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Supply and demand-oriented economic policies to boost robust growth in Europe – Addressing the social and economic challenges in Europe

Deliverable 6.5

R&I policies and productivity growth

WP 6 – Macroeconomic and policy underpinnings of productivity. Implications for future economic policies

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Key word list

Science & Innovation, Science & Innovation Policy, Growth, Macro-models; micro-impact-assessment

Definitions and acronyms

Acronyms	**Definitions**
CNRS	Centre national de la recherche scientifique
DSGE	Dynamic and Stochastic General Equilibrium
GDP	Gross Domestic Product
ICT	Information and Communication Technologies
OECD	Organisation for Economic Co-operation and Development
R&I	Research and Innovation
SME	Small Medium Enterprises
SMP	Single Market Programme
STI	Science, Technology, Innovation
TFP	Total Factor Productivity
UK	United Kingdom

Introduction

1.1. General context

Deliverable 6.5 entitled “R&I policies and productivity growth” analyses the aggregate relation between existing EU R&I policies and productivity growth. Being part of a set of papers to be developed within WP6, D6.5 contributes to better understand and capture the feedback loop effects between the micro and macro dimensions of policies by identifying key elements – here focusing on R&I – that have the potential to generate virtuous cycles among them.

1.2. Deliverable objectives

Within D6.5, capitalising on the findings in WP3 and specifically in D3.2 and D3.4, we provide a bird’s eye view on the evidence and analysis on the impact of R&I policies by first looking at the evidence of the impact of public intervention on private research and innovation, mainly focusing on how R&I and R&I policies affects GDP growth and jobs. To this end, we look at macro-models most commonly used in EU policy analysis (NEMESIS; QUEST III).
D6.5 wraps up with some policy recommendations from the reviewed evidence for improving R&I policies assessment for growth.

1. Methodological approach

Conceptualizing the results from empirical and theoretical literature

2. Summary of activities and research findings

We review the evidence and analysis on the impact of R&I policies. We first look at the evidence of the impact of public intervention on private research and innovation, and how R&I and R&I policies perform in affecting growth in applied macro-models most commonly used in EU policy analysis.

Reviewing the evidence on whether R&I policies can be a growth enhancing instrument leaves a positive answer with caveats. Substantial positive effects can be expected from R&I policies. With substantial “spillovers” social rates of return can substantially exceed the private rates of return from R&I investments. Yet, the evidence also shows that the realized returns are still below their potential, at least on average. So, how can we improve the overall effectiveness and efficiency of the R&I policy kit?

When looking at the effects of R&I policy on innovative investments, the evidence as it stands now suggests that by and large R&I grants and R&I tax credits have the scope for positive effects, especially at a coordinated international level, but only if they are targeted towards firms that are impeded to develop R&I projects where social rates of return are substantially exceeding private rates of return. That leaves as important challenge for policy to identify and select projects of higher social rates of return. Apart from subsidies for basic research efforts and industry science collaboration, it is not obvious that governments are able or willing to pick the projects with higher social rates of return.

When looking beyond the effects of public R&I interventions on innovation, to evaluate whether they induce economy wide GDP growth and jobs, the available applied macro-models generate a large interval of predicted long-term effects on GDP growth and jobs. in order to see the positive effects from public R&I support on GDP growth and jobs, one needs a long-term horizon, before the positive effects fully play out, being able to more than compensate for the short-term negative effects associated with reallocations of high-skilled labour from other productive activities to generate the extra innovations and the negative effects from displacing older more labour-intensive production processes.

3. Conclusions and future steps

Whether R&I policies can serve to power growth, the answer can only be a timid yes at this stage. R&I policies certainly have the potential, but we still know too little of its actual effects. More proper micro and macro-evaluations are still needed.

At the micro-level, we are particularly missing studies with a (quasi-) experimental design to nail down the causality effect of public funding. At the macro-level, there are few models applied in policy evaluation that have an explicit and sufficiently rich modelling of the R&I growth process. And even these models miss important features such as the formation of human capital for the creation and adoption of innovation; the modelling of risk and uncertainty, role of the public R&I sector and the heterogeneity and dynamics of the innovative firms' population. Further developments to these models are needed to better cover these key features of R&I and R&I policy.

High on the to-do list should be to improve the data availability for modelling of the key R&I features and key R&I policy interventions. Models can only be a good laboratory for the evaluation of R&I policies, if they are as close as possible to the available data on those dimensions in which the policy is supposed to operate. Modern macroeconomic models should be designed and calibrated consistently with the latest insights and results from micro studies.

4. Publications resulting from the work described (if applicable)

This paper will be also published as a Bruegel policy contribution.

5. Bibliographical references (*if applicable*)

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R&I policies and economic growth

1 Introduction

Identifying Research & Innovation (R&I) policies as instrument for economic growth and therefore of smart government spending requires several issues to be cleared. A first question is: does R&I contribute to growth? At present, it is widely acknowledged that innovation is an important force behind long-run economic growth. Particularly the models using an endogenous growth framework make a strong case for the growth power from R&I and innovation (e.g. Aghion (2006). But this does not yet make the case for R&I policies. Will R&I policies lead to innovation and growth, sufficiently to cover the opportunity costs of using public funds for R&I?

To address these questions, we review the evidence and analysis on the impact of R&I policies. We first look at the evidence of the impact of public intervention on private R&I and innovation, which is mostly from micro-analysis. To assess the impact from public R&I on growth, we need to complement micro-results with a macro-perspective. To this end, we look at how R&I and R&I policies perform in affecting GDP growth and jobs in applied macro-models most commonly used in EU policy analysis. We start this contribution with a brief description of the critical features and enablers of the R&I process needed to appropriately account for its role[1] in economic growth as well as the main policies oriented to promote R&I to boost growth. A proper understanding of the R&I features, its enablers and policies is important to be better able to use the appropriate models and data to evaluate the impact of R&I policies. We conclude with some policy recommendations from the reviewed evidence for improving R&I policy assessment for growth.

2 R&I and growth

Based on the existing **literature on R&I**, this section describes and analyses the critical features of the innovation process needed to appropriately account for its role on economic growth and welfare.

2.1 Main features of R&I

Technological knowledge is the sum of techniques employed in the production of goods and services. It results from the cumulative aggregation of new technological ideas or innovations, resulting from a systematic effort of research and development (R&I) benefiting from multiple forms of knowledge spillovers. ***R&I*** refers to those economic activities undertaken with the purpose of improving the actual state of technology. Like for physical and human capital, R&I is a form of investment that cumulates in the stock of technological knowledge. The stock of technological knowledge also relates to ***intangible capital***, which includes computerised information, innovative property and economic competencies [2.]

[1] See also Veugelers (2016) and EC (2020b) for more on R&I policies and their impact on growth.

[2] Corrado et al. (2005) and (2009) extend, in the framework of the economic growth literature, the definition of a production technology to include the stock of intangible capital. They find for the US that the growth rate of output per worker increases more rapidly when intangible capital is included, that capital deepening (on physical

Innovations represent additions to the stock of technological knowledge. Creating new technological knowledge requires a systematic effort of research and development (R&I), and benefits from multiple forms of knowledge spillovers. In the pioneering work of Romer (1990) and Aghion and Howitt (1998), R&I activities are undertaken with the purpose of improving the actual state of technology, which in Romer (1990) takes the form a new product and in the *Schumpeterian* framework a better-quality version of an existing product -see Aghion and Howitt (1998)

During the R&I stage, researchers benefit from their past experience and are conditioned by their state of knowledge and their past technological choices. This is where **path dependency** or **technological cumulativeness** comes into the picture. To quote Dosi and Nelson (2010), "… advances are likely to occur in the neighbourhood of the techniques already in use within the firm." Following Griliches (1979), one way of modelling the cumulative nature of R&I is to consider not the flow of R&I expenditure but the accumulated stock of past and present R&I expenditure as the appropriate variable to affect productivity or to enter as an input in an extended production function. *Learning-by-doing* and learning-by-using is another important element in knowledge building.[3]

In a world of open innovation, firms may collaborate in their research efforts, exploiting knowledge complementarities. Firms may also benefit from scientific progress, coming from universities or public research labs. Instead of searching themselves for new ideas, firms may prefer to acquire technological knowledge, in embodied or disembodied form, e.g. by licensing the latest technology.

A specific feature of technological knowledge is its **non-rival nature,** i.e. it can be used by many agents at the same time. In this sense, it entails high generation costs but can be easily reproduced. However, technological knowledge does not get transmitted as easily. First, technological knowledge is partially **tacit**, that is, it cannot be entirely explained in a manual by means of words, symbols or graphs, as opposed to codified knowledge. Second, it is **cumulative**, meaning that it cannot be understood without grasping prior knowledge. Third, it cannot be assimilated, adopted and reproduced without incurring substantial costs, those related to building the needed ***absorptive capacity***. It bears the cost of learning, adaptation and reproduction. Technological knowledge is therefore not a free good that falls like manna from heaven for economic actors wishing to use it, but it requires a deliberate effort on the part of the actors to generate, adopt and use it. In summary, the process of building technological knowledge can considerably benefits from ***knowledge spillovers***. In order to benefit from R&I spillovers, firms have to develop their ***absorptive capacity***[4]. The absorptive

and intangible capital) becomes the unambiguously dominant source of growth, diminishing the role of total factor productivity, and find that the labour income share has significantly decreased over the last 50 years due to the rise of intangible capital

[3] The role of learning-by-doing in the growth process was first studied by Arrow (1962)

[4] For Cohen and Levinthal (1990), absorptive capacity is the "firm's ability to recognize the value of new, external information, assimilate it, and apply it to commercial ends." In more precise terms, Leahy and Neary (2007) define firm's absorptive capacity as "its ability to absorb spillovers from other firms." Cohen and Levinthal (1989)

capacity of a firm positively depends on the accumulation of its previous R&I investments. It helps understanding why private R&I and knowledge spillovers are likely to be complements in the creation of new technologies.

New technological ideas, after discovery, diffuse throughout the economy by affecting the design of products and production process of firms in different industrial sectors and geographical locations. This process is referred as the **diffusion of new technologies**. Extensive empirical work was undertaken by Comin et al. (2008) and Comin and Hobijn (2004) and (2010), among others, describing the long process of diffusion of new technologies across time and countries. The diffusion of technologies can take place through the various mechanisms by which knowledge spills over across space and time: trade relationships, foreign direct investment, mergers and acquisitions, movement of personnel, patents, patent citations, publications, research collaborations, and networks. A new product or process is more likely to be widely and/or faster adopted if it uses existing or familiar technologies, or if complementary goods or services already exist. It is not always the superior technology that gets adopted.

2.2 Main Enablers for R&I creation, adoption and diffusion

2.2.1 Size of the market

Firms may be more willing to do R&I when there is a large market in order to quickly be able to recover their R&I investment expenditure. The market can be national or international depending on the presence or not of trade and non-trade barriers. Acemoglu and Linn (2004) find for the pharmaceutical industry a large effect of potential market size on the entry of non-generic drugs and new molecular entities.

2.2.2 Competition and intellectual property right protection

Patents' systems grant temporarily monopoly rights to innovators in order to protect them from being copied or imitated. By restricting competition, the patent system aims at solving the market distortion generated by the non-rivalry feature of technological knowledge; patents are expected to promote innovation restoring the incentives to innovate.

Competition, however, can be beneficial to innovation too, since in competitive environments firms innovate with the hope of *escaping competition* -see Aghion et al. (2001). This argument relates to the so-called *replacement effect*: entrant firms have more incentives to innovate than incumbents since innovation allows them to steal at least partially the monopoly rents of incumbents -see Arrow (1962). In the extreme case when the prospect of entry is very low, incumbents have little incentives to innovate. However, under the prospect of their monopoly rents being stolen, incumbents innovate to escape competition from potential entrants. Competition may also promote innovation through the type of market size effect described supra, if it results in increasing the size of the market by lowering prices.

"suggest that R&I not only generates new information, but also enhances the firm's ability to assimilate and exploit existing information."

Theoretical and empirical research has been developed asserting that the relationship between competition and innovation follows an inverted U-shape. When competition is low, incumbents do not need to protect their monopoly rents, having little incentives to innovate (*replacement effect*). When markets become more competitive, incumbent firms innovate more to escape competition (*escape competition effect*). However, when there is too much competition, the gains from innovation dilute to the point that neither incumbents nor potential entrants have incentives to innovate (*Schumpeter's argument*). Aghion et al. (2005) find strong evidence of an inverted U-shape relation between product market competition and innovation, and develop an endogenous growth model to understand this evidence. Aghion et al. (2009b), find that "the threat of technologically advanced entry spurs innovation incentives in sectors close to the technology frontier, where successful innovation allows incumbents to survive the threat, but discourages innovation in laggard sectors, where the threat reduces incumbents' expected rents from innovating."

2.2.3 Human capital

Innovation requires an education system able to generate a large enough body of scientists and applied researchers capable of moving the frontier of knowledge. The adoption of new technologies also requires a large body of highly qualified workers able to easily understand and operate the frontier technology, as well as an important effort of making the frontier technology user-friendly. Human capital and skills formation are endogenously determined by educational choices and training. The role of human capital formation for economic development has been emphasized by Lucas (1988).

2.2.4 Financing of R&I

Innovation financing faces in a world of imperfect information a problem of asymmetric information between the innovator and the fund provider. Because of the non-rival nature of knowledge, the innovator has no interest in sharing with the fund provider some of the information the latter would need to justify the funding. Therefore, R&I is as much as possible financed through internal funds. In the absence of sufficient self-funding possibilities, external funding will have to be accessed. This external funding can be private or public. Major sources of private funding include bank financing, capital markets and venture capital. Major sources of public funding include grants, subsidies, tax incentives and public venture capital. In their survey of empirical evidence, Hall and Lerner (2010) conclude "that while small and new innovative firms experience high costs of capital … the evidence for high costs of R&I capital for large firms is mixed. Nevertheless, large established firms do appear to prefer internal funds for financing such investments and they manage their cash flow to ensure this."

2.3 Evidence on rates of return from R&I

To assess the effects of R&I on innovation, the concept of *knowledge production functions* is used. Innovation is assumed to be produced by means of an R&I technology using as inputs labour, capital (tangible and intangible, like research infrastructure, computers and software) and other intermediate inputs (like research materials such as protein structures). R&I labour is to a large extent comprised of scientists and technicians, i.e. highly skilled and specialized labour, where research skills are acquired by specific R&I education (typically PhD degrees) and training. The productivity of firm specific R&I technologies benefits from multiple knowledge spillovers, the assimilation of which may require some form of absorptive capacity.

To obtain evidence on rates of return from R&I knowledge production functions are estimated. Hall, Mairesse & Mohnen (2009), summarizing results from these studies, conclude that the rate of return in developed countries has been strongly positive, with the estimated private rate of return to R&I usually exceeding that of physical capital. Most studies obtain rates of return within the range of 10%–30%; At the same time, they also report a large heterogeneity in rates of return for R&I across firms, technologies, sectors and countries.

The returns to R&I may depend on the existence of complementarities, between R&I and innovation and communication technologies (ICT) that allow productivity gains in doing research -see Mohnen et al. (2018), or between in-house research and purchased technology -see Cassiman and Veugelers (2006), or between process and organizational innovation -see Bresnahan et al. (2002).

Another important issue is whether returns to R&I are constant. The original Romer (1990) model assumes that returns to R&I are constant, which generates the undesirable property known as *scale effect*: since returns are constant, the growth rate of the economy positively depends on the economy size. Jones (1999), among others, argues that scale effects are counterfactual since large countries don't grow on average faster than small countries. This controversy gave rise to the so-called semi-endogenous growth models, under the assumption of **decreasing returns to R&I**. Bloom et al. (2017) claim that *ideas are getting harder to get*, pointing out that research effort is rising sharply while research productivity is declining substantially in a wide range of sectors. By contrast, returns may also increase because of intertemporal R&I spillovers; the so-called *standing on the giant's shoulders* argument -see Scotchmer (1991) and Caballero and Jaffe (1993).

3 R&I policies

3.1 The case for R&I policies: market failure

The fundamental justification for government support of research is the classic market failure argument: markets do not provide sufficient incentives for private investment in research owing to the non-appropriable, public good, intangible character of knowledge and its risky nature. In addition, public research is needed to meet specific needs of public interest, "common goods" which the market would not supply on its own, such as defence, public health, clean environment. Once invented, the new knowledge created from R&I is non-rivalrous and only partially non-excludable. Others may learn and use the knowledge, without necessarily paying for it. It is these "spillovers", which include pure knowledge spillovers as well as pecuniary spillovers, that lead to social rates of return above private rates of return, and private investment levels chosen below the socially desired levels. This divergence

between social and private rates of return, calls for government intervention to stimulate private R&I investment to the higher socially optimal level[5].
Beyond the spillover case, another market failure follows from the highly risky and uncertain nature of the outcomes of R&I. This uncertainty coupled with asymmetries in information between capital markets and R&I investors causes financial market imperfections, impeding access to finance for risky innovation projects. This will hold particularly for small young risky innovators. In sum, the wide scope for market failure in the case of R&I investments for growth, makes a theoretical case for government intervention to bring the private R&I investments closer to the socially optimal investment levels.

Unfortunately, robust estimates of social rates of return are scare. Most of the available empirical evidence comes from selected cases, which carry the risk of a positive selection bias towards more favourable cases. By and large, this empirical literature finds that the social or economy-wide returns to R&I are usually much higher than the private returns to individual firms (Hall, Mairesse & Mohnen 2009). For example, Griliches (1958) found that the social rate of return to research in hybrid corn between 1910 and 1955 was between 35% and 40%. Mansfield et al. (1977) computed the social rates of return of 17 industrial innovations and found that the median social rate of return is about 56% against a median private rate of return of about 25%. Jones and Williams (1998) argue that even conservative estimates suggest that optimal R&I investment in the US is at least four times the actual investment. Bloom et al. (2013) find, using US firm-level panel data, that “gross social returns to R&I are at least twice as high as the private returns.”

As the divergence between social and private R&I is caused by knowledge spilling, one can also look at the evidence on spillovers directly, as a motivation for government intervention. Knowledge spillovers are associated with researcher mobility as well as flows of goods, services and investment. Belderbos and Mohnen (2013) review the various methodologies for measuring spillovers. Trade based indicators are most often used in aggregate empirical analysis. The evidence suggests however that patent-based indicators are better able to capture knowledge spillovers than trade-based indicators. Bottazzi and Peri (2003) use regional R&I and patent data for Europe to find that “spillovers are very **localized** and exist only within a distance of 300 km.” Bottazzi and Peri (2007) use OECD data to study the dynamic relationship between R&I employment and patent applications. They report large spillover effects: “A 1% positive shock to R&I in US increases the knowledge creation in other countries by an average of 0.35% within ten years. The same shock generates a maximum 6% effect on the US stock of knowledge after five to ten years.”

3.2 R&I policies: why it may not work: government failure

Innovation policies are designed to address the potential market failures and distortions discussed supra, such as non-rivalry of ideas, knowledge and market spillovers (positive and negative), asymmetric information between innovators and providers of finance, coordination failures, and uncertainty, among others. Yet, innovation policies also come at a

[5] Note that the case of social rates of return below private rates of return is also possible, for instance when R&I is used strategically to pre-empt other research or technology avenues from developing. In this case, government intervention would be targeted on reducing the private R&I investments.

cost, including the cost of administering the policies and the cost of failure to reach the aimed targets. They may also generate other distortions.[6]

There are several reasons why R&I policy interventions may not be effective. First, public funded R&I may directly substitute for private funding of R&I projects that would have been undertaken anyway in the absence of this public funded R&I. Second, extra R&I generated by the public funding may crowd out private R&I indirectly by increasing the demand of R&I inputs, leading to higher costs of research inputs. This crowding out effect will be more significant the more inelastic the supply of research inputs. This holds particularly for labour supply, as the stock of R&I workers can be considered to be more or less fixed in the short run. As the majority of R&I spending is salary payments for R&I workers, this effect may turn out to be major, as argued by Goolsbee (1998). Goolsbee states that, because of this wage effect, conventional estimates of the effectiveness of R&I policy may be 30 to 50% too high. Wolff and Reinthaler (2008) find on a panel of 15 OECD countries (81-02) that an increase in the R&I subsidy rate increases expenditure for business research more than R&I employment by roughly 20-30%, which is consistent with subsidies raising scientists' wages. They find that the effect is stronger in the short run, when the increase in expenditure is 60% higher than the increase in employment, consistent with a more inelastic demand for R&I labour in the short run. Third, ideally policy triggers research projects with the highest social rates of return. But this assumes that the government is sufficiently informed about these social rates of return, which is notoriously difficult, particularly ex ante. And finally there is the problem of political capture, resulting in the selection of wrong projects.

3.3 The R&I policy toolkit

The evidence on social returns well in excess of private returns and the evidence on technological spillovers would justify public intervention. In this section, we look at the major R&I policy instruments used in practice, which include R&I tax incentives (like R&I tax credits), R&I subsidies (like research grants), research loans and public venture capital, public R&I and public-private partnership, public procurement and patents.

3.3.1 R&I tax incentives

R&I tax incentives are designed to promote innovation, aiming at reducing the gap between private and social returns to R&I, and alleviating the financial problems faced by R&I performers. They are directed towards lowering R&I costs by means of R&I tax-credits, R&I tax allowances, accelerated depreciation of investment in research equipment, or reduced tax rates on corporate revenues from R&I, innovation or patents (patent box/innovation box). The use of R&I tax incentives is worldwide spread and represents a sensible contribution to the reduction of R&I costs incurred by firms. The OECD (2018) report is a comprehensive study of the extent and deepness of this type of policies.

A big virtue of R&I tax credits relative to R&I subsidies is that it lets the firms choose the projects and lets it foot part of the bill. It is also a more predictable, reliable scheme, as all

[6] For a comprehensive discussion of various innovation policies and an analysis of their effectiveness, see e.g. Edler et al. (2016).

firms qualifying for the criteria can use it, thus economizing on bureaucratic decision making. A wide variety of R&I tax credit schemes abound, ranging from volume based to increment based, for R&I employment costs only, tax credits vs tax allowances etc. (OECD 2018). Although mostly hailed for its generality, tax credits can be specifically targeted towards selected sectors, firms (like SMEs, or young firms) and different types of R&I projects (e.g. R&I collaboration with universities). To allow firms benefit from the tax incentives even if they have no taxes to pay (absence of profits) the tax-credits can be made refundable, carried back or forward, or they can be deducted from social security contributions.

Besides the stimulating effect, tax incentives may lead to deadweight losses by supporting R&I that would be done anyway. The R&I tax-credits involve administration costs for government and implementation costs for receivers, in addition to the tax distortions related to raising tax revenues. Some studies have found that they can also raise the wages of R&I labour if there is a lack of researchers with the required qualifications. And finally, it must be kept in mind that the effectiveness of R&I tax-credits can be substantially reduced by R&I tax competition.

3.3.2 Direct subsidies

Another way of lowering the cost of R&I, reduce the gap between private and social returns to R&I and alleviate financial frictions is through direct support in the form of grants and subsidies. Direct subsidies are used by every single country in the EU as one of their major innovation policy instruments -see the Appendix box *R&I policies in the EU and its member states*. Certain projects are chosen to receive (partial) support from the government in the form of grants.

The major conceptual difference between direct R&I support (like grants) and indirect support (like tax-credits) is with respect to the neutrality of policy instruments. Whereas tax incentives can be claimed automatically as long as a firm does R&I (sometimes under some additional restrictions), grants and subsidies are granted generally through a competitive process where the “best” projects are selected by experts. The idea is to support the projects with the highest estimated social return. As pointed out by Bloom et al. (2019): “A disadvantage of tax-based support for research and development is that tax policies are difficult to target at the R&I that creates the most knowledge spillovers and avoids business-stealing. In contrast, government-directed grants can more naturally do this type of targeting.”

Generally, direct subsidies programs are designed, targeted to promoting excellence in research; promote the emergency of new technological paradigms (like robotics); promoting research cooperation between top universities/research centres and the leaders in the private sector; promote research in areas of fundamental relevance for society (environment, digitalization, health) through mission-oriented objectives.

3.3.3 Loans and public venture capital

Public financial support for innovation can also be given via cheap loans, loan guarantees or a guaranteed financing from government. Such government financial support schemes to R&I vary along three main dimensions: (i) the interest rate charged on loans; (ii) whether repayment is conditional on the project's outcome; (iii) the co-financing requirements applicants must comply with.

An alternative way is for the public sector to provide financing by participating in the capital of startup firms, the so-called public venture capital. Not only financing is provided but also management guidance and network connections to give the innovative projects the best chances to succeed.

3.3.4 Public R&I and public-private partnerships

Instead of just subsidising or participating in the financing of R&I, governments can also decide to perform the R&I itself in public universities or public research labs. This would be the case for projects too basic, too large, expensive or risky to be undertaken by a private company, like space exploration or the production of nuclear energy. Examples of publicly funded research labs would be the German Max Planck Institute or the CNRS in France. Bloom et al. (2019) in their *toolkit for innovation policy makers* rank direct public funding at the very top. Public R&I can also be done joint with the private sector, where both sides co-finance projects, share knowledge and research facilities.

3.3.5 Public procurement

Instead of stimulating innovation on the supply side by lowering the cost of innovation, an alternative way for the government is to provide demand for innovations. Through innovative public procurement, innovators can more quickly recover the investment costs and at the same time increase the diffusion of innovations. Public procurement can also be used to define the functional requirements of innovations. Shaping markets for innovations decreases the risk of investing in R&I. Demand can also be encouraged by giving subsidies to private consumers of new products (e.g. photovoltaic panels) or by encouraging the adoption of new products through information campaigns or by regulations.

3.3.6 Patents

Patents are the instrument generally used to protect innovation from copy and imitation, thus enhancing the incentives to innovate**.** Patents provide temporary monopoly rents that are expected to let firms recover their R&I investments. By doing this, patents distort the static allocation of resources, eventually affecting the diffusion of innovations and knowledge. Given the complexity of the problem, various dimensions of patents can be adjusted to make monopoly rents close to its optimal level (length, breadth, height, renewal fees, etc…). This monopoly position, which conflicts with competition policy, is seen as the price to pay to stimulate private R&I.[7] Patents can also be more or less strongly implemented, depending on how much patent infringement can be defended by the patent holders. Moreover, various strategies exist to make patents even more anti-competitive (patent trolls, patent thickets).

[7] For a historical analysis of patent protection, see Lerner (2002). Boldrin and Levine (2013) argue against patent protection. In the same direction, Bessen and Maskin (2009) argue that when innovations are sequential (so that each successive invention builds in an essential way on its predecessors) and complementary (so that each potential innovator benefits from the discoveries of others), the prospective profits of inventors may actually be enhanced by competition and imitation rather than patent protection.

An important property of patents is that they grant property rights protection to innovators in exchange for the disclosure of the relevant information behind the innovation being patented. Disclosure favours the spread of knowledge spillovers. Secrecy is a mutually exclusive alternative strategy to patents, also creating monopoly rents when successful, with the additional social cost of reducing knowledge spillovers. Arundel (2001) studies the relative importance of secrecy vs. patents using the European Community Innovation Survey (CIS). He finds that the probability that a firm rates secrecy as more valuable than patents declines with firm size for product innovation, while there is no relationship for process innovations.

3.3.7 Regulations

The relationship between regulation and innovation is multi-faceted, depending on the nature and the quality of the regulation itself, on the sectors involved and the time horizon considered[8]. At times tight regulations tend to exert pressure on companies forcing them to innovate. Specific regulations addressing negative environmental externalities or dealing with health and safety of citizens may affect the direction of technical change and act as a powerful stimulus to innovation. On the other hand, more prescriptive regulations envisaging high compliance costs and red-tape burdens may hinder innovation activities.

3.4 Main R&I policies deployed in the EU

This section describes the main R&I policy instruments deployed in Europe. EU landscape of research and innovation (R&I) policies is complex, characterised by the interplay of different levels of governance, with policy initiatives being undertaken at the regional, national and the European level. Next to the national level, regional policy is a crucial dimension of the R&I framework in Europe, since huge differences persist across regions and within countries in terms of economic development, R&I investments and performance.. The EU R&I budget represented in 2017 6.6% of public funding in the EU (Source: EC-RTD SRIP 2020).

3.4.1 R&I policy at the EU: Framework Programmes

The main policy instrument of the EU is the Framework Programmes, its multi-annual (7 years) budget for investments in R&I. *Competitive, mission-oriented grants* are the main policy instrument used in these programmes aimed to promote excellence in research, knowledge diffusion and collaboration between universities and private firms.

The currently running Framework Programme is **Horizon Europe**, the Framework Programme 9 (2021-2017). Horizon Europe is the largest ever Framework Programme, including novelties compare to its predecessor, Horizon 2020 (2014-2020). These include EU-wide missions, i.e. time-bound and specific goals on issues (e.g. cancer) where Europe needs to deliver, the European Innovation Council (EIC), as a major tool to support Europe transition into the next wave of innovations across digital/AI and deep tech, and more emphasis on partnerships responding to strategic priorities of Member states and stakeholders, including industry and civil society (such as *Alliances* and *IPCEIs*).

[8] See Pelkmans and Renda (2014) and Blind (2016).

With Horizon Europe, **EU R&I policy** has embraced a more directed, transformative framework, to deliver on the transition to a more sustainable and inclusive Europe. (European Commission, 2020). Within the framework of the sustainability transition, R&I policies at the EU level aim to promote **convergence across regions**.

EU's current Framework Programme "Horizon Europe"'s planned budget for the period 2021-2027 is about **94 billion EUR.** Its major components are:

- **Global Challenge Pillar and Industrial competitiveness (56%):** directly supports research related to societal challenges reinforcing technological and industrial capabilities[9]. Within this pillar, about 30% goes to Digital and Industry, 30% to Climate, Energy & Mobility, 15% to Health.
- **Open Science Pillar (27%):** Supports research through European Research Council grants, Marie Curie Fellowships, and investments in infrastructures, i.e. mostly **basic** research, selected from investigator-initiated proposals.
- **Open Innovation Pillar (14%):** Supports market-creating innovation, breakthrough ideas, and scaling-up innovative enterprises through the European Innovation Council (10.5 billion EUR) and the European Institute of Innovation and Technology to foster the integration of business, research, high education and entrepreneurship (3 billion EUR)

Furthermore, the European Commission aims to guarantee affordable finance and mobilise private funds for R&I investments through different instruments. These include the dedicated window under the **InvestEU Fund**[10], for which the European Commission has proposed a mobilization of about 11 billion EUR through market-based instruments (as e.g. guarantees) which are expected to leverage 200 billion EUR in the private sector.

3.4.2 Major R&I Policy instruments at the EU and its Member States

In this section we look at the major policy instruments deployed in the EU and its member states, following the characterization of R&I Policy instruments, as reported supra. For an overview of major R&I policy instruments by type deployed in the Member States, see Appendix. Furthermore, regional governments and stakeholders are key actors when it comes to R&I policy interventions[11].

[9] Most notably, 7.7 billion EUR are foreseen for Health, 2.8 for Inclusive and Secure Society, 15 for Digital and Industry, 15 for Climate, Energy and Mobility and 10 for Food and Natural Resources. Finally, 2.2 billion EUR go to non-nuclear direct actions of the Joint Research Centre (JRC) of the European Commission.

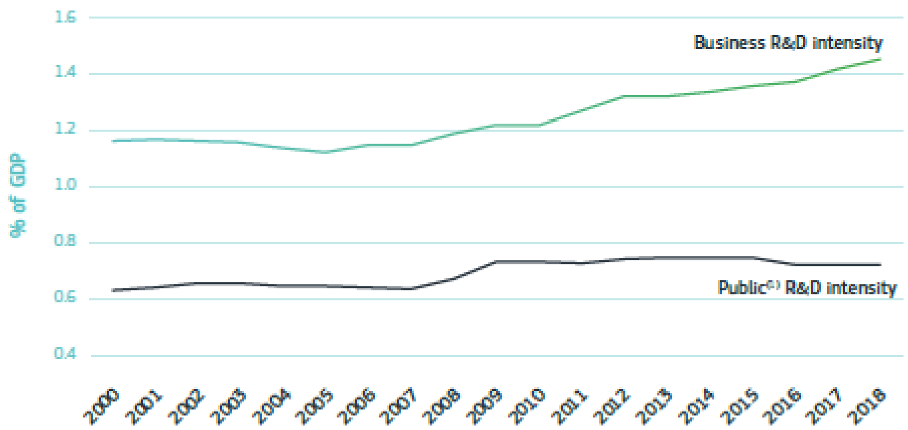
[10] See https://ec.europa.eu/commission/priorities/jobs-growth-and-investment/investment-plan-europe-juncker-plan/whats-next-investeu-programme-2021-2027_en.

[11] Consistently with the acknowledgement of the importance of place-based policies that account for and embrace the specificities of regional ecosystems, EU regions are required to develop their Smart Specialisation Strategies. These are conceived within the Cohesion policy of the European Commission For further information see https://s3platform.jrc.ec.europa.eu/what-is-smart-specialisation-

3.4.2.1 Major trends in EU R&I policy deployment

Public spending on R&I has remained fairly stable overall in the EU, hovering close to 0.8% of GDP, as Figure 1 shows. There is therefore little catching up to the 1% target set by the EU. Business spending on R&I has been trending up, which would suggest that there are some gains in effectiveness of public spending to boost private spending. But of course no causal statement can be made from Figure 1. And in any case, business R&I in the EU remains still far below its 2% target.

Figure 1: Trend in Business and Public R&I in the EU (as % GDP) (2000-2018)



Source: EC, RTD, SRIP 2020

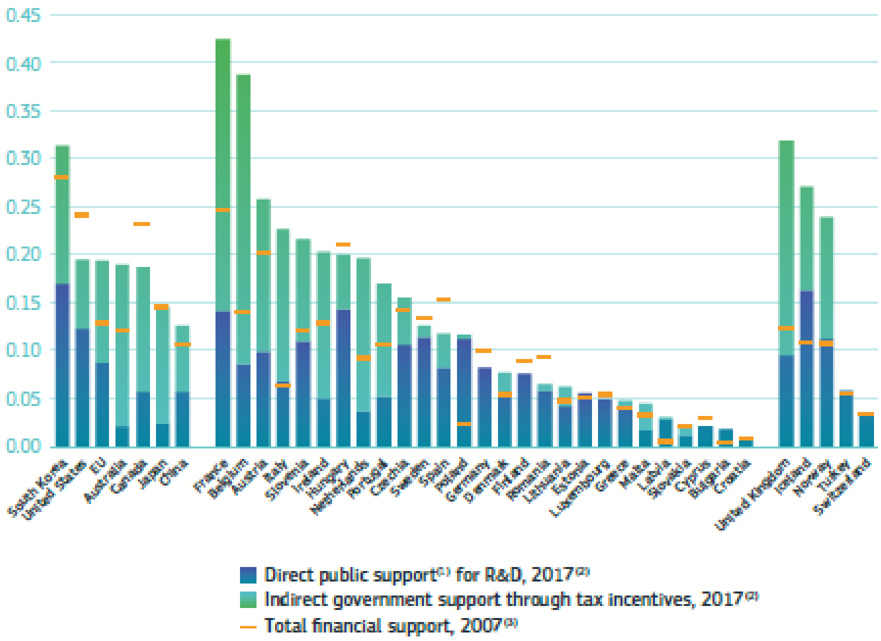
Public R&I spending varies greatly across EU Member States. Denmark scores >1%, Germany is at 1%, Italy only spends around 0.5%, Romania and Bulgaria only 0.2%. Furthermore, there is little evidence of convergence, as Denmark and Germany are forging ahead with above EU average growth rates in public R&I spending, Italy without any growth and Romania and Bulgaria decreasing (Source: EU-RTD-SRIP 2020).

When looking with public R&I spending to the public support for business R&I, we see that this part increased substantially in the EU, from 0.13 % of GDP in 2007 to 0.2 % of GDP in 2017. As this growth is within a more or less stable share for public R&I on average in the EU, it reflects a growing emphasis on this part of the R&I policy toolkit compared to financing of public R&I actors, which was the top favourite in the Bloom et al (2019) S&I policy toolkit (cf infra). Public support for business R&I grew in most Member States, but particularly in France, Belgium and Italy (Figure 2).

R&I tax incentives and grants

Zooming in on public support for business R&I, the two major instruments are tax incentives and grants. While grants used to be the biggest R&I policy instrument (at least in terms of budgets spent), R&I tax incentives have seen a most marked increase. By 2017, grants and R&I tax incentives have become about equally sized as R&I policy instruments (Figure 3). R&I tax incentives in the EU almost tripled from 0.04 % of GDP in 2007 to 0.11 % in 2017. OECD's latest 2020 STI outlook confirms this shift in the policy mix towards tax incentives continuing more recently, with tax support doubling in the EU over ten years, from 26% of total government support in 2006 to 57% % in 2018.

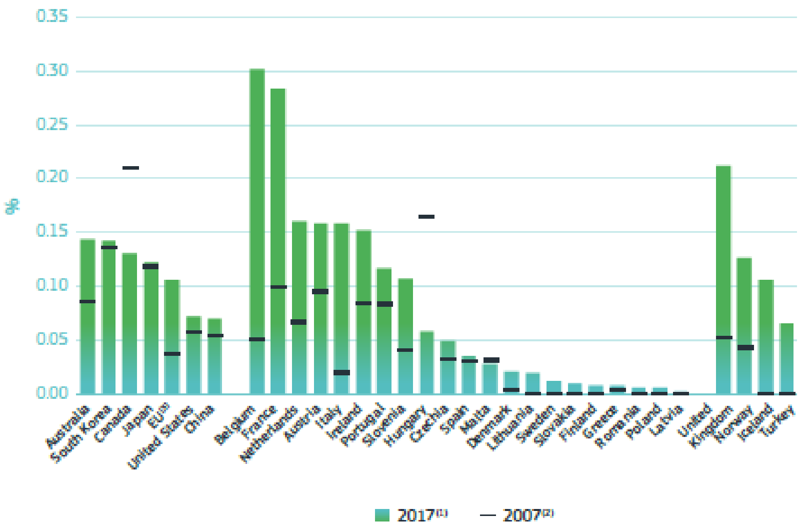
Figure 2: Public Support for Business R&I (as %GDP) (2007&2017)



Source: EC, RTD, SRIP 2020

This growing preference for tax incentives hasn't been uniform across EU Member States. Belgium, France, the Netherlands and Italy, as also the UK, have shifted their policy mix towards tax incentives, while others, like Denmark, Germany, Sweden and Finland are sticking to grants rather than tax incentives.

Figure 3: Tax incentives for R&I (as % of GDP) (2007&2017)



Source: EC, RTD, SRIP 2020

Direct public R&I

The public sector may decide to directly perform R&I investments, rather than leaving it to or financing business efforts. This is done through public research centres, universities and public administrations. In the EU, direct public R&I accounts for around 33% of total R&I expenditure in 2018, of which 2/3 are performed in the higher education sector. Public efforts have remained substantially unchanged in the last two decades in the EU, R&I performed by the public sector remains close to 0.7% of GDP in 2018.

Public-private partnerships

At the EU level, European Partnerships provide a framework for programme level collaboration in the EU. It allows to translate common EU priorities into concrete roadmaps and coordinated implementation of activities. European Partnerships are specific collaborative research instruments involving a broad range of public and/or private actors, such as research funders and organisations, universities, industry, bodies with a public service remit at local, regional, national or international level or civil society.

Public procurement

Public procurement aims at directly creating demand for innovation. According to a report by the OECD (2017), around 80% of OECD countries have developed a strategy to support innovative outcomes through the use of public procurement. In the EU, 14% of EU GDP is spent every year on public procurement (European Commission, 2020). Yet only a few Member States have in place public procurement programmes for research and innovation, as for instance Belgium, France, Austria and Italy (see Appendix). For an assessment of the effectiveness of the public procurement instrument, see a.o. Slavtchev et al (2016).

Loans and venture capital

Loans and venture capital funds address the issue of inadequate access to finance for innovative projects. Countries can set up agencies or schemes that may reduce the cost of loans or by providing public guarantees for the access to credit, as for instance in Italy (Cassa Depositi e Prestiti). There are also instances of public venture capital, e.g. Banque Publique d'Investissement in France. Public venture capital has proven to be crucial in Europe in the last decade. Indeed, while private sources have been volatile during macroeconomic shocks as the last economic crisis in 2008, public venture capital has been resilient overtime and has increased its share on total fund from 13% in 2007 to 22% in 2018. Some examples are reported in Appendix.

The European Union provides programmes to ease the access to venture capital for innovative SMEs and midcaps. They include:

- **VentureEU** the EU will provide funds for 410 million EUR for the period 2021-2027 (200 from Horizon 2020) aiming to raise up to 2.1 billion EUR of public and private investments.

- **Single EU Equity Financial Instrument**, supporting businesses' growth and R&I activities at different stages.
- The European Fund for Strategic Investments **(EFSI) Equity Instrument**. In particular, the **InnovFin Equity** instrument mobiles 4-5 billion EUR to be invested in companies operating in innovative sectors covered Horizon 2020.

Regulation

Regulation in the labour, product and goods market is country specific. At the European level, there is the EU Single Market Programme (SMP), which aim is to create a market without any internal borders or other regulatory obstacles to the free movement of goods and services. While not specific to research and innovation, the SMP incentivates private R&I investments from a larger market for innovations. It also contributes to the diffusion of knowledge and technology and their take-up. Furthermore, free mobility of researchers as a key priority of the European Research Area contributes to research circulation between EU countries.

More specifically for the EU regulatory agenda, there is the Innovation Principle, which is a regulatory tool conceived to help policy makers achieving EU policy objectives by ensuring that legislation is designed in a way that creates the best possible conditions for innovation to flourish. In particular, the innovation principle implies that future initiative undertaken by the European Commission, e.g. policy or regulations, will consider the effect on innovation. The purpose is to set up an innovation-friendly regulatory framework.

4 R&I policies and growth

In this section we address the question whether R&I policies will lead to innovation and growth? To this end, we review the evidence and analysis on the impact of R&I policies. We first look at the evidence of the impact of public intervention on private R&I and innovation, which is mostly from micro-analysis (Section 4.1). To assess the impact from public R&I on growth, we look at how R&I and R&I policies perform in affecting GDP growth and jobs in applied macro-models most commonly used in EU policy analysis (Section 4.2). This section focuses on the two most important R&I policy instruments for supporting growth through innovation, R&I tax incentives and grants.

4.1 R&I policies: do they work to stimulate private R&I? Evidence from evaluations at the micro level

4.1.1 R&I tax incentives

As R&I tax incentives are taking up an increasing share of the R&I policy toolkit in the EU, at least in some EU countries (cf supra), it's important to look at the effectiveness of the instrument.

The effectiveness of fiscal incentives to stimulate private R&I is typically measured by the so-called tax price elasticity: the amount of additional R&I that is generated by one dollar of tax deduction[12]. There is a good deal of heterogeneity in the findings on tax price elasticities. In a review of the literature, Hall and Van Reenen (2000), report econometric estimates ranging from 0.1 to 2, concluding that the most plausible estimates of the tax price elasticity are around unity, which implies that each dollar forgone in tax credit for R&I stimulates a dollar of additional R&I. Mohnen (2013) equally concludes that “the existing evidence about the effectiveness of R&I tax incentives, although it is mixed, seems to tilt towards the conclusion that they are not terribly effective in stimulating more R&I than the amount of tax revenues foregone.” The tax price elasticity is somewhat higher for incremental than for level-based R&I schemes. The power of the tax policy instrument seems therefore to lie more in stimulating new R&I projects and firms, rather than in supporting existing ones. In addition, some of the benefits are wiped out because of the rise in wages for R&I employees[13].

Further evidence directing towards low additionality is the bias in favour of large persistent R&I firms, even if small firms are often given higher rates of R&I tax credits (Mohnen (2013)). Unless tax credit rates are much more generous for SMEs or that there are caps on the tax credits that large firms can claim, there is a blatant inequality in the tax credit scheme in favour of large firms. Small and new firms or first time R&I active firms do not bother to apply in view of the too high fixed cost of applying, lacking information and experience. This is particularly unfortunate, not only because small firms have a higher tax elasticity than large firms, but also because these firms are also more likely to face financial constraints. In this respect, the R&I tax credit being too general, misses its objective of alleviating the financial market failure. To reach this objective, a more targeted R&I tax credit approach is needed, with more generous tax credits to firms facing financial constraints such as small, starting, and first-time-R&I-performing firms. Dechezleprêtre et al. (2016) show that in the UK the young firms among the small firms are more responsive to R&I tax credits because they are credit constrained. A higher additionality for small firms than for large firms is also reported in Lokshin and Mohnen (2012) for the Netherlands and Hægeland and Moen (2007) for Norway. Not only do small firms receive higher R&I tax credits, but they are also more responsive to the tax incentives.

Concerning the heterogeneity of R&I tax credits, Busom et al. (2014) report that in Spain financially constrained firms and new entrants prefer direct subsidies over R&I tax credits because they are not able to fully benefit from R&I tax credits, and that small firms contrary to large firms prefer tax credits over direct support because they are easier to get without having to reveal any information about the amount and the kind of research that is being performed.

[12] A first exercise to do when evaluating R&I credits is assessing the size of the actual R&I tax credit. This is the well known B-index introduced by McFertridge and Warda (1983). The B-index is the ratio of the net cost of a dollar spent on R&I, after all quantifiable tax incentives have been accounted for, to the net income from one dollar of revenue.

[13] Mohnen (2013) reports that the elasticity of the R&I wage with respect to the fraction of the wage supported by the fiscal incentives scheme is estimated at 0.1 in the short run and 0.13 in the long run.

A more recent literature has looked at the specific case of patent boxes, i.e., special tax regimes that apply lower taxes to patent revenues. Bloom et al. (2019) strongly argue against patent boxes. They give to multinationals considerable freedom in deciding where to book taxable income from patents, but have little effect on the real location of R&I. In this sense, they claim “patent boxes are an example of a harmful form of tax competition that distorts the tax system under the guise of being a pro-innovation policy.”

Overall, the evidence shows the potential of the tax credit instrument, but it also warns on its general effectiveness. To improve effectiveness, a tailoring of the instrument is needed.

4.1.2 Direct subsidies

A growing body of econometric work has been produced, evaluating the effects of R&I subsidies on private R&I spending, correcting for other determining firm, industry and market characteristics affecting private R&I spending. The majority of the empirical literature thus focuses on the issue of whether public R&I spending is “additional” to private R&I spending, or whether it substitutes for and tends to “crowd out” private R&I.

Additionality has to do with how much a policy can generate in addition to what would have been the case without the policy. There are different dimensions of additionality, namely input additionality, output additionality and behavioural additionality. Input additionality refers to the effects that R&I policy interventions may have on private R&I expenditure. Output additionality is related to increases in the proportion of innovation outputs that would not have been achieved without the public intervention (e.g. number of patents, new products, enhanced productivity etc..) as a result of the policy. Finally, behavioural additionality refers to the changes that occur in firms’ behaviour and strategy as a result of a policy. In the presence of behavioural additionalities, the traditional input- and output additionality concepts may not adequately capture the impact of public R&I policies on the innovation process itself.

Reviewing the literature, David, Hall & Toole (2000), conclude that "the findings overall are ambivalent", although on average there is more evidence in favour of positive effects. Also Garcia-Quevedo (2004) finds that a little less than one quarter (17 out of 74) of the reviewed studies report substitutability. Substitution is more prevalent among the studies conducted at the firm level, than among those carried out at the industry or country level. This is suggestive of the beneficial effects from positive spillover effects captured in more aggregate industry and country levels of analysis. Yet, David et al (2000) warn that " the existing literature as a whole is subject to the criticism that the nature of the “experiment(s)” that the investigators envisage is not adequately specified. A major issue is the correction for the selection bias: positive effects associated with R&I subsidies are generated from better firms being selected for subsidies, rather than that subsidies cause better performance. More recent studies have come up with better data and methodologies (see Hünermund & Czarnitzki (2019) for a review. Although the conclusions are still ambivalent, positive effects still seem to prevail more often. Lach (2002) finds evidence of partial additionality. For Israel manufacturing in the 90’s, he estimates that an extra dollar of R&I subsidies increases long-run company financed R&I expenditures by 41 cents (total R&I expenditures increase by 1.41 dollars).

4.1.3 The R&I Policy Toolkit

In a recent survey of the empirical literature on R&I policies, Bloom et al. (2019) synthetize the evidence into what they refer as a *toolkit for innovation policy makers*. They rank R&I policies in terms of their overall impact from a social cost-benefit perspective and in terms of their distributional effects, conditional on the strength and quality of the evidence and the magnitude of the estimated effects. In their view, "In the short run, research and development tax credits and direct public funding seem the most effective, whereas increasing the supply of human capital (for example, through expanding university admissions in the areas of science, technology, engineering, and mathematics) is more effective in the long run." Competition and trade policies seem to have small benefits for innovation but they are inexpensive for the public budget. R&I tax credits and trade policies tend to increase inequality, as they boost the relative demand of skilled labour, while human capital policies have the opposite effect.

Akcigit et al. (2016) study the optimal design of corporate taxation and R&I subsidies in an endogenous growth framework of heterogeneous firms with heterogeneous innovation capacity, knowledge spillovers and private information. The model is estimated using firm-level data matched to patent data. In this framework, they show that very simple innovation policies, such as linear corporate taxes combined with a nonlinear R&I subsidy – that provides lower marginal subsidies at higher R&I levels – can do almost as well as full unrestricted optimal policies.

The potential interactions between policies implemented at different governance levels represent another important dimension that needs to be considered in the EU Toolkit. Nationwide innovation policies are likely to influence the performance of self-contained regional innovation plans and of R&I policies targeted at regional strengths, such as cluster policies, smart specialization strategies or cohesion funds. Similarly, the goals pursed by supranational R&I policies and the instruments used for these purposes may not always be consistent with national and regional innovation policies.

4.2 R&I (policies) and their effect on (productivity) growth: evidence from macro-models

The discussion so far has concentrated on the effect of R&I policies on private R&I and innovation. Ultimately this extra R&I and innovation needs to translate into economy wide productivity and GDP growth. This requires also taking into account higher order effects, such as impact on demand, wages, interest rates, prices. To capture these higher order effects, we need to resort to macro models. Macroeconomic models are a prime tool to assess the impact of R&I policy interventions on growth at various horizons (short-, medium- and long-term). [14]

[14] For more on the macro-economic modelling of R&I and R&I policies, see EC (2020b)

Early macro models either had no explicit treatment of investment in knowledge capital differently from other capital investments or they treated R&I exogenously and modelled public R&I policies as TFP shocks (e.g. Worldscan). These neo-classical macro-models with a dynamic and stochastic general equilibrium (**DSGE)** framework are still the standard instrument for macro policy evaluation used by most Central Banks and Ministries of Finance all around the globe. These models lack details on the process of how R&I and R&I policies impact GDP. The introduction of R&I in **models of endogenous growth**, pioneered by Romer (1990) and Aghion and Howitt (1998), among others, endogened the growth rate of productivity. This is an evolution of the macroeconomic literature of fundamental importance for the macro-modelling of R&I and R&I policy evaluation.

In the remainder we will look at macro-models presently in use at the European Commission to assess the impact of its R&I policies on growth: the Quest model and the NEMESIS used by EC-DG ECFIN and NEMESIS, the model used by EC-DG Research and Innovation. A third model used at the European Commission is *RHOMOLO*, a Dynamic General Equilibrium model covering the EU at the regional level. It is developed by the Joint Research Centre (JRC-IPTS) together with DG REGIO to assess the impact of the EU's cohesion policy. As RHOMOLO is a DSGE model where the effects of R&I investments are modelled as exogeneous TFP shocks, we do not discuss this model here[15].

4.2.1 NEMESIS

NEMESIS is a large scale *multisector macroeconometric model* covering all the European Union countries. NEMESIS is mainly used for the impact assessment of *research and innovation policies* carried out at country and EU level.

4.2.1.1 The NEMESIS model specifications for R&I

The NEMESIS model includes endogenous technical change mechanisms, which link innovations realized by sectors to knowledge accumulation and diffusion between production sectors and countries, and to the profit maximization behaviour of the representative firms. Four main mechanisms are involved in the assessment of R&I policies to calculate the competitiveness, growth and employment consequences of the policy: (i) *The crowding in or leverage effect from R&I public funds on R&I expenditures*: the current version of NEMESIS calibrates the leverage effect to be 0.74: i.e. one euro of extra subsidies generate 0.74 euro of new R&I expenditures. This number is based on past econometric work, as reported in the previous sections of this contribution. (ii) *The knowledge spillovers across sectors and countries* that describe all the positive externalities induced by an R&I increase to capture the

[15] TFP growth is determined through RTDI investment and catching up with other regions. It is assumed that the further away a region from the technology frontier, the greater the potential for absorption and imitation of technological progress produced elsewhere. This implies that catching up by regions is assumed, that an increase in R&I produces a bigger impact on factor productivity in regions where the level of technology is originally low. In order to simulate RTDI policies, the RTDI investment under cohesion policy is first expressed as an increase in the R&I intensity compared to the baseline and subsequently a TFP equation is estimated to model the increase in TFP resulting from R&I, reflecting that it takes time for an investment in R&I to be turned into innovation and consequently a productivity improvement.

social returns: NEMESIS uses a matrix on technological flows based on PATSTAT patent data. (iii) *The improved performance resulting from R&I for each productive sector*: R&I investments in the sector and all the knowledge spillovers coming from other sectors and other countries flow into the knowledge stock of the sector. An increase in this stock boosts Total Factor Productivity (process innovation) and simultaneously the quality of goods produced, increasing demand (product innovation). The effects on number of jobs are highly dependent on the allocation of R&I expenditures to process innovation and those allocated to product innovations. Process innovation leads to productivity gains with unfavourable effects on the labour market (at least in the short-term), whereas product innovation leads to quality product improvements which directly favour employment (higher demand for the products). The efficiency of increased knowledge is calibrated on past econometric work. The knowledge stock depreciates at a constant rate over time. (iv) *The intersectoral and macroeconomic feedbacks* are modelled in a hybrid fashion, combining pure top-down forces, mainly savings and consumption, linked to wages, employment prices and profit, and bottom-up forces that come from the interactions between 30 heterogeneous sectors in terms of dynamics and R&I effort.

4.2.1.2 EU R&I policy assessment with NEMESIS

DG RTD regularly uses NEMESIS to analyse the impact of its policies. For instance, the NEMESIS model has been used to provide an ex-ante-assessment of two EU innovation policy scenarios the impact on GDP and employment of the FP7 2013 budget of € 8 billion.

A first step to assess the impact of this shock in public R&I expenditures is to assess its impact on overall R&I investments. The allocation of the extra FP7 funding between Member States is assumed to be as observed at the beginning of the FP7. The allocation of research and innovation funding between economic sectors in each country is based on the 'grandfathering' principle, i.e. proportionate to the level of R&I expenditure in each sector. This does not necessarily accord with the actual funds' allocation. The exercise furthermore takes as assumption that the leverage effect of FP7 2013 funded projects is the same as for all other public R&I projects and is the same for all EU countries, an assumption that is likely to be violated, in view of the heterogeneity across countries in effects from public R&I funding. Using an average calibrated leverage effect of 0.74 and an international and intersectoral technology spillover matrix based on patents yields 13.9 billion of extra R&I from the Euro 8 billion of FP7-2013.

A next step is to estimate with NEMESIS the impact of this extra R&I on GDP and employment. The total cumulative extra GDP estimated from the Euro 8 billion shock amounts to Euro 75 billion after 15 years, 86 billion after 20 years. This would imply a multiplier of around 10 from the extra 8 billion of FP7 funds. The extra jobs estimated in the EU after 15 years is 38.000 jobs each year.

While the effect on GDP and jobs from the extra EU public R&I is substantial, it takes patience to enjoy it. The effect is cumulated over time where 4 phases can be identified. Initially there is only a pure effect of the shock. There is no effect on and from innovation yet. The increase in research equipment investment and research jobs results in higher pay and more consumption. Part of this higher consumption goes into imports, which results in some "leakage" of the shock. In the second phase, innovation results are realized from the increased R&I in the form of increasing TFP, lower costs and enhanced product quality. But there are not yet positive demand effects, as these take more time to materialize. There is however job destruction from the increased productivity. The third phase is when the positive effects set in from the take up of the innovation results. Lower prices and higher quality will increase demand and improve competitiveness. Increased profitability will continue to feed further innovations in the endogenous growth framework employed by NEMESIS. These effects will also diffuse across sectors and countries, through the intersectoral and inter-country technology spillover matrix employed by NEMESIS. This third phase is the phase where most of the benefits are reaped. There is however also knowledge depreciation, where the value of the innovations spurred by the one-off shock will slowly evaporate, being replaced by other newer innovations. In a fourth stage this depreciation effects start to become more powerful, slowly dying out the positive effect on GDP and jobs of the shock. Similar results are obtained for the first Horizon 2020 call. The cumulative wealth from this shock, in terms of GDP after 15 years is 119 billion euro. 49.000 extra jobs are created each year in average in this 15-year period

Using the NEMESIS model to study the impact of more public R&I investment for GDP growth and jobs in Europe, shows the potential for a considerable impact, which could reach a multiplier of around 10. But these positive effects require a long time to realize, with initially the stimulus effects being absorbed in higher wages for researchers and resulting in job destructions from increased labour productivity. Only in the longer term, the endogenous growth power of the additional private investments in R&I are leveraged into positive competitiveness, growth and job effects.

4.2.2 QUEST III

The QUEST model is a large-scale *Dynamic Stochastic General Equilibrium* (DSGE) model used by DG ECFIN as a tool to assess concrete policy initiatives and reform proposals on their short and long run growth and employment impacts. **QUEST III** has an explicit modelling of *knowledge creation* and of *technology adoption,* which allows the evaluation of *R&I policies*. To this end, QUEST III adopts a *semi-endogenous growth* framework à la Romer.

4.2.2.1 The QUEST III Model specifications for R&I

The QUEST III model economy is populated by households, final and intermediate goods producing firms, a research industry, a monetary and a fiscal authority. In the final goods sector firms produce differentiated goods which are imperfect substitutes for goods produced abroad. Final good producers use a composite of domestic and imported intermediate goods and three types of labour - (low-, medium-, and high-skilled). Households buy the patents of designs produced by the R&I sector and license them to the intermediate goods producing firms. The intermediate sector is composed of monopolistically competitive firms which produce intermediate products from rented capital input using the designs licensed from the household sector. The production of new designs takes place in research labs, employing high skilled labour and making use of the existing stock of domestic and foreign ideas.

Technological change is modelled as increasing product variety in the intermediate sector, following Romer (1990). The QUEST III model includes knowledge externalities. Domestic and international R&I spillovers are calibrated, based on trade data. Foreign R&I stock is calibrated to grow at a constant rate and there is no depreciation of intangible capital. The total factor productivity of R&I and the elasticity of R&I wrt to skilled labour are calibrated (constrained by equations). The stock of high-skilled labour is calibrated in the model and fixed. The research sector competes with intermediate and final producers for high skilled labour. It faces an adjustment cost of hiring.

An increase in tax credits for R&I allows the non-liquidity constrained households to lower the rental rate for intangibles, thereby reducing the fixed costs faced by intermediate goods producers. This translates into a rise in the demand for patents and stimulates R&I. In the short-run, the reallocation of high-skilled labour to R&I reduces final goods production and has a negative impact on growth, but in the long-run, the positive output effects dominate as productivity increases. Due to the supply constraints for high skilled workers, part of the fiscal stimulus is offset by wage increases for these workers.

4.2.2.2 EU R&I policy assessment with QUEST III

For R&I policies, two types of interventions are looked at: a tax credit to private R&I and a subsidy on wages of researchers in the R&I sector.

Roeger et al (2008) work out a scenario of an *R&I tax credit* of 0.1% of GDP to the non-liquidity constrained households on their income from intangible capital. These R&I tax credits are financed in a budgetary neutral manner through an increase in lump-sum taxes to households. The results for the EU show a 0.31 percent increase in GDP in the long run. Important to note is that the positive effects on GDP only start occurring after 10 years, because of the initial short run output losses due to the reallocation of high skilled workers from production to research. For employment, QUEST III generates no significant long-run effect. In the long-run the number of employees in the R&I sector increases by around 4 percent and R&I intensity rises by 0.08 percentage points. About 25% of the total increase in R&I spending is due to higher wages in these simulations.

The alternative scenario considered is a *subsidy on the wages of researchers in the R&I sector* of 0.1 percent of GDP. The results show somewhat stronger GDP effects compared to the tax credit case: a 0.44 percent increase in GDP in the long run. Compared to R&I tax-credits, this scenario gives more stimulus to the employment of researchers in the long-run: the number of researchers increases by 5.7 percent and R&I intensity rises by 0.12 percentage point. According to these model simulations wage subsidies in the R&I sector are more efficient than R&I tax credits.

In Roeger et al (2008), the QUEST III model is used to analyse the effects of various structural reforms in Southern European countries (Italy, Spain, Portugal and Greece). Reforms are modelled as closing the gap of the country with the average of the three best performing countries in the Euro area. The use of R&I tax credits yields positive long run effects on GDP but they are only of minor size. The long-run GDP effects are the largest for Greece and Italy, the countries with the lowest current R&I tax-credits, but still are only about 1.4% for Greece and 0.9% for Italy. For Spain it is even lower: 0.1%. In comparison, the structural reforms that yield the most significant results in the long run are education policies decreasing the share of low skilled workers. This gives an increase of 15% in GDP for Italy and Spain, an increase in employment with 11% for Italy, 10% for Spain. For Greece, the highest economic gains are realised from product market reforms. Such reforms leave significant economic gains in the long-term, 39% of GDP. Also in Spain product market reforms leave substantial LR increase in GDP: 16% of GDP.

Simulations show a characteristic feature of semi-endogenous growth models: R&I policies yield a permanent increase in GDP levels but not in the growth rate of GDP (Roeger et al (2008)). Like in the NEMESIS model, the positive effects from public R&I instruments only play out in the long term, with initially negative effects from reallocations of high-skilled employees from production into R&I and job losses associated with improved labour productivity. An important obstacle for leveraging R&I into growth and jobs are entry barriers and market power in the intermediate and final goods sectors.

Overall, the QUEST III model generates less scope for positive effects from public R&I instruments, compared to the NEMESIS model. Despite the semi-endogeneous growth modelling and the national and international spillovers, and the lack of knowledge depreciation in QUEST III, tax credits or wage subsidies to private R&I offer limited growth potentials in the QUEST III model. The lower scope for positive effects in the QUEST III model is because of differences in modelling. The QUEST III model has R&I performed in a separate R&I sector which competes with the production sector for high skilled talents. Furthermore, the results from R&I serves only the intermediary sector, generating process innovations. There is no room for final product innovations. Finally, there are some minor differences in calibrating the impact of R&I, with respect to additionality and spillovers[16].
The lower scope for positive effects in QUEST III holds particularly for the effect on jobs. This is because in the QUEST III model the support to private innovation, with a fixed stock of high skilled labour, leads to a reallocation of high skilled workers from the production sector to the R&I sector. A complementary education or immigration policy to increase the stock of high skilled workers would ease this constraint. Also the presence of market power in the intermediate goods sector using the R&I lowers the efficiency of the R&I policy instrument. The QUESTIII model also does not incorporate R&I that would enhance final demand by increasing the quality of final products or new final products. With its focus on process innovations (new varieties of intermediate goods) it ignores the micro-econometric evidence of larger positive effects from final product innovations for employment compared to process innovations

5 Conclusions and further steps

Reviewing the evidence on whether R&I policies can be a growth enhancing instrument and should thus be part of smart fiscal consolidation leaves a positive answer with caveats.

[16] QUEST III uses trade-based measures for spillovers, rather than patent-based measures.

Substantial positive effects can be expected from R&I investments: with substantial "spillovers" social rates of return can substantially exceed the private rates of return from R&I investments. Yet, the evidence also shows that the realized returns are still below their potential, at least on average. So, how can we improve the overall effectiveness and efficiency of the R&I policy kit?

A first important policy issue to deal with is the paucity of empirical evidence on the (relative) effectiveness of different policies based on sound evaluation studies with proper counterfactuals. Particularly missing are studies with a (quasi-) experimental design to nail down the causality effect of public funding. More data and analysis are needed to have a more evidence-based effective and efficient R&I policy deployment.

Nevertheless, the evidence as it stands now suggests that by and large R&I grants and R&I tax credits have the scope for positive effects, especially at a coordinated international level, but only if they are targeted towards firms that are impeded to develop R&I projects where social rates of return are substantially exceeding private rates of return. That leaves as important challenge for policy to identify and select projects of higher social rates of return. Apart from subsidies for basic research efforts and industry science collaboration, it is not obvious that governments are able or willing to pick the projects with higher social rates of return.

When looking beyond the effects of public R&I interventions on innovation, to evaluate whether they induce economy wide GDP growth and jobs, we need to turn to macro-models. These macro-models are also able to identify which complementary framework conditions needs to be in place for higher private and social rates of return from innovation. Unfortunately, there are few macro-models applied in policy evaluation that have an explicit and sufficiently rich modelling of the R&I growth process. Those that do, treating either R&I as semi-endogenous (like the QUESTIII model) or fully endogenous (like the NEMESIS model), show that in order to see the positive effects from public R&I support on GDP growth and jobs, one needs a long term horizon, before the positive effects fully play out, being able to more than compensate for the short term negative effects associated with reallocations of high-skilled labour from other productive activities to generate the extra innovations and the negative effects from displacing older more labour intensive production processes.

Unfortunately, the available macro-models generate a large interval of predicted long-term effects on GDP growth and jobs, depending on how R&I is modelled within these models and calibrated. Further work on testing the robustness of the results from variations in modelling is needed. Calibrations on the effectiveness of public R&I to instigate innovations should be as country specific as possible. Transferring results obtained from other countries is hazardous in view of the important heterogeneity across countries in effects from R&I (policies).

Where the macro-models are as yet underexploited and where they would be a very useful R&I policy instrument is in assessing which framework conditions need to be in place to improve the impact of public R&I funding instruments such as grants and tax credits. Particularly the interaction with product market reforms, improving competition, and labour and education reforms, improving the stock of skills, seem to be the most important structural reforms to improve the impact of policy instruments, particularly in Southern Europe.

Although the macro-models present a rich set of mechanisms and parameters through which R&I policies can be simulated, none of the models covers all of the key characteristics of innovation and innovation policy. Missing features in both models include the formation of human capital for the creation and adoption of innovation; the modelling of risk and uncertainty, role of the public R&I sector, the heterogeneity and dynamics of the innovative firms' population. All models require further developments to better cover these key features of innovation and innovation policy.

Models can only be a good laboratory for the evaluation of R&I policies, if they are as close as possible to the available data on those dimensions in which the policy is supposed to operate. All models struggle with a lack of sufficiently recent and disaggregated data to calibrate/estimate critical parameters. High on the to-do list should be to improve the data availability for modelling of the key R&I features and key R&I policy interventions. Modern macroeconomic models should be designed and calibrated consistently with the latest insights and results from micro studies on different dimensions of the model.

So on the question whether public R&I can serve in smart fiscal consolidation strategies the answer can only be a timid yes at this stage. Public R&I certainly has the potential, but we still know too little of its actual effects. More proper micro and macro-evaluations are still needed.

6 References

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7 Appendix 1: R&I POLICIES IN THE EU and its MEMBER STATES

A sample of policy instruments in EU Member States

Policies	Policy instruments	Country examples	Budget p.a.
Direct and indirect financing	Grants and matching grants for innovation and/or R&I projects	**AT: Impact Innovation Programme**	1-5M€
		MT: R&I Feasibility Studies	<1M€
		NL: SME Innovation Support to Top Sectors	20-50M€
		FI: Business Finland Programme for young innovative companies	20-50M€
		ES: Grants for innovative clusters	5-20M€
		IE: Enterprise Ireland R&I&I Fund	20-50M€
	Vouchers for innovation and collaboration	EE: Innovation vouchers	<1M€
		LT: Innovation vouchers	1-5M€
		PT: Innovation Vouchers	5-20M€
	Loans & guarantees for innovation	SI: Slovenia enterprise fund - bank loans guarantees / interest rate subsidy	50-100M€
		PT: Incentive scheme for the qualification of SMEs	20-50M€
	Tax incentives for R&I (e.g. tax credits)	LV: Corporate income tax incentive for R&I investments	
		PT: Fiscal incentives for the employment of doctorate holders	
		NL: Innovation Box	
	Equity finance for innovative enterprises	MT: Business Startup Funding Programme	
		FR: Digital Ambition Fund	100-500M€
		FI: European Angels Fund Finland	20-50M€
		LU: Luxembourg Future Fund	5-20M€
		SI: Seed capital for startup innovative enterprises	1-5M€
Demand pull instruments	Public procurement for R&I	CY: Financial support to business R&I and innovation: procurement grants for R&I and innovation	20-50M€
		BE(Flanders): Programme for innovative public procurement	
		FR: Online platform for public procurement of innovation	5-20M€
		AT: Action plan on public procurement promoting innovation	
	Pre-commercial procurement	LT: Pre-commercial public procurement	20-50M€
		IT: Pre-commercial Procurement	
	Supplier Development programmes	PT: INTERFACE Programme- Suppliers' Clubs	
		AT: Open Innovation- A strategy for Austria	1-5M€

	Corporate open innovation	EL: Special call on aquaculture, industrial materials and open innovation culture	5-20M€
Technology adoption and generation instruments	**Business advisory services**	FI: Activating Finnish Living Labs	<1M€
		CY: Innovation habitats	
		ES: International Network (Red Exterior) programme	
	Technology extension services	IE: Knowledge Transfer Ireland	>500M€
		EE: Technology Competence Centers	1-5M€
		EE: Product Development Masterclass	<1M€
	Technology centres	DE: Innovative Hochschule	50-100M€
Early-stage support for innovative ventures	Incubators	LU: Technoport	
		BE (Flanders): IMEC.ISTART- Business acceleration programme	
	Accelerators	PT: Collaborative laboratories	
Cooperation	Supporting clusters and networks for innovation	DE: Innovation Forums SME	1-5M€
		DE: WIR! Change through innovation within the region	
		PT: INTERFACE Program	
		PT: Competitiveness Clusters	
		IE: Innovation 4 Growth	
Framework conditions	Inducement (incentive setting); recognition awards; appropriate IPR; standard setting; quality infrastructure; investing in education/ skills; 'green cards' for highly skilled immigrants	CY: National policy statement on enhancing the entrepreneurial ecosystem	
		PT: Startup Visa	
		DE: Technology Transfer with Norms and Standards	
		PT: SME Leader and SME Excellence	
		LV: Guidelines for the Development of Education: STEM Skills	
		LV: Structural Funds Programme for the development of STEM infrastructure in Colleges	
		NL: 2020 National Technology Pact	
		IE: National Skills Strategy 2025	
		SI: Co-financing of Research Equipment	

Source: European Commission (2019). Selection based on the information available at the EC-OECD STIP Compass portal.