe and the effect of the crisis on capital investment in Europe

¹³ The sharp increases in capital deepening in Ireland and Spain during the 2007-2015 period are mainly driven by a strong increase in unemployment that affected the amount of capital available per employee, but was not driven by significant increases in overall capital investments.

Figure 6: Contribution of capital deepening and multifactor productivity to average annual real growth in labour productivity



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

Data: OECD, DG Research and Innovation

Notes: ⁽¹⁾EU was estimated by DG Research and Innovation and includes: BE, DK, DE, IE, ES, FR, IT, NL, AT, PT, FI, SE, UK.

⁽²⁾IE, ES: 2007-2013; PT, JP: 2007-2014.

R&I can drive productivity growth.

Traditionally, R&I has been widely acknowledged to create and help using new and existing knowledge to generate new technologies, new products and services or new production techniques that can have a positive impact in raising the level of productivity of an economy. Box 1 presents a summary of the main diffusion channels by which R&I investment drives productivity growth.

Box 1: Role of R&I investment as a source of productivity growth

R&I is crucial to support the creation of new knowledge, techniques and technologies that support innovation

Investment in R&I result in the creation of new knowledge that is then used by research institutes and private companies to develop new technologies or techniques to develop innovation in the shape of new products, processes, organisation models or open new market opportunities OECD (2015).

In addition, R&I investment is vital to enhance the ability of research agents to absorb new knowledge that is generated elsewhere, i.e. improving the technology diffusion and utilisation for innovation.

R&I investment also allows an organisation or company to absorb faster and more efficiently existing knowledge that has been generated elsewhere that can then be transformed into innovation. The role of R&D in improving the absorptive capacity of firms has been widely documented in the economic literature (e.g. Cohen and Levinthal, 1989) and is regarded as one of the key benefits of engaging in this type of activities, even if they do not directly lead to a specific innovation outcome.

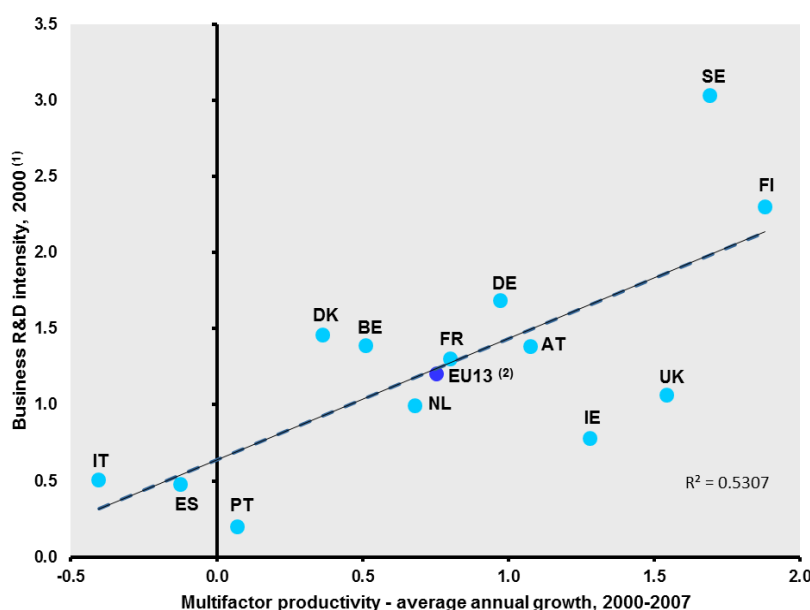
In turn, innovation, and the diffusion of innovation, is one of the main drivers of productivity growth and job creation.

The creation of new products or the implementation of new production techniques are crucial to raise the value of production and the efficiency of the production processes that are behind improvements in productivity. The speed in the launch of innovations, by putting together existing and new knowledge, and how it is diffused in the system, is a crucial factor that affects the final impact of innovation on productivity. This will depend on the specific characteristics of the innovation eco-system and the ability of knowledge producers and knowledge users to build a thick weave of knowledge flows (Crespi et al, 2008, Peri 2005). In addition, innovation is a key factor for the creation of new jobs in an economy. Companies that introduce new products, for example, are those that are able to remain competitive in the markets and generate new jobs (Peters 2016).

Empirically, a review of the main historic periods when the level of prosperity remarkably improved unveils the strong connection between productivity rises and technological advance, and technological advance and investment in science, research and innovation. From the development of the steam engine that enabled the industrial revolution of the 18th century, to the invention of electricity or the introduction of mass production techniques in the 19th and 20th centuries or to the development and deployment of Information and Communication Technologies (ICT) in the past fifty years, sharp rises in productivity, economic growth and levels of prosperity can be traced back to technological advancements.

As Figure 7 shows, there seems to exist a strong connecting between R&I investment, proxied in the chart by business investment in R&D, and multifactor productivity growth.

Figure 7: Business R&D intensity in Europe, 2000 versus average annual growth in multifactor productivity, 2000-2007



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

Data: Eurostat, OECD

Notes: ⁽¹⁾SE: 2001; AT: 2002. ⁽²⁾EU13: Multifactor productivity was estimated by DG RTD and includes BE, DK, DE, IE, ES, FR, IT, NL, AT, PT, FI, SE, UK

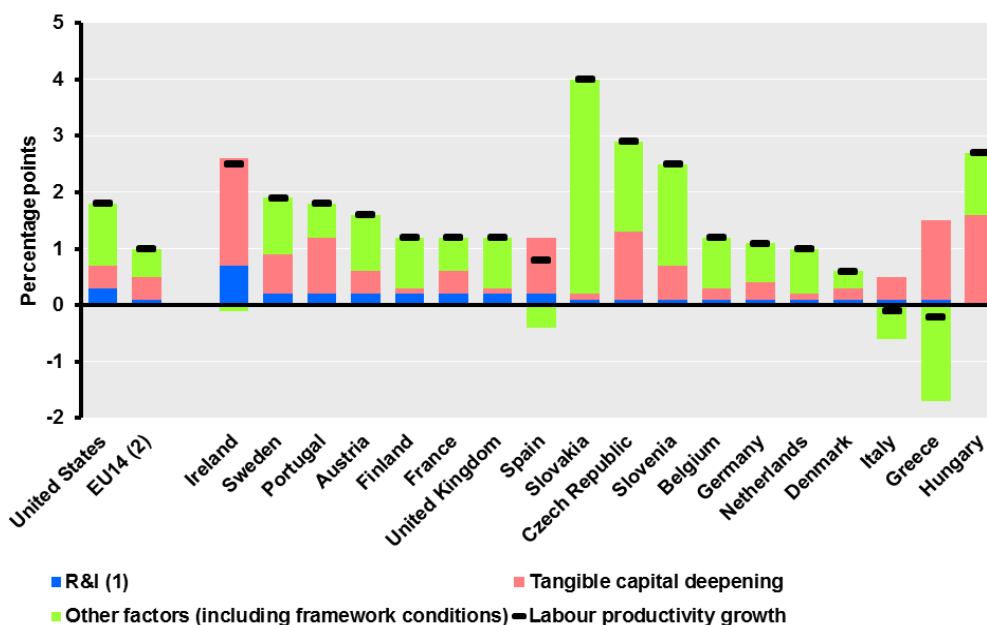
This positive relationship seems to be backed up by several empirical studies that have demonstrated the strong role of R&I as a driver of productivity and economic growth. Based on a broad definition of R&I, some studies have estimated R&I contribution to be of two-thirds of economic growth in Europe between 1995 and 2007.

Bravo-Biosca et al (2013) in a recent analysis of the composition of economic growth in Europe using growth accounting methodologies¹⁴ argue that Europe's economic growth between 1995 and 2007 has been driven by R&I broadly defined. In their study, they argue that innovation is driven by R&D investment, but also by other factors and investments that may be difficult to account for using statistical data, despite recent improvements for their measurement, and thus remains as "hidden innovation". As a result, the authors argue that R&I related investments should be responsible for that growth that is not accounted for due to investments in tangible assets, such as infrastructure or machinery for example, or an increase or improvement in the number or skills of employees.

A more restrictive definition of R&I, in terms of R&I investment, also shows its important contribution to productivity growth, accounting for 10% of all labour productivity growth for the 2000-2013 period, although with important national differences. For countries like Finland, the United Kingdom or Germany, it accounted for 17%. For Ireland, almost 30%

Based on a more restrictive definition of R&I¹⁵, and based on more recent data, the positive contribution is also estimated to be significantly positive, although lower than that estimated by Bravo-Biosca et al (2013). Using growth accounting methodologies, Figure 8 presents the contribution of R&I and other factors to labour productivity growth in a set of EU countries as well as in the United States during the 2000-2013 period. The results show that the largest contributor to labour productivity growth has been multifactor productivity gains that are not associated to higher levels of investment, but rather to better framework conditions. R&I investment, on average accounted for around 10% of labour productivity growth in the EU, while in the United States it was 17%. However, there are large national disparities. Notably for countries such as Finland, Germany and the United Kingdom, R&I accounted for 17% of all labour productivity growth, while in Ireland it reached almost 30%. By contrast, R&I played a minor role in driving labour productivity growth in countries such as Hungary, Slovakia and Slovenia.

Figure 8: Contribution of R&I and other factors to the growth of labour productivity in 18 EU Member States and the United States, 2000-2013



Source: DG Research and Innovation, based on data from INTAN INVEST and EIB (2016)

¹⁴ In the study, the authors use data from INTAN-INVEST

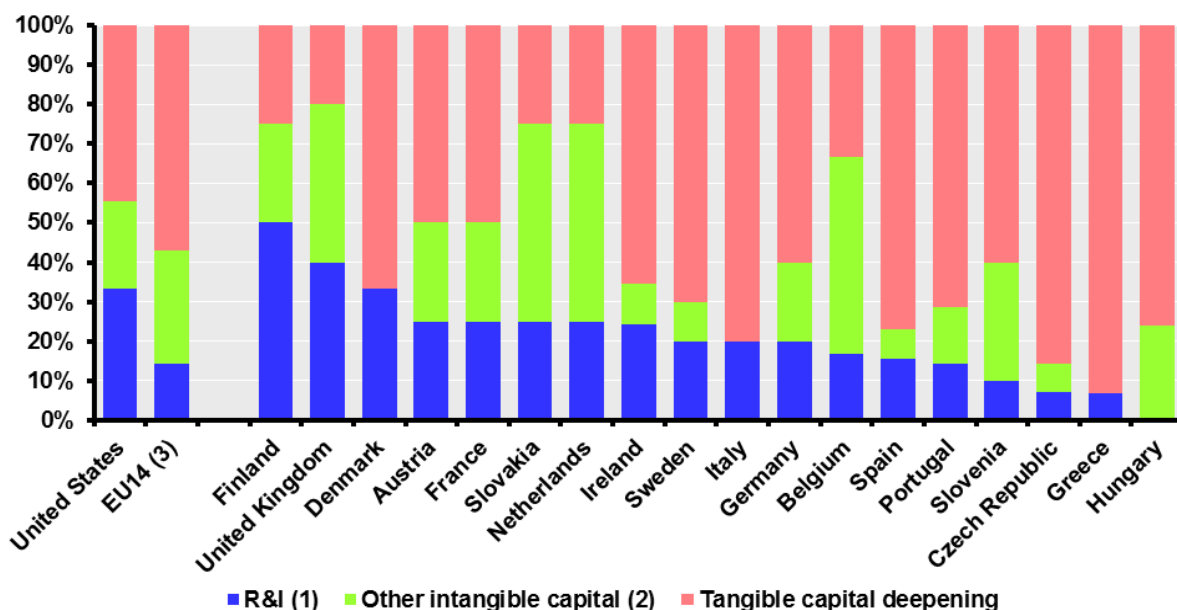
¹⁵ This definition of R&I included in the INTAN-INVEST project would include R&D investment, Design, New Financial products and minerals and artistic originals

Notes: R&I is defined as investment in R&D, design, New financial products and Mineral and artistic originals
EU-14 is a weighted average of all included EU countries except CZ-HU-SI-SK

This strong contribution of R&I investment to productivity growth stresses its crucial role as one of the key assets Europe needs to invest in to accelerate growth. Among all investment categories that contributed to labour productivity growth, R&I accounted for 15% of all gains. In the United States, this contribution was one third of such gains, and in Finland and the UK, it was even higher, 50% and 40% respectively

Improving labour productivity depends on many factors that include not only investment decisions. Structural reforms and sound company strategies that allow for a better re-allocation of resources to more productive activities played an important role. Among investment decision, companies and countries in general can invest in tangible capital, such as infrastructure, housing, machinery; and intangible assets, e.g. R&I, software, branding or organisational capacity.

Figure 9: Total investment by types of contribution factors to the growth of labour productivity in 18 EU Member States and the United States, 2000-2013



Source: DG Research and Innovation, based on data from INTAN INVEST and EIB (2016)

Notes: (1)R&I is defined as investment in R&D, Design, New financial products and Mineral and artistic originals.

(2)Other intangible assets include economic competences, branding, organisation capacity and training

(3)EU14 is a weighted average of all included EU Member States except, CZ, HU, SI and SK.

As Figure 9 shows, the importance of R&I in the total investment portfolio of a country to drive labour productivity growth in Europe is quite significant, notably in certain countries that have become increasingly knowledge intensive and that rely more heavily on R&I and other intangible assets to spur productivity and economic growth. This is particularly the case for countries like Finland or the United Kingdom, where R&I accounts for a large contribution in the overall investment portfolio to drive labour productivity growth. As more countries in Europe continue to shift their economic structures towards more knowledge-intensive activities, the importance of R&I is likely to continue increasing going forward

These results are consistent with the positive estimates found by several econometric studies that analyse the relationship between R&I investment and productivity and economic growth, although the values of the impacts tend to vary based on the used methodology and the period

of analysis. Overall, at the macro level, an increase of 10% in R&D is associated with gains in productivity between 1.1% and 1.4%¹⁶.

Using econometric modelling¹⁷, a large number of studies have aimed at calculating the impacts of R&I related investments¹⁸. The empirical literature has studied the impact of R&D investment on output growth, e.g. sales, value added, productivity and job creation; at the micro and macro levels. These studies¹⁹ have focused on measuring output elasticities, i.e. how a given output variable changes based on increases on R&D investment in a firm (micro studies) as well as measuring the impacts on output that spill over outside a firm to other firms in similar industries (meso studies) or other sectors of activity (macro studies).

A compilation of the results of several of these studies can be found in Donselaar and Koopmans (2016). The authors present 38 empirical studies, 17 at the micro level, 7 at the meso or industry level and 15 at the macro level, carried out for different industries and countries, including several EU Member States, the United States, China, Japan or South Korea, during different periods of time. In almost all cases, the impact of R&D investment to boost final output was estimated to be significant and positive. More precisely, for micro studies, i.e. studies at the firm level, output R&D elasticities²⁰ ranged from 0.02 (Los and Verspagen 2000) for a study of US companies, to 0.25 (Capron and Cincera, 1998) for a worldwide study. The mean output elasticity was estimated at 0.1. In other words, an increase of 10% in R&D investment in a company results in an increase in sales²¹ of a range between 0.2% to 2.5%, with a mean increase of 1%, depending on the specific cases.

At the macro level²², the mean R&D elasticity on productivity growth²³ was between 0.11 and 0.14, i.e. an increase of 10% in R&D in a country could result in an increase between 1.1% and 1.4% in productivity levels that would then result in higher economic growth.

Some other studies, while still showing a positive impact on productivity growth, have estimated lower impacts. More precisely, Comin (2004), using a different methodology²⁴ estimates that the contribution of R&D to productivity growth in the postwar US economy is not higher than 10%.

At the company level, empirical evidence shows that R&D investment yield positive returns. While the results are contingent on company, sector and national characteristics²⁵, research

¹⁶ It should be noted that in absolute terms, an increase in 1.1%-1.4% in labour productivity is much higher than an increase in 10% of R&D. In the European case, for example, provided that the same number of hours were worked, an increase of 1.1% in labour productivity would represent an increase of 1.1% in GDP. An increase of 10% in R&D at the current investment level would represent 0.2% in GDP terms, i.e. the increase would be five times bigger in absolute terms.

¹⁷ Much, if not all, the econometric modelling relies on a production function framework where the output of a firm, for micro studies, or an economy, for macro studies, is related to a stock of R&D or knowledge capital.

¹⁸ Most of these studies have focused on estimated the impacts of R&D investment as until very recently there were very few

¹⁹ These studies have focused on estimating these returns using production functions where a firm's output is determined by the amount of labour and capital that is used, in addition to the level of total factor productivity that is believed to be influenced by investments in research and innovation.

²⁰ In microeconomic studies, output elasticities refer to the increase in sales revenue or value added following an increase in private R&D investment.

²¹ In some studies, the output variable that has been used is value added instead of sales.

²² These estimates are based on a meta-analysis of output elasticities of own R&D using different econometric techniques, from basic OLS to OLS with equal weights for each study, including random effects or random effects with equal weights for each study.

²³ The studies used in the meta-analysis referred to output elasticities that in most cases referred to total factor productivity. Different studies have assessed these elasticities in different context, e.g. G7 vs non G7 economies, specific countries, and the elasticity value many times differ from case to case.

²⁴ Comin (2004) does not use a knowledge production function in his analysis. He uses a model where firms make zero profits from R&D in equilibrium.

²⁵ Calculating specific industry and country effects on the rate of return to R&D investment is many times challenging because most studies have focused on either particular countries, sectors and specific periods of time using similar, but not always comparable methodologies. There are some exception, e.g. Mairesse and Hall, 1994) who assessed the rate of return to R&D investment in France and the United States for the period between 1981 and 1989 and showed

has shown that these results are widely applicable and that could be averaged to around 10% - 30%, i.e. an investment of 100 euro in R&D would report a net benefit of 10 to 30 euro for every year the R&D investment is considered not to have become obsolete.

Building on the econometric analyses presented previously, some studies have gone a step further and besides calculating the output elasticities of R&D investment, they have also aimed at calculating the private rate of return²⁶ to these investments, i.e. the benefit companies achieve by investing in R&D activities. Studies, such as those carried out by Grilliches (1995) estimate the private rate of return to be of 27% for US companies, a value similar to the one reported by Hall et al (2010), who, based on a review of existing studies and for a broader set of economies, highlights that "the rate of return in developed economies during the past half century have been strongly positive, may be as high as 75% or so, although they are most likely to be in the 10% to 30% range (p24) and many times higher than the returns to physical investments (p33)". For example, Bernstein (1989) estimated that the rate of return on R&D in Canada was 2.5 to 4 times greater than those on physical capital. Other recent metadata studies (Ugur et al 2016) have also concluded that the rate of return to R&D investment is positive and probably around 14%, although they observed high heterogeneity.

The role of R&I to support economic growth by raising productivity has been theoretically argued and empirically assessed, although an accurate assessment of the level of the impacts is not universally agreed and can vary across countries, sectors and companies; and over time.

that the rate of return in France was of 75% and in the United States of 28% for that period using a more than 1000 firm sample in both countries.

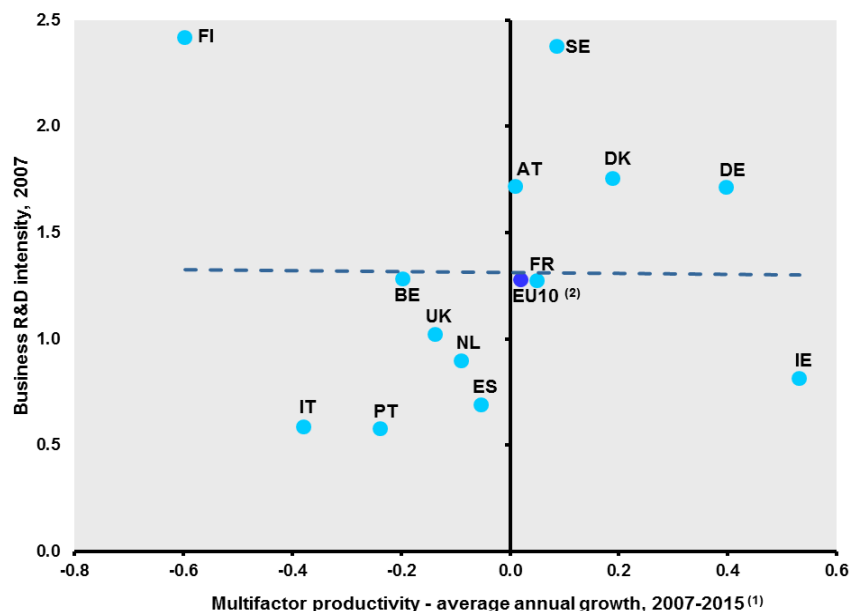
²⁶ The calculation of the private rate of return of an investment is normally calculated in micro-econometric studies as a multiply of the estimated elasticity by the average output R&D capital ratio in the sample. They normally need to estimate a measure of the depreciation or obsolescence rate of R&D in order to compute the net rate of return

3. HOW IMPORTANT IS R&I IN THE CURRENT ECONOMIC CONTEXT? WHAT ARE THE FACTORS INFLUENCING THE IMPACTS OF R&I?

As previously described, there has been a general slowdown in productivity growth in recent years, notably in terms of total factor productivity in Europe. This has casted some doubts about the strength of the R&I-Productivity nexus and the returns to R&I investment.

As previously shown, productivity growth has slowed down in Europe while investment in R&I, proxied by investment in R&D carried out by the business sector has remained relatively stable in most countries.

Figure 10: Business R&D intensity in Europe, 2007 versus average annual growth in multifactor productivity, 2007-2015



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

Notes: ⁽¹⁾IE, ES, PT, JP: 2007-2014. ⁽²⁾EU10: Multifactor productivity was estimated by DG RTD and includes BE, DK, DE,

FR, IT, NL, AT, FI, SE, UK.

This has casted some doubts about the strength and nature of the link between R&I and productivity growth described above. In other words, the "productivity paradox" suggests that the "Knowledge-Innovation" machine that supports productivity growth may be broken or dysfunctional, and thus, further analyses is needed to understand the reasons behind this phenomenon.

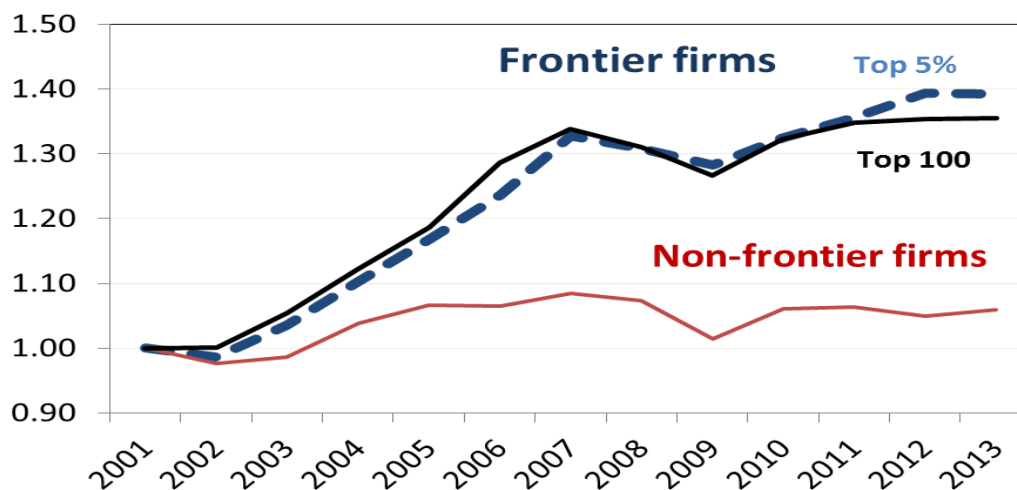
A more detailed analysis of recent productivity trends since the beginning of the millennium shows that the main drivers of the productivity slow-down in Europe can be traced back to potentially three interrelated factors: (1) a sharp slow-down in the diffusion of innovation from productivity leading to lagging companies; (2) an insufficient development of new firms in productivity growing sectors in Europe; and (3) a change in the nature of the innovation process that appears to have given way to the appearance of negative externalities on R&I, making this investment potentially less productive.

Recent analyses conducted by the OECD²⁷ have shown that much of the productivity slow-down around the world, and notably in Europe, is driven by an increasing gap in productivity growth between highly productive firms or "firms at the global frontier", whose productivity growth has remained robust since

²⁷ For more information, please refer to Andrews, Criscuolo and Gal (2013), and OECD (2015) on the future of productivity

the beginning of the millennium; and the rest of companies, that have been lagging behind. Figure 11 shows this increasing gap.

Figure 11: Comparing labour productivity: Global frontier firms vs non frontier firms



Note: 2001 = 1 (log points), average across 24 OECD countries and 22 manufacturing and 27 market services industries. **Global frontier has two definitions here (see two series on figures). Global frontier is defined as the 100 most productive firms within each industry and is defined as the 5% most productive firms within each industry, by each year.**

Source: OECD preliminary results based on Andrews, D., C. Criscuolo and P. Gal (2016), "Mind the Gap: Productivity Divergence between the Global Frontier and Laggard Firms", OECD Productivity Working Papers, forthcoming;

Data Source: Orbis database of Bureau van Dijk.

This rising productivity gap across different type of companies raises questions about the ability of technology and innovation to diffuse across companies and hint to the possibility of a shift in the nature of innovation. New technologies that are driving productivity growth seem to be first adopted by global frontier companies, while its diffusion to other firms is far from being automatic. This may be due to the fact that in some cases, new technology enabled innovations may require significant scale and benefit from important network effects and therefore being the first in the market can pre-empt or hinder the ability of other companies to enter or benefit from the technological development; or due to the increasing complexity of the technological diffusion process within and across sectors and countries. In this regard, the process of diffusion of these new technologies seems to follow a two-step approach: first, national frontier firms adopt them, and second, after testing and adapting them to the local context, they start diffusing them to laggard firms (Andrews et al 2013).

This is consistent with complementary findings that show that much of the R&I and productivity gap in Europe against the United States is driven by the fact that the EU has fewer young leading innovators (also referred to as "Yollies") that are most productive; and even more importantly, that these companies are less R&D intensive, which is largely explained by their different sectoral composition and the fewer number on high productivity growth sectors such as health or information technology (Veugelers and Cincera, 2010). More precisely, the annual average compound growth rate of productivity growth of frontier firms in the ICT sector was of 6.1% between 2001 and 2013, while in non-ICT sectors was of 3.5%²⁸ for the same period.

Finally, closely related to the potential shift in the nature and diffusion process of new technology enabled innovations, the weaker link between R&I and productivity may be traced back to a change in the nature of the innovation process and to the rise in negative R&D externalities, which cannot be excluded. More precisely, the celerity of change in the innovation process that makes yesterday's innovations obsolete today can lead to a speed up of the creative destruction process that does not allow sufficient time to reap enough benefits of R&D investment²⁹. In other words, a new good may functionally replace an

²⁸ Data calculated by the OECD following the productivity microdata project (<http://www.oecd.org/sti/inno/oecdinnovationmicrodataproject.htm>)

²⁹ This negative externality is described as the "creative destruction" factor

existing good, which would allow the new innovator to take advantage of the entire flow of rents, while the past innovator fails to get any further returns (Jones and Williams, 2000). In addition, multiple firms can run in parallel similar research programmes to develop a new product, service or business model, in the hope of being the first to launch and benefit from the innovation. This leads to a duplication of R&I investments, while only one company may benefit from the returns to those investment, either because they will benefit from a patent, or because of the scale and network effects associated to many of the new innovations. In other words, there is a concentration of benefits on a limited set of companies that benefit from the innovation to a very large extent, without adequate fast diffusion of the resulting benefits to other potentially innovative firms. In this regard, Autor et al (2017) sketch a "superstar firm" model where industries are increasingly characterised by "winner takes most" competition, leading a small number of highly profitable firms to benefit from growing market shares. In addition, the complexity of the new technologies and innovation processes may lead to what it has been denominated as "erosion effects", where technological adoption is slower and requiring complementary investments, such as in human capital. All these factors can affect negatively the productivity and impacts of R&I on the economy.

This analysis indicates that the impacts of R&I cannot be analysed in isolation, but on the contrary, that they are dependent on a set of factors that influence their strength and that can evolve over time. Macroeconomic stability, framework conditions and economic and technological structure are some of the factors influencing innovation creation and diffusion and therefore the impacts of doing R&I.

Against a backdrop of slower technology and innovation diffusion in the economy across companies, sectors and countries, and a potential shift in the nature and pace of innovation with a potential increase of negative externalities, accurately assessing the impacts of R&I requires identifying the specific conditions that influence the results of R&I. As demonstrated by a large empirical literature, macroeconomic stability, existing framework conditions, economic and technological influence both the level of R&I investment and its impacts. Here below there is a summary of some of these factors:

- Macroeconomic stability

Macroeconomic stability, with supportive fiscal and monetary policies that can help dampen recessions and close the economic slack can play an important role in promoting both higher R&I investment in areas such as R&D or ICT (Aghion et al 2014, Aghion et al, 2015, Fercuri and Jalles, 2017) and better conditions for the diffusion of innovation.

- The regulatory framework

Product and labour market regulations, levels of competition, openness to trade, appropriate fiscal policy or protection of Intellectual Property Rights, bankruptcy laws and a strong institutional set-up have been widely empirically analysed (European Commission 2017, Andrews et al, 2013, Mohnen 2017) in terms of their effects on R&I investment and the impact they can have on firm and industry productivity. In general, while the relationship tends not to be linear and many times follows an inverted U-type shape, rigidities in product and labour market regulations affect negatively R&I investment levels and the ability of innovation to diffuse and foster productivity through the rise of new innovative and disruptive companies and the inability to get rid of low productivity firms (also referred to as "zombie firms").

In the European case, continued fragmentation of the single market also affect the ability to benefit from a more innovation-prone regulatory environment that can foster R&I investment and the adoption and diffusion of innovation.

- Financial conditions

Financial condition and the availability of sufficient specialised financing schemes, such as venture capital, can help channelling available financial resources into R&I activities that can help innovation creation and diffusion. In this regard, empirical evidence has shown that venture capital accounted for 8 percent of industrial innovations in the decade ending in 1992 (Kortrum and Lerner 2000) and that recent entrepreneurial surveys, such as the one carried out by European Investment Bank, have continued emphasising access to finance as one of the main handicaps to engage in R&I, despite the ultra-accommodative monetary policy that Europe is experiencing.

- Availability of human capital

Innovation adoption and diffusion requires the complementarity of different investments, notably the availability of high quality human capital and skills that can help the absorption of innovation. Kahn et al (2010), Piva and Vivarelli (2007) or the European Commission (2017) have shown the positive impact of skills accumulation and innovation.

- Distance to the technological frontier

R&I investment is important to boost innovation creation that shifts the levels of the production frontier as well as ensuring higher levels of absorption capacity. Griffith, Redding and Van Reenen (2014) showed empirically that the estimated rate of return of R&D investment varied depending to the distance to the technological frontier, and that returns could be higher for those countries that may be further out from the frontier because of the higher impact in terms of supporting higher absorption capacity. Goñi and Maloney (2014) found that the relationship R&D and productivity probably followed an inverse-U shape as beyond a certain point, the gap is too high for firms to be able to catch up and absorb further and transform it into higher productivity enhancing products, services or processes.

As a result, R&I impacts need to be better nuanced as they vary across countries, sectors and type of companies, and evolve over time.

While assessing cross-country R&I economic impacts can be challenging due to the difficulty of isolating the effect of specific factors that co-evolve and influence both investment and impact levels and the use of different methodologies and model specifications, some studies such as Kokko et al (2015) using a meta analysis of studies across 49 countries have shown that the rate of return is lower in EU15 than in the United States, while there are no significant differences among EU 15 Member States.

At the micro level, the rate of return of R&D intensive companies tends to be higher than those companies that invest less in R&D. In Europe, it could be up to 54%, i.e. a net benefit of 54 euros for every 100 euros invested. In recent years, new databases including longer time series and detailed data at the company level, have allowed us to expand our current understanding of the impacts of R&I investment on the productivity and efficiency levels of a company for particular types of companies. In a recent study, Castellani and Schubert (2014) using the EU R&D Scoreboard panel data, i.e. a database of the most R&D intensive companies in the world, found that the effect of R&D investment driving labour productivity in these companies is very high, as it accounted for 83%, 64% and 54% of the labour productivity increases in those companies based in the United States, Japan and the EU respectively. Moreover, these results are particularly high in technology intensive sectors, and for companies with high levels of past R&D investment (Hervás and Amoros, 2016).

The economic impacts of R&I largely depend on the framework conditions, economic and technological structure and they can evolve over time based on the nature and pace of innovation and its ability to diffuse across countries, sectors and companies.

4. WHAT ARE THE IMPACTS OF R&I ON JOBS?

R&I-enabled new technologies such as ICT or Artificial Intelligence are deeply transforming the workplace and the job market in several industries and countries.

Job markets and skills requirement are being deeply transformed due to technological change, and this trend is like to continue. In many industries and countries, the most in demand occupations or specialities did not exist 10 years ago (World Economic Forum, 2016). McLeold et al (2016) have estimated that 65% of children entering primary school today will work in job types that do not exist today.

These technologies are likely to automatise out a large number of existing jobs and deeply transform others. At the same time, they will also create new job opportunities. As a result, the relationship between R&I and total level of employment is yet unclear.

At the macro level, the relationship between R&I and overall levels of employment is inconclusive. As described by Aghion and Akcigit (2015), innovation-led growth can have three counteracting effects on job creation:

- Job destruction driven by the loss of employment in existing companies that are forced to shrink or exit the market due to new firms;
- Job creation by (new or existing) innovative firms that expand their activities and thus need more employees;
- Job creation by the fact that innovation implies higher growth and thus more activity or output? of higher value is being produced.

In other words, the deployment of new technologies that render production processes more efficient and less labour intensive has a negative impact on displacing jobs in the economy. On the other hand, R&I and new technologies are also responsible for creating new job opportunities as part of the process of destructive renewal of an economy, and where innovative companies produce more and better job opportunities. The final result on the net effect of new technologies on the creation of new jobs is not a priori clear. The nature of the relationship may not necessarily be linear or in the direction (either positive or negative), and this may change over time. In other words, there is still not clarity about whether technology and innovation destroys jobs, perhaps in a first phase, and whether afterwards, it creates more and better jobs and how long and under which conditions, this process may occur.

Despite this lack of sufficient empirical evidence, at the macro level, some technology and knowledge intensive sectors have generated, and are expected to continue generating, new jobs

In addition, at the aggregate level, employment in knowledge-intensive activities, which are those where the role of R&D and other innovation-related activities is crucial, accounts for more than 33% of total employment in Europe. Perhaps more importantly, during the economic and financial crisis in Europe, jobs in these areas grew from 28.9 million in 2008 to 29.3 million in 2013, i.e. an average annual growth rate of 1.7%. This occurred during a period when the overall number of jobs in Europe decreased by a 2.7%, reinforcing the idea that innovation stimulates employment in Europe (Peters 2016). In addition, some estimates indicate that in Europe, we will have 900000 vacancies in the ICT industry alone by 2020 (European Commission, 2013).

At the micro level, companies that introduce innovative products are those that create more jobs. In manufacturing, the creation of new products has been estimated to generate between 30% and 40% of the next employment in this sector for four EU countries³⁰. It should be noted, however, that these positive effects at the company level may be cancelled out due to job losses in other companies when analysed from a macro perspective.

What seems to be clear is that part of the creative destructive process is taking place in Europe and companies that introduce new products are creating new jobs. The vast majority of empirical evidence on the impact of R&D and innovation on employment at the firm level suggests positive impacts, particularly

³⁰ Harrison et al (2014)

for some types of innovation. Firms which introduce innovative products grow faster and create more jobs. A firm level analysis for France, Germany, Spain and the UK conducted by Harrison et al. (2014) finds that product innovations create more employment due to the demand effect than is destroyed due to the productivity and substitution effect between the old and the new product. More precisely, these new products increase employment by around 3–5 percentage points in manufacturing, roughly between 30% and 40% of the net employment created by these firms (Harrison et al. 2014). Van Roy et al. (2015) also investigate the relationship between innovation activity and employment using panel data of European patenting firms over the period 2003-2012. The authors also found a positive relationship between innovation and job creation, although this was mainly significant for high-tech sectors.

R&I and the rise of new technologies and business models will have an impact of jobs. It is still unclear whether technology will destroy or create new jobs, but it is clear that many jobs will be thoroughly changed and can become increasingly productive.

5. DO WE NEED PUBLIC R&I FUNDING?

The empirical evidence presented above supports the positive impacts of R&I both for a company and the country. Positive rates of return to private investment in R&I suggest that these are profitable investments businesses would follow. Against this backdrop, given those positive results, do governments need to provide public R&I funding? Why?

Despite the positive effects of R&I investment, many times, business R&I investment remains low because companies face important barriers that hinder investment³¹.

In general, a company adopts its investment decision based on a cost-benefit analysis where the expected benefits are larger than the costs associated to the investment, providing a positive economic return. All investment decisions require engaging in a set of financial (e.g. payment of salaries, materials, financing) and economic (e.g. opportunity) costs and accepting a risk in terms of the expected result that this investment will yield. While accurately estimating the financial and economic costs, the level of risk and the expected returns is difficult for all type of investments, in the case of R&D, these difficulties become even more pronounced. In general, some of main bottlenecks that are associated to the specific nature of R&I investments are:

- 1. Uncertainty concerning the return to investment: Scientific, technological and market risks.** R&D systematically involves entering unexplored fields, which requires testing and verifying multiple options, and often implies failures. For instance, according to a comprehensive study concerning development of new medical drugs,³² a company engages in research in thousands and sometimes millions of compounds that fail (more than 80% of the molecules initially investigated); and even then, the overall probability of clinical success is estimated to be less than 12%.³³ Moreover, even if the R&D activities can be concluded successfully, sometimes the newly developed product/process/technology turns out to be commercially unviable, which adds to the risks and uncertainties related to investments in R&D.³⁴
- 2. Relative high investments combined with high sunk costs and long time lags before payback.** Ensuring critical mass in terms of knowledge and skills accumulation is often a precondition for achieving any meaningful R&D results. This can lead to large upfront investment requirements with high sunk costs and thereby high risks. In addition, the time lapse between investing in R&D and yielding any economic returns can be long (and difficult to estimate *ex ante*). For instance, in the pharmaceutical sector, the cost of developing a new drug is estimated to be around USD 2.6 billion³⁵, and the process to bring a new chemical compound into a new drug in the market is very long (going from basic research to drug discovery, pre-clinical trials, clinical trials, regulatory reviews and finally the market launch). This process has been estimated to last 17 years in the UK.³⁶
- 3. Inability to fully appropriate the results from investment in R&D**

The outcome from R&D activities is typically hard to codify as it may be ideas or information, many times embedded in people, not easily transferable, non-rival and non-excludable, i.e. potentially used by different agents, which makes it difficult to be fully protected. A company may struggle to fully appropriate the benefits from own R&D as positive externalities and knowledge

³¹ For more information on bottlenecks to investment in R&I and other intangible assets, please see the LIME note on "Intangible Assets: Barriers to investment in intangible Assets" (European Commission, 2016b)

³² Full information about the study and the estimates see Tufts Centre for the Study of Drug Development (2014).

³³ Note that the scientific and technological risk varies depending on the nature of the R&D activity the company performs.

³⁴ For instance, the Beta format for videocassettes proved to be technically superior, but did not manage to beat the VHS format, partially due to a misjudgement of the home video market, which did not develop as anticipated.

³⁵ PhRMA (2015): Biopharmaceutical Research and Development: The progress behind new drugs.

³⁶ Wellcome (2008): "Medical research: what's wrong? Estimating the economic benefits from medical research in the UK"

spillovers are common (IMF 2016a,b), i.e. it is difficult to deter others from benefiting / freeriding. Legal frameworks ensuring the protection of intellectual property rights, such as patents, brand and design protection, are important but often remain insufficient to ensure full appropriation of the potential benefits.³⁷

4. Lack of financing

The private capital sector sometimes lacks the ability to understand or assess the risks these investments may entail given the level of scientific and commercial uncertainty, or the capacity to support investments through prolonged periods of time before they can yield positive returns, e.g. scaling up new innovative companies, rolling out new technologies, launching a new software programme in the market. Therefore, even if these investments can ultimately result lucrative, there is a lack of financing for them.

5. The existence of spillovers implies sub-optimal private R&D spending

Closely related to the inability of a private firm to appropriate fully the return of its investment in R&D is that they can yield positive externalities due to spillover effects. In other words, the benefits in terms of creation of new ideas, technologies or skills are also positively felt by other firms in the same industry or in an economy more broadly, which can use these ideas, technologies or skills to develop or apply new technologies or innovations.

Many of these barriers are persistent in Europe to support investment in R&I and other intangible assets as demonstrated by a recent large survey carried out by the European Investment Bank, as presented in Box 2.

Box 2: Long term investment barriers in intangible assets and investment finance. Results accruing from the European Investment Bank's Annual Investment Survey³⁸

Given the importance of a better understanding of investment and investment finance needs and constraints and the changing nature of innovation and its influence on productivity and economic growth, the European Investment Bank runs an annual Investment Survey, which collects unique qualitative and quantitative data from 12500 Small and Medium-sized and larger non-financial companies in all 28 EU Member States³⁹. The data covers information of firm characteristics and performance, past investment activities and future plans, sources of financing and challenges that businesses face. In this regard, this box presents some results accruing from this Survey that highlight the nature of some of the main barriers that companies face to engage in investment in R&I and other intangible assets, as well as the sources of investment finance⁴⁰.

It is vital for effective policy-making to understand the constraints that hold back investment, and in particular if long term barriers are more (or less) severe for firms that invest more in intangibles.

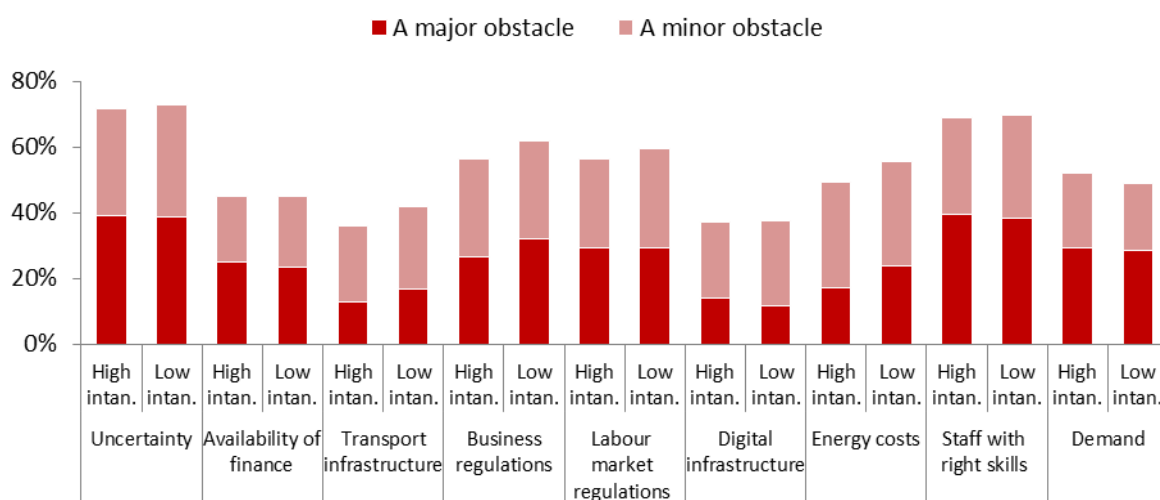
³⁷ Cohen, Nelson and Walsh (2000) pointed out that firms typically rely on range of measures to protect their invention-related benefits, including patents, secrecy, lead time advantages and complementary marketing and manufacturing capabilities.

³⁸ The full results of the EIB Investment Survey will be published in March 2017 in a publication called "EIBIS 2016/2017 – Surveying Corporate Investment Activities, Needs and Financing in the EU "

³⁹ For more information on the EIB Investment Survey, please, check <http://www.eib.org/about/economic-research/investment-survey.htm>

⁴⁰ Intangibles include R&D (including the acquisition of intellectual property), software, data, IT networks and website activities, training of employees, and organisation and business process improvements.

Figure A: Long term investment barriers for firms, by intangible investment intensity⁴¹



Question: Thinking about your investment activities in your country, to what extent is each of the following an obstacle? Is a major obstacle, a minor obstacle or not an obstacle at all?

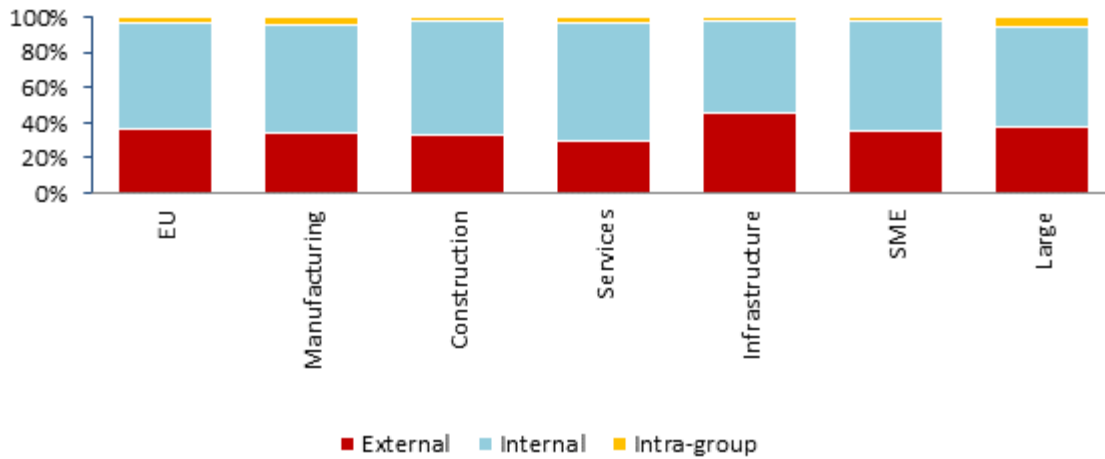
EU firms consider uncertainty about the future and availability of staff with the right skills as the main structural barriers to investment, with more than two third of the firms considering them to be obstacle to their investment activities. The majority of EU firms also consider that business regulations (e.g. licenses, permit, and bankruptcy) and taxation, labour market regulations, and energy costs are also important long term investment barriers. Comparing firms with high intangible investment intensity with those with lower intangible intensity allows us to identify whether some obstacles are more severe for these firms. Firms with *high* intangible investment intensity are more likely to report that demand conditions are long term obstacles to their investments, while they are slightly less likely to consider that the availability of adequate transport infrastructure, business regulations, labour market regulations, and energy costs are long term investment constraints (Figure A).⁴²

Another aspect that is particularly relevant for public policy to relaunch productive investment in the EU is to better understand how firms finance their investment. Firms in the EU rely to a large extent on internal funds (60%) to finance their investment activities, while external finance represents only 36% of investment finance (Figure B). However, there is some variation across sectors and infrastructure firms (46%) are more likely to rely on external funds. The share of external finance also varies across countries: firms in France (53%), Italy (45%) and Spain (43%) are most likely to rely on external finance, while those in Greece (18%) and Malta (20%) are least likely to rely on it.

⁴¹ Firms with high intangible investment intensity in Figures A and C are defined as firms that invest 50% or more in intangibles. There are 35% of firms in the EU that invest a majority of their investment in intangibles. The results are similar when using a different threshold to define high intangible investment intensity.

⁴² These results hold in a regression controlling for country, sector, firm size and firm age.

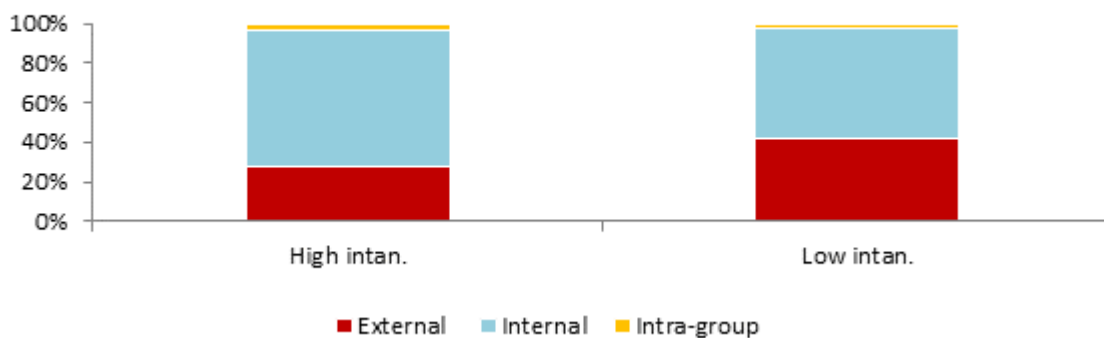
Figure B: Sources of investment finance



Question: Approximately what proportion of your investment in the last financial year was financed by each of the following? Base: All firms who invested in the last financial year (excluding don'tknow/refused responses)

Firms who invest the majority of their investment in intangibles tend to rely less on external finance, with a share of only 27%, compared to those with lower intangible investment intensity (whose share of external finance is 42%, Figure C). The lower use of external finance is also associated with higher dissatisfaction with available opportunities. Firms who invest more in intangibles are more likely to report that they are dissatisfied with the external finance conditions, particularly for the cost of funding and collateral requirements.

Figure C: Source of investment finance, by intangible investment intensity



On a policy perspective, improving the operating environment remains a clear milestone, reducing uncertainty and focusing on improving education and skills on a broad basis. Some policy measures could be developed to increase the sources of external finance for firms who invest more in intangibles. Bank loans are the most common source of external finance, particularly for the services sector. Leasing is also a common type of external finance, particularly in the infrastructure sector. The Capital Market Union project aims at increasing the opportunities for more diversifications in firms financing sources, also via non-bank products. Additional measures to be considered include more resources related to guarantee products and/or development of an effective collateral infrastructure also for intangible assets.

Underinvestment in business R&I can have a negative effect in society because the social rates of return, i.e. the overall net benefit for society, have been estimated to be higher than

the private returns due to the presence of positive spillover effects. Therefore public intervention is justified in order to ensure a social optimum investment level.

There is extensive literature proving that the social returns to investments in R&D, i.e. the overall benefits for society, are higher than the private ones, thus justifying public intervention to address the corresponding market failures, e.g. by public investment in R&D or support for private R&D.⁴³

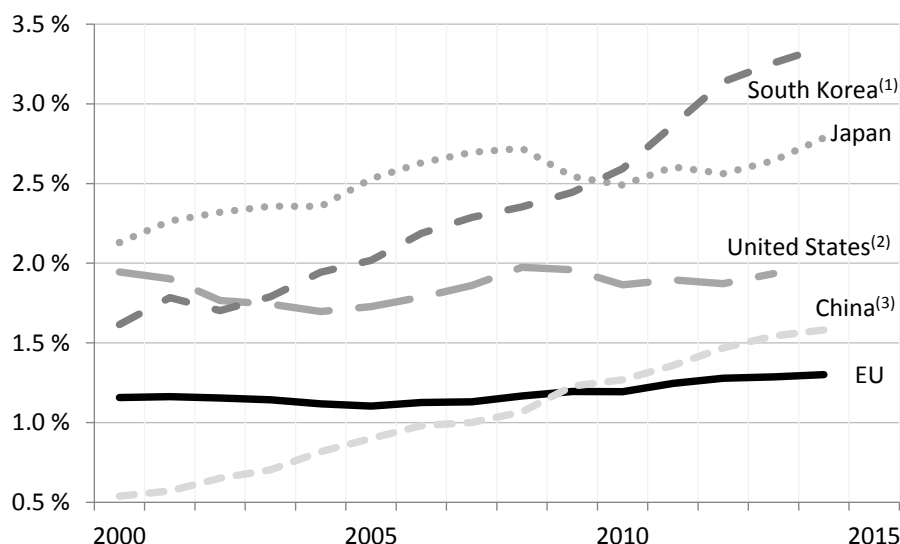
The social rate of returns to R&D investment has been estimated to be large, and many times exceeding the private return rates (Mansfield et al 1977). Sectoral studies in particular industries and innovations have shown significant social returns. For example, in a study of 17 industrial innovations, Mansfield et al (1977) estimates a social return of 56% (in comparison to a private return of 25%). Trajtenberg (1989) estimates the capitalised benefit/cost ratio of R&D investment in CT scanners to be of 270%.

In addition to these specific case studies, the social rate of return has also been estimated at the aggregate level following growth accounting techniques. Several research studies have used this methodology to estimate the spillover effects within an industry, across industries and internationally and the calculation of the social rate of return. While comparing the results is many times difficult due to the definition and calculation of different spillover effects and the results vary largely from study to study, most have unequivocally calculated a large and positive social rate of return for different countries and analysis periods. Some examples of these calculations are covered in the works of Mohnen (1990), who calculates a social rate of return of 29% for Canada; Coe-Helpman (1995), who estimate a social rate of return of 32% for 22 countries, or Kao et al (1999), who calculate a social return average of 29% for 22 countries. A recent study estimated the social rate of return to be two to three times larger than private R&D for the UK (Frontier Economics 2014)

Private R&D investment in Europe has remained low in comparison to other advanced economies, suggesting that Europe is not suffering from overinvestment.

Despite the recent efforts and political commitment to increase R&D investment by creating right conditions for this to flourish, R&D investment rose just slightly over 2% in 2015, well below the 3% R&D target, with the public sector accounting for 0.72% and the private sector for 1.31%. Private investment is significantly lower in comparison to other advanced economies, such as the United States, Japan, or South Korea, where it reaches 1.94%, 2.79% and 3.36% of GDP.

Figure 12: Evolution of Business R&D intensity, 2000-2014



Source: DG Research and Innovation, based on Eurostat and OECD data. Business R&D spending in %-age GDP

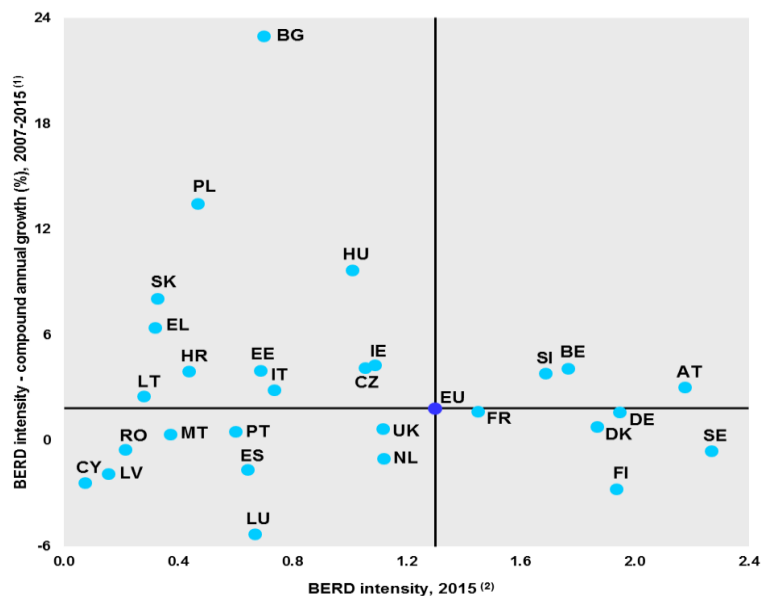
Notes: Business R&D intensity measured as business R&D expenditure in % of GDP. (1) South Korea: break in the series between 2007 and the previous years. (2) USA: Business enterprise expenditure on R&D (BERD) does not include most or all capital expenditure. (3) China: break in the series between 2009 and previous years.

⁴³ See for instance Mansfield et al (1977), Hall and Lerner (2009).

This is particularly true for certain countries, where private R&D has decreased since the onset of the global financial and economic crisis.

Private R&D investment in several EU Member States has decreased in the past years. This is affecting both traditionally large R&D investors such as Finland or Sweden, as well as middle range investors, e.g. The Netherlands or Luxembourg; and countries lagging behind, such as Spain.

Figure 13: BERD intensity (business enterprise expenditure on R&D as % of GDP), 2015 and compound annual growth, 2007-2015



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

Data: Eurostat

Notes: ⁽¹⁾IE: 2007-2014; EL, ES, SI: 2008-2015. ⁽²⁾IE: 2014.

In addition, public R&I funding can also be directed to perform R&I activities carried out by the public sector, e.g. in public research organisations or universities, that can also help addressing some of the bottlenecks to investment by reducing, for example, scientific and technological uncertainty

Public R&I funding can also be directed towards R&I activities that are carried out by the public sector, either A strong public knowledge base and the availability of high levels of skills can help reduce the costs and some uncertainty about the investment outputs that companies face when engaging in, for example, scientific and technological investments. A strong public science base allows new R&D investments to build on the "shoulders of giants" i.e. existing publicly-available scientific knowledge. In this sense, companies can avoid investing in scientific areas where the level of uncertainty to obtain commercially viable scientific results would be too high but yet needed to develop other activities, and concentrate on some other (lower risk) R&D investments. This is for example the case of fundamental research, a type of public good characterised by non-excludability and non-rivalry, which companies and the economy as a whole can benefit from.

Public investment in knowledge generation activities is then crucial for companies to be able to capitalise on these investments. While an adequate level of public funding is an important pre-condition for a high quality science base, merely increasing investment is not sufficient. Ambitious reforms of national R&I systems are often needed to increase the capacity to obtain the most value from these investments. Policy levers to increase the efficiency of public R&I spending include for example the use of international peer reviews to allocate project-based funding and the use of performance criteria in distributing institutional funding (European Commission 2014). In addition, the ability to build on knowledge generated in other countries will also depend on the openness and integration of a country and its research agents with others, either via trade links, research networks, such as the European Research Area, or other mechanisms (European Commission 2016d).

Finally, public knowledge can help bridge information asymmetries to better understand and assess the scientific and technological risks that companies engage in and thus, make investment output more predictable and calculable.

Overall, public R&I funding is important to address persistent barriers to R&I investment and ensure a social investment optimum that can provide higher possible social rate of return thanks to positive knowledge spillover effects.

6. HOW SHOULD PUBLIC R&I INVESTMENT EVOLVE IN ORDER TO SHAPE CHANGES IN INNOVATION AND ENSURE HIGHER ECONOMIC IMPACTS?

The role of public R&I investments and the activities that require public R&I investments are evolving in line with the fast pace changes in the nature of innovation dynamics. The celerity of innovation-induced change, the complexity of the innovation process and the concentration of innovation-related benefits among a compact set of firms raise stronger barriers for firms to invest throughout the research and innovation cycle. This leads to potentially larger business underinvestment in R&I and carries along negative economic impacts.

Firms can engage in several types of R&I activities and the severity of the bottlenecks described in section 5 can thus differ depending on these activities. Traditionally, R&D activities, and notably those that are closer to the "R" (research) component of R&D, such as fundamental research, have been regarded as facing higher levels of scientific and technological uncertainty as well as higher difficulties to fully appropriate the investment results. Therefore, these are more prone to the risk of market failures and to underinvestment (OECD 2001).

However, in recent years, it has become increasingly apparent that - even in innovation activities, where the level of scientific and technological uncertainty in principle tends to be lower and the ability to appropriate investment results tends to be higher - companies can face important bottlenecks in terms of patenting or capacity to access financial resources. This is particularly the case for market-creating innovations, where technologies need substantial resources to mature⁴⁴ and market conditions may not be ripe. As a result, the availability of financing is generally scarce and innovation investments can be severely affected in terms of scale and/ or timing, even if profitable. This has important negative economic consequences, notably as market-creating innovations are increasingly time sensitive and first mover advantages (the first firms in the market) provide larger market shares, which are crucial for the subsequent success of the innovations (Choi et al 2012).

Box 3 below presents in more detail the bottlenecks that investments in market-creating innovation faces in Europe.

Box 3: Bottlenecks to investment in market creating innovation and economic impacts in Europe

Market-creating innovations are crucial to ensure that the "destructive creation" process of an economy supports its structural change and transformation towards more productive and more knowledge-intensive activities. Achieving new and revolutionary R&I-based products, services, business models and firms that respond better to the rapidly evolving consumer needs involves a change in the entrepreneurial landscape which, if effectively nurtured, creates new jobs and higher levels of productivity. A recent study by the OECD (2015) shows that much of the productivity gap across countries is driven by sharp productivity differences between a set of leading companies, whose market lead results very often from the introduction of disruptive innovations, and those firms that lag behind.

Companies such as Uber, Airbnb, Google, Facebook or Amazon are examples of leading companies that drive productivity levels upwards through deeply disruptive innovations on traditional markets, that create new and skilled jobs. More broadly, many of the recent disruptive innovations have been carried out by new or young leading innovative companies, also referred as Yollies (Young Leading Innovators, Veugelers and Cincera, 2010). Many of these Yollies grew up to become what is known as "unicorns", or fast growing, global-scale start-ups that managed to achieve at least \$1 billion valuations and that are driving both economic growth and job creation.

In Europe, the number of Yollies and unicorns is lower than in the United States. For example, in term of unicorns, from the 174 identified by Fortune magazine, only 18 were European, with the large majority finding their origin or expansion thrust in the United States or China⁴⁵. The examples of Spotify, Blabla Car, Feedzai or Abris-Capital, tend to be the exception, rather than the norm. As for Yollies, a similar

⁴⁴ A recent presentation of the DRUID collective highlighted the important bottlenecks in terms of high investment requirements and access to financing for deep technology companies and digital start-ups (https://ec.europa.eu/research/eic/pdf/workshop/eic_workshop_martin_bruncko.pdf#view=fit&pagemode=none)

⁴⁵ <http://fortune.com/unicorns/>

picture emerges with Europe, despite wide national disparities, trailing behind the United States, notably in R&D intensive sectors such as Health care Information and Communication Technologies, despite early technological leads in these sectors, or aerospace, biotechnology or computer hardware and services.

There are several potential reasons that may be behind Europe's lag. Notably, the still fragmented single market, for example, is hindering the ability of these firms to benefit from the economies of scale and scope that are many times needed for disruptive innovative businesses. Well-functioning markets that allow for the rapid reallocation of resources towards more productive activities or a predictable regulatory framework can also provide a partial answer. In addition, bottlenecks driven by high technological and market uncertainty can lock up the investment capacity of firms and make it difficult to access finance in order to be able to engage and scale up these innovations.

More precisely, deep technology companies that introduce market-creating products require large levels of investment before the expected technologies yield those new products. To a large extent innovation investments are associated with high sunk costs that will only be partially recovered, and hence cannot act as collateral assets for loans. In addition, market-creating innovations, by their very nature face a very important degree of market uncertainty, no matter how predictable the regulatory framework may be. Finally, accessing financing from the conception phase to the scale-up of innovation represents a challenge, given the high levels of technological and market uncertainty and information failures in capital markets and the financial sector to measure the associated benefits and risks. In fact, the report stemming from the public consultation on the "Start-up Initiative"⁴⁶ carried out by the European Commission (2016c) confirms that in order to scale up, 65% of the respondents identified "securing financing for expansion" as the main barrier.

As a result, addressing Europe's existing challenges to secure higher levels of market-creating innovations in Europe that would drive higher levels of productivity and growth and new jobs requires a mix of actions. These include improving the overall business conditions for innovation as well as developing targeted support to help bridge the market failures derived from insufficient investment due to the high degree of market uncertainty and unavailable sufficient access to financing.

Against this backdrop, the rationale for public R&I funding for market-creating innovations is strong given the much higher potential risks of market failures for such innovation.

Innovation creation and diffusion depends on the ability of research and innovation agents to develop, absorb and use existing knowledge and technologies. As innovations become increasingly complex, with the need to engage different technologies and competencies, they will require enhanced resources and probably time to be able to master the complexity. This can hinder the ability of firms to engage in this process. A step-up of public science and technology is likely to facilitate the speedy creation and diffusion of knowledge that can be more readily available for firms. The concentration of innovation benefits on some global innovators with first-mover advantages in creating and shaping markets for their business and consumer solutions also calls for public R&I funding to support these activities, especially in the absence of patient and sufficiently informed providers of financing.

The evolving nature of innovation, that becomes increasingly complex and whose benefits many times tend to get concentrated in a few first-moving firms leads to increasing barriers for timely and sufficient investment, especially in certain areas such as market creating innovations, with the potential for high economic returns. This calls for an enhanced role of public R&I funding to lower existing barriers and for fresh rethinking on the type of activities that should require public funding, notably to include market-creation innovation.

⁴⁶ http://ec.europa.eu/growth/tools-databases/newsroom/cf/itemdetail.cfm?item_id=8723

7. HOW MUCH PUBLIC R&I FUNDING DO WE NEED? WHAT ARE THE IMPACTS OF PUBLIC R&I FUNDING?

Identifying and measuring how much public R&I funding is needed is a complex task that would require a certain estimation of the underinvest gap that exists vis-à-vis a perceived social optimum. However, measuring this gap in practices is hard due to the lack of sufficiently developed analytical tools (Tassey, 2005), and in practice, an assessment of the impacts of R&I funding can help obtaining an approximation of whether public R&I funding is achieving the expected impacts.

The benefits of public R&I⁴⁷ are multiple, ranging from the creation of new knowledge to the development of new skills or leveraging private R&D investments that would otherwise not be carried out.

The positive economic benefits of publicly performed R&I have been widely documented in economic research. Meyer-Krahmer and Schmooch (1998), Pavitt (1998), Salter and Martin (2001) or Georghiou (2015) have identified different channels through which public R&D contributes to economic growth:

(1) skills development by training researchers. It is a crucial mechanism for the transfer of knowledge from public research to companies, especially when this knowledge is embodied in the researcher that carries out the specific research. More precisely, one of the wider economic benefits from publicly-funded basic research is associated with scientists' migration into the commercial sector of the innovation system. The benefits are notably associated, not only with applying the latest theoretical knowledge accruing from scientific research, but rather, scientists transfer elements of problem-solving strategies that are fundamental in basic research (Zellner, 2003). ;

(2) generation of new knowledge. It expands the number of ideas that are available in the economy and that can then be translated into new or improved technologies, new products, services, improved processes that generate more value added;

(3) new scientific instruments and methodologies. Public scientists, in the course of their research activities develop new methodologies to resolve specific problems. In addition, they may also develop new scientific instruments that are necessary to advance their research. These can be incorporated in new products and processes, and can be developed in collaboration with the users of such facilities or processes (Georghiou 2015);

(4) the creation of new products and companies, such as spin-out, spin-offs (OECD 2008). Over past two decades, entrepreneurship accruing from public research organisations and universities has been widely acknowledge as one of the key benefits accruing from public R&D (Pattnail et al, 2014) More precisely, universities and academics within universities are increasingly considered as a source for the creation of new companies, in particular high-technology firms, as universities are moving from their traditional roles of research, teaching, and knowledge dissemination to a more advanced role of creating spinoffs and promoting academic entrepreneurship (Lerner, 2004).

(5) creation of networks with private researchers and users. They can lead to the coproduction of knowledge that can address directly a specific problem or challenge with a direct economic impact. The relevance to spur innovation of collaborative research, contract research, consulting and informal relationships between university-business have been widely documented across several studies. This can take the shape of academic engagement and commercialisation of public research outputs that can be then be used by the private sector in order to develop innovation (Perkmann et al 2013). The role of public research organisations or universities to complement private R&D activities, notably for SMEs, has been extensively research as many times, SMEs source their R&D capacity on these public bodies (Deschamps et al 2013).

(6) Funding of private R&I activities that would otherwise not be carried out. Governments also provide direct or indirect funding for businesses to carry out R&D activities that would otherwise not be carried out. This can take the shape of R&D tax incentives, R&D grants or

⁴⁷ It should be noted that many of these benefits are not uniquely associated to public R&I investment, but private R&I can also accrue several of these benefits.

financial schemes such as loans, guarantees or public venture capital. In general, several studies have shown the positive impacts of these tools in ensuring additional private R&D investment by the private sector.

At the European level, these benefits are intensified through the roll out of the European Research Area (ERA) agenda, through which the EU and its Member States strengthen their scientific and technological bases, competitiveness and their capacity to collectively address grand challenges.

The benefits of public R&I depend on the specific context where these investments take place. In Europe, the creation of a ERA has created an environment where national research systems are increasingly becoming more efficient. As the recently published "European Research Area: Progress Report 2016"⁴⁸ points out, Member States have made good progress in delivering the ERA by (1) building more effective national research system, (2) striking an optimal transnational co-operation and competition; (3) opening labour markets for researchers; (4) improving gender equality and mainstreaming gender in research; (5) boosting access to and transfer of scientific knowledge and its optimal circulation; and (6) enhancing international cooperation. These are the six priority axes that continue to build a more effective ERA.

However, measuring the full impacts of public R&D is many times difficult because the impacts are difficult to be traced back, can have multiple and unexpected channels and be beneficial to multiple users. In addition, public R&D may address social challenges that may not focus on obtaining a direct economic return.

Measuring the full impacts of public R&D funding is many times a difficult task because R&D spillovers and unintended effects are likely to come out from scientific discoveries and thus may not be accounted for. Moreover, publicly performed R&D, that in most cases engages in basic scientific discoveries, may take a very long time to generate its full impacts and therefore, the measurement of the impacts may be premature and partial (OECD 2008). In addition, even when the impacts accrue, tracing back their origin to specific funding schemes can be quite complex, as innovations many times source from very different strands of work that go back and forth and do not follow a linear model. Finally, public R&I may be directed towards addressing societal challenges, such as environment, health or quality of life, and measuring the impacts in economic terms may be quite challenging as an increase in GDP or productivity is not the primary aim (Radosevic 2016, Veugelers 2016). Box 4 presents some examples of public R&D that primarily pursue addressing societal challenges rather than economic benefits, even if these economic benefits are also present.

Box 4: Public R&D for addressing societal challenges

Societies face important social challenges, such as climate change or need for improved health that require substantive investment in R&I to ensure that new technologies and innovation can be developed to improve the quality of life of the citizens. Many times, investments in these areas suffer from clear market failures (Foray et al 2012) due to the inexistence of sufficient economic returns and that may require public intervention.

An example of mission-driven non-economic purpose research is in the area of health, that despite providing large economic returns, its main objective may not be per sé to maximise the economic returns, even if they are large and have sometimes been estimated. An example of this is the research conducted by the United States National Institutes of Health (OECD, 2008). Research funding in 2000 represented USD 16 billion. An analysis of the benefits associated with medical research in terms of reductions in the direct costs of illness due to new drugs and treatments, reduction in indirect costs of illness due to a healthier workforce, and the reduction in intangible costs due to increases in longevity and better quality of life was estimated to be USD 240 billion; i.e. 15 times the annual investment (United States Senate, 2000).

Another example is in the area of fighting climate change, where public R&D in developing low carbon technologies can have a significant impact in improving citizen's life, but where technological development, at least in a first instance, may have high risks and thus deter private initiative. This may occur even if the long-term benefits for society may be significant, e.g. by ensuring better agriculture productivity or lower losses from uncontrolled and unpredictable weather incidents.

⁴⁸ http://ec.europa.eu/research/era/pdf/era_progress_report2016/era_progress_report_2016_com.pdf

This has led many times to an under-assessment of the full impacts of public R&D funding.

The above described challenges have resulted in some instances in an underassessment of the impacts of public R&I funding. Methodological challenges associated with the modelling of the innovation process and the definition of the impact channels, and the need to calculate specific parameters or indicators measuring these impacts has prevented many times, and continues to do so, providing an accurate estimation of the impacts of public R&I funding using macro-economic models. Box 5 presents some of the main bottlenecks for existing macroeconomic models to provide an accurate assessment of the full impacts of public R&I.

Box 5: Existing shortcomings in the measurement of the impacts of R&I investments and policy changes, using macroeconomic modelling

In recent years there has been some progress in developing macroeconomic models that aim at providing macroeconomic aggregates of ex-ante economic and social impacts of public investments. These models have aimed at modelling the complex interrelationships in a given economy and by complex set of simultaneous equations identify the final economic and social impact that one given particular policy shock, e.g. increase public R&D investment by 1 million euros, could have.

While the interest and policy benefits of these models are high for policy makers, existing models seem to have fallen short in measuring the impacts of public R&I funding. At the moment, it seems that some of these models suffer from a set of obstacles to do so and that could be summarised as follows:

1) Model specification

Any model needs to make a set of assumptions and simplifications about the functioning of an eco-system. In the case of R&I, the level of complexity given the number of interactions is very high, and therefore, sometimes how R&I is incorporated in the model may fail to reflect reality, notably in terms of measuring the impacts of R&I in relation to other production inputs, identifying the dissemination channels of the impacts of R&I investment, or understanding the role of R&I policies.

2) Methodologies for the calibration of key parameters

One of the main reasons behind the existing model specification may lie on the shortcoming of existing methodologies to define, isolate and measure the dissemination channels of the impacts in the model. Obtaining more robust measurement, including at the microeconomic level, is thus needed.

3) Creation of updated national and sectoral specific databases of key parameters

Models require the calculation of updated parameters that are context specific and that change over time. R&I eco-systems are dynamic and therefore the values of the key parameters that are used in a model change and evolve over time. Having updated parameters is thus important to measure changes in the econ-system and thus, the impacts on the different dissemination channels.

Against this backdrop, improving the modelling of R&I investments and policies should be a priority in order to get a better handle of the ex-ante evaluation of the impacts they could bring about.

In addition, other macro-econometric approaches, as will be detailed below, have also faced difficulties in measuring the full impacts of public R&D due to the lack of sufficiently robust impact measures.

Notwithstanding these difficulties, progress has been achieved using different methodologies. Several case studies have underlined the large and significant impacts of public R&I funding for particular institutions or research programmes.

In past years, several studies have aimed at measuring the economic impacts of public R&D investment. Given the complexity of the topic, they have used a mix of different methodologies to try to assess these impacts.

Some studies have focused on measuring the impacts of publicly performed R&D in specific research councils, public research organisations or research funding schemes⁴⁹. These evaluation studies have tracked forward the results accruing from public funding of R&D through the administration of impact-oriented surveys and estimate the share of increased value added embedded in specific innovative products or technologies that could be attributed to this funding. Georghiou (2015) presents numerous individual studies that have addressed the rate of return on public research investment by tracing back the linkages between research and innovations in the market across several sectors. According to most studies, the overall value generated by public research is between three and eight times the initial investment, which in rates of return represents a median value between 20% and 50%.

In addition, some macro-econometric models have also estimated the positive impacts of public R&I funding that could yield a return around 10%-20%, i.e. around 10 to 20 euros net benefit for every 100 euros invested. The results, however, are not always robust.

Some studies have adopted macro-econometric approaches to measure the impacts of public R&D investment. Guellec and van Pottelsberghe de la Potterie (2004) estimated the contribution of technical change to multifactor productivity growth in 16 major OECD countries from 1980 to 1998, and differentiated between public and private R&D investment. Based on its analysis, the elasticity of public R&D to multifactor productivity was of 0.17, i.e. an increase in public R&D of 10% would result in an increase of 1.7% in total factor productivity. The associated rate of return to public R&D could range around 10% - 15% (Sveikauskas 2012). In a similar study with more recent data, Khan and Luintel (2006) also found a positive rate of return to public R&D, with an estimated elasticity on total factor productivity of 0.21, i.e. an increase of 10% in public R&D would result in an increase in total factor productivity growth of 2.1%. A similar conclusion in terms of the positive effect of public R&D on multifactor productivity in market sectors is found by Haskel et al (2014) for the UK. Based on a regression model, the authors provide a range of potential returns to public R&D funding in the UK that would centre around 20%. However, other macro-econometric studies have not been able to find a positive return to public R&D funding. In some cases, the results were insignificant, and in some other cases, the results were negative (e.g. Park, 1995, Lichtenberg 1993). Van Elk et al (2015), in a study for 22 advanced economies for the 1963-2011 period and after reviewing several models, argue that the relationship between public R&D and economic performance is highly country-specific and that only those models that allow to include heterogeneity across countries provide positive and statistically significant estimates of the rates of return. In other words, these results suggest that the effect of public R&D depends on the relationship of public R&D investment with other factors embedded in the country that affect its returns.

Public funding of private R&I, either via R&D grants, tax incentives or public R&D financial schemes or venture capital programmes, has also proved positive to leverage increasing private R&D investment⁵⁰.

Addressing some of the barriers that hinder higher private R&I investment will require actions on many fronts, including well-designed fiscal incentives that can reduce the cost of doing R&I. In this regard, direct R&I subsidies or R&D tax incentives are high in the list of policy instruments. According to estimates presented by the IMF (2016), fiscal support for private R&D in advanced economies is low and is considered insufficient to fill the investment gap. However, while both measures can have a positive impact to spur private R&I investment, the two differ both in the mechanisms through which they operate and the effects across firms and industries. In this regard, tax incentives are typically made available to all firms that invest in R&I and therefore provide a level playing field. R&I subsidies, on the other hand, tend to be targeted to specific companies or R&I projects and require significant administrative capacity and appropriate information to achieve the desired objectives. In addition, the effects of these tools can vary across firms. Evidence from the IMF (2016) and (Furceri and Jalles, 2017) suggest that higher R&D subsidies can spur higher productivity growth in industries that are highly dependent on external finance and in the ICT sector. In contrast, R&D tax incentives tend to have larger effects in industries characterised by high R&D intensity and small firms.

More precisely, in terms of R&D grants, numerous studies based on firm data come to the conclusion that direct funding has a positive impact on companies' R&D expenditure. Although the results of this public funding in crowding in, i.e. generate additional investment, rather than crowding out, i.e. substitute,

⁴⁹ The next section will present in detail the impact assessment of the EU R&D Framework Programme, one of the largest publicly funded R&D schemes in the world.

⁵⁰ For a thorough revision of the impacts of public R&D funding schemes on private R&D, please see Ognyanova (2016)

private R&D, depends on how this funding is implemented and on the specific national conditions, empirical research has proven that in most cases, public R&I funding crowds in private R&I investment (e.g. Jeaumotte and Pain 2005). More precisely, the possibility that private funds might be completely replaced by government funding is generally ruled out (Aristei et al. 2015, Correa et al. 2013, Zúñiga-Vicente et al. 2014, Becker 2015), even if a partial crowd-out is possible. Recent micro-level studies in major EU countries conclude that R&D expenditure in companies grew less than the amount of the government subsidies received (Aristei et al. 2015). In other words, government funding replaced some of the funds for R&D provided by the companies themselves, even if the total amount of private and government funding for R&D is ultimately higher than it would have been without the direct funding (Belitz 2016).

For R&D tax incentives, the vast majority of empirical studies from different countries conclude that R&D tax incentives are effective in stimulating business investment in R&D. The estimates of the size of this effect are diverging, due to differences in the design of the tax incentive, the methodology used and the countries covered in each study. Although findings on the input additionality vary, most studies show that companies tend to respond to R&D tax incentives by increasing their R&D expenditure, whereas the effect was found to be much stronger for small and young companies. However, as with direct support measures, a loss in tax revenue amounting to one euro often results in growth in R&D spending of less than one euro i.e., here, too, partial crowding out is observed (CPB 2014, Becker 2014, Köhler et al. 2012).

While the positive impacts of public R&I funding seem less conclusive than of R&I in general, much of the empirical evidence suggests that they are significant and large, and thus supports the idea for the need of higher levels of R&I funding. An effective design and implementation of R&I-promoting policy instruments, such as R&D grants or tax incentives will be crucial in supporting R&I investment and will need to be context specific.

8. IS THERE A CASE FOR EU R&I FUNDING? IF SO, HOW IMPACTFUL IS IT?

Since 1984, the European Union has funded multi-annual R&D Framework Programmes. These are meant to foster research and innovation excellence as a vehicle for creating new job opportunities, ensuring Europe's long term sustainability, growth and economic development, as well as for supporting social inclusion, industrial competitiveness and addressing societal challenges. The EU's Seventh Framework Programme for Research and Technological Development (FP7) ran from 2007 and 2013 and counted on a funding of over 50 billion euro, while the current Programme, Horizon 2020, runs until 2020 with a budget of EUR 74 billion. In these R&I funding activities, the EU has aimed at maximising the European added value and impact of its intervention, focusing on objectives and activities that the Member States alone cannot realise efficiently.

A recent study assessing the EU added value of EU Framework Programmes (in particular, FP7 and Horizon 2020), carried out a counterfactual analysis (based on a regression discontinuity and propensity matching) of high quality research teams across Europe whose FP7 applications happened to be just above and below the funding threshold. Preliminary results from this analysis reveal that the Framework Programme:

- helped research teams grow more (both in size and in budget) than similar non-funded teams;
- had a large relative effect on the of funded organisations' networks and research collaborations, both within and outside the EU;
- increased the ability of funded research teams to attract international talent beyond what non-funded teams could achieve.

A counterfactual bibliometric analysis also revealed that FP7 projects produced scientific publications with higher impact factor than other, non FP-funded publications published by the same authors.

The ex-post evaluation⁵¹ of FP7 provided quantitative and qualitative evidence of the economic impacts and returns of the funded activities, even if the full impacts may only accrue in the coming years⁵². Based on this evaluation, the main economic and social impacts using macro-sectoral modelling⁵³ techniques assessed that FP7 will increase GDP by approximately 20 euro billion a year over the next 25 years, or 500 billion euro in total, through direct and indirect economic effects. In other words, it is estimated that for every euro spent in FP7, the direct and indirect economic effects through innovations, new technologies and products is of 11 euro. In addition, the number of new jobs is estimated to amount to over 130000 research jobs over a period of 10 years and 160000 additional jobs indirectly over a period of 25 years. In addition, at a microeconomic level, there is evidence that companies participating in FP7 also report innovative product developments, increased turnover, improved productivity and competitiveness. See Box 6 for a summary of some of the key impact estimates of FP7.

In addition to the analysis of the macroeconomic impacts, an analysis of the different channels that support the economic impacts of public R&I funding also reveal the important impacts of FP7. It should be noted that at the time of the ex-post evaluation, only around half of the projects had been concluded. Therefore, it is expected that the full impacts would be substantially higher.

More precisely, FP7 has contributed to:

- Improve scientific and technological excellence: The share of publications created during the life time of FP7 that is in highly-ranked journals lies above the EU average, with some publications ranked among the top 5% of highly cited publications. This finding supports some recent empirical analysis that shows

⁵¹ For more details on the FP evaluations, please consult https://ec.europa.eu/research/evaluations/index_en.cfm

⁵² This analysis of EU funded research through the FP7 is intended as an illustration of the economic impacts of EU R&I funding scheme. Currently, more research on the impacts of public R&I funding at supranational level needs to be carried out. A more thorough analysis of the European Value Added of EU R&I funding programmes is currently under preparation through an interim evaluation of Horizon 2020 and the preparation of the ex-ante Impact Assessment of the new R&I Framework Programme and will provide a wealth of data and analysis.

⁵³ The NEMESIS model was used to calculate the economic growth and job creation

that international collaboration increases the quality of the research output⁵⁴. In addition, more than 1700 patent applications and more than 7400 commercial exploitations were directly attributed to FP7 projects.

- Trained and develop research skills: FP7 was an open system that allowed more than 21000 new organisations to receive EU funding. FP7 strengthened the training and long-term mobility of researchers, enhanced the quality of doctoral training and helped improved working conditions for researchers. FP7 supported at least 50000 researchers, including 10000 PhD students.

- Support private research activities through R&I funding: In addition to the R&D grants and the extensive participation of private companies in FP7, notably via the Joint Technology Initiatives and other Public-Private-Partnerships, the FP7 improved access to loan finance for research and innovation focused companies through loan agreements worth 11.3 billion euro.

- Improved knowledge flows and the creation of research networks: FP7 has helped creating durable cross-border, cross-sectoral, inter-disciplinary networks.

- Develop EU-wide large research projects, e.g. large research infrastructures: Many FP7 activities have funded very complex and large investments in terms of knowledge and skills, involving different sectors and disciplines that would otherwise not been carried out. More precisely, the EFSRI programme⁵⁵ that finances large international research infrastructures would not have been possible without the FP7 funding.

All these activities have contributed to improving the conditions to leverage private R&I investment that in turn has contributed to have a positive impact in economic growth and job creation.

Box 6: EU level example - summary of estimations of FP7's economic impact

- Based on macro-sectoral model, the economic returns of FP7 is expected to result in a cumulative increase in GDP of 500 billion until 2030, i.e. an extra 0.15% annual GDP growth;

- It is estimated that FP7 has generated around 11 euros of direct and indirect economic effects through innovations, new technologies and products, per euro invested;

- FP7 is expected to create over 130000 research jobs directly over a period of 10 years, and additional 160000 additional jobs indirectly over a period of 25 years;

- Based on the OpenAire database, scientific production involves over 200000 publications from FP7 projects, with almost 65% being peer-reviewed.⁵⁶;

- More than 1700 patent applications have been filed;

- 50000 researchers, including 10000 PhD students, have been funded thanks to FP7.

EU R&D funding has proved significant in yielding significant economic impacts in terms of boosting economic growth and jobs in Europe. In addition, it has also proved effective in improving the conditions for more private R&I investment by raising the scientific and technological quality and building stronger knowledge flows across actors in Europe

⁵⁴ As part of the Small Advanced Economies Initiative composed of Denmark, Finland, Ireland, Israel, New Zealand and Singapore, a steailed set of analyses carried out using Scopus showed that the two key factors affecting the likelihood of a paper to be highly cited, and thus highly relevant, are co-authorship between universities and industry and international co-authorship.(forthcoming study)

⁵⁵ For more information on the EFSRI, please consult https://ec.europa.eu/research/infrastructures/index_en.cfm?pg=esfri

⁵⁶ <https://www.openaire.eu/fp7-stats>

9. CONCLUSIONS

This paper has reviewed the importance of R&I to support economic growth, notably in the current European economic context. Sluggish productivity growth has prompted fears that Europe, as other advanced economies, may be entering a period of secular stagnation characterised by low economic growth and the inability to provide raising prosperity opportunities to large segments of the population.

Against this backdrop, the theoretical and empirical evidence has shown that R&I is a key driver of productivity growth that yields positive economic returns. Based on vast empirical evidence, the paper shows that about two-thirds of economic growth in Europe between 1995 and 2007 came from R&I broadly defined. Among all investment categories that drive productivity, R&I investments were found to account for 15% of all investment-related productivity gains in Europe, and this figure went up to 40% and 50% in countries like the United Kingdom and Finland respectively. In financial terms, the private returns to investment in R&I range on average between 10% and 30%, and are higher for R&I-intensive firms. In addition, R&I enabled new technologies such as The Internet of Things, Advanced Robotics or Artificial Intelligence and the new business models associated with them, will have a deep impact on the future of jobs. It is yet unclear, however, whether jobs will be destroyed or created, but certainly they will be transformed and expected to become more productive.

The paper has also aimed to unveil the factors driving the "productivity paradox" phenomenon that several advanced economies, and notably in Europe, have experienced in the past years and understand the role of R&I, and notably of public R&I funding, in this process. The slowdown in productivity of the past decade has been accompanied by large R&I-enabled technological changes that promised to revolutionise our economies and obtain large productivity gains. However, these gains are not materialising yet and this has casted some doubts about the ability of R&I to continue support economic growth, about its positive impacts and economic returns.

The analysis of the factors behind the productivity slowdown shows that productivity growth has remained robust among the most productive firms at the global frontier, notably in some key sectors, such as ICT. However, the diffusion of technology and innovation across countries, sectors and companies, from leaders to laggards, has been slow and this has hindered the ability to boost higher levels of productivity. The lack of appropriate framework conditions, insufficient economic and technological structural change and the evolving nature of many technology-enabled innovations are interrelated factors that seem to have acted as barriers for a more effective diffusion of innovation, and thus, higher productivity growth in Europe.

This has consequences for public policies, including public R&I funding. While the benefits of public R&I funding have been widely documented and estimated to yield returns around 20%, governments will need to develop holistic strategies to maximise the impacts. More precisely, governments will need to improve the framework conditions in terms of markets functioning, including measures to complete the single market in Europe, and make science and innovation more open; improve the availability of financing for R&I and boost human capital to enable a better environment for innovation diffusion. In addition, public R&I funding must also evolve in order to ensure that persistent barriers to R&I investment and to the ability to benefit from these investments are overcome. As shown by several empirical studies, market forces do not always deliver the level of investment that would be desirable for society. Market failures, coupled with the presence of positive spillover effects have traditionally called for public R&I funding, notably for basic research where the spillover effects are estimated to be higher.

However, recent changes in the nature of innovation dynamics, characterised by fast-pace change, increased complexity in the creation, development and uptake of innovations and higher concentration of benefits in a compact set of key innovators, highlight the risks of enhanced barriers to innovation investment. The role of public R&I funding seems more important than ever before to nurture market-creating innovation. Public R&I investments should be well targeted to foster the quick diffusion of the benefits of certain innovations and to allow firms to get access to the necessary resources in time and with the necessary scale to lead to market-creating innovations, as these report large social gains in terms of economic growth and job creation. This is an area where Europe still lags behind and that needs to be addressed. As a result, the paper argues that public R&I funding should be available from fundamental research to the development and introduction of market-creating innovations. Barriers to knowledge spillovers and the realisation of economic gains can appear at different stages of the research and innovation process.

Moreover, the design and implementation of different R&I funding tools, e.g. R&I grants, tax subsidies or financing schemes, need to be appropriately targeted to address the persistent barriers that hinder the R&I process and adapted to the local conditions, as these mechanisms differ both in the mechanisms through which they operate and their effects across firms and industries in a country.

These conclusions are also applicable to EU R&I funding, whose impacts have been estimated to be large and significant in terms of contributing to economic growth, 500 billion euro in 25 years, and job creation, over 130000 research jobs over a period of 10 years and 160000 additional jobs indirectly over a period of 25 years. In addition, EU R&I funding also contributes to building better conditions to leverage private R&I investment and contribute to addressing societal challenges.

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The Directorate-General for Research & Innovation (DG RTD) of the European Commission regularly carries out policy-oriented in-house analyses on the economic impact of research and innovation (R&I) investments and reforms.

The current paper highlights the economic rationale for public R&I funding, presents a number of empirical estimates about the impacts of R&I investment in general, and of public R&I in particular, and concludes that the impacts of public R&I funding are large and significant and that acts as a catalyzer to boost higher levels of productivity growth that are needed to accelerate economic growth and create more and better job opportunities.

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