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RESEARCH AND INNOVATION POLICIES AND PRODUCTIVITY GROWTH

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We review the evidence on the impact of public intervention on private research and innovation, and how research and innovation and R&I policies affect growth in the applied macro models most commonly used in European Union policy analysis. The evidence suggests that R&I grants and R&I tax credits can have positive effects in terms of stimulating investment in innovation. In terms of the impact of public R&I interventions on economy-wide GDP growth and jobs, the available applied macro models predict positive effects over the long term. It therefore takes time before 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, are compensated for. To the question of 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 still too little is known of what drives their actual effects. More micro and macro evaluations are still needed.

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1 Introduction

Before research and innovation (R&I) policies can be identified as instruments for economic growth, and therefore of smart government spending, several questions must be answered. First: does R&I contribute to growth? At present, it is widely acknowledged that innovation is an important force behind long-run economic growth. In particular, models that use an endogenous growth framework make a strong case for the growth power from R&I and innovation (eg Aghion, 2006). But this does not yet make the case for R&I policies. Will R&I policies lead to sufficient innovation and growth to cover the opportunity costs of using public funds for R&I?

To address these questions, we have reviewed the evidence on the impact of R&I policies. We first looked 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 needed to complement micro-results with a macro-perspective. To this end, we looked at how R&I and R&I policies perform in affecting GDP growth and jobs in the applied macro-models most commonly used in European Union policy analysis. We start 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 aimed at promoting R&I to boost growth. A proper understanding of the features of R&I, and 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 recommendations for improving R&I policy assessment for growth.

2 R&I and growth

Based on the **literature on R&I**, this section describes and analyses the critical features of the innovation process needed to account for R&I's role in 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 research and development (R&I) effort and benefiting from multiple forms of knowledge spillovers. ***R&I*** refers to those economic activities undertaken with the purpose of improving the actual

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

state of technology. As 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].

Innovations represent additions to the stock of technological knowledge, and result from R&I activity. 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 are other important elements 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, eg by licensing the latest technology.

A specific feature of technological knowledge is its **non-rival nature:** 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 related to building the needed ***absorptive capacity***. It bears the cost of

[2] Corrado *et al* (2005, 2009) extended, in the context of the economic growth literature, the definition of a production technology to include the stock of intangible capital. They found for the United States that the growth rate of output per worker increases more rapidly when intangible capital is included, that capital deepening (on physical and intangible capital) becomes the unambiguously dominant source of growth, diminishing the role of total factor productivity, and that the labour income share has significantly decreased over the last 50 years because of the rise of intangible capital.
[3] The role of learning-by-doing in the growth process was first studied by Arrow (1962).

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 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 benefit from ***knowledge spillovers***. In order to benefit from R&I spillovers, firms have to develop their ***absorptive capacity***[4]. The absorptive 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 processes 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, 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 more quickly 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 if there is a large market, enabling them to recover their R&I investment expenditure quickly. The market can be national or international depending on the presence or not of trade and non-trade barriers. Acemoglu and Linn (2004) found for the pharmaceutical industry that potential market size had a major effect on the entry of non-generic drugs and new molecular entities.

[4] For Cohen and Levinthal (1990), absorptive capacity was 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) defined a firm's absorptive capacity as *"its ability to absorb spillovers from other firms."* Cohen and Levinthal (1989) *"suggest that R&I not only generates new information, but also enhances the firm's ability to assimilate and exploit existing information."*

2.2.2 Competition and intellectual property right protection

Patent systems grant temporary 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 (Arrow, 1962). In an extreme case when the prospect of entry is very low, incumbents have little incentive to innovate. However, if there is a risk 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 above, if it results in increasing the size of the market by lowering prices.

Theoretical and empirical research has found 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 incentive 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) found strong evidence of an inverted U-shape relationship between product market competition and innovation, and developed an endogenous growth model to understand this evidence. Aghion *et al* (2009b) found 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 produce 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. There must also be a major effort to make 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 emphasised by Lucas (1988).

2.2.4 Financing of R&I

In a world of imperfect information, innovation financing faces 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) concluded *"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, including research infrastructure, computers and software) and other intermediate inputs (including research materials such as protein structures). R&I labour is to a large extent comprised of scientists and technicians, ie highly skilled and specialised labour, whose research skills are acquired through 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 *et al* (2009), summarising results from these studies, concluded 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 percent to 30 percent. 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 information and communication technologies (ICT), which allow productivity gains from doing research (Mohnen *et al*, 2018), or from in-house research combined with purchased technology (Cassiman and Veugelers, 2006), or from process and organisational innovation (Bresnahan *et al*, 2002).

Another important issue is whether returns to R&I are constant. The original Romer (1990) model assumed 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's size. Jones (1999), among others, argued 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) claimed that *ideas are getting harder to get*, pointing out that research effort is increasing 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 (Scotchmer, 1991; Caballero and Jaffe, 1993).

3 R&I policies

3.1 The case for R&I policies: market failure

The fundamental justification for government support for 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' that the market would not supply on its own, such as defence, public health or a clean environment. Once invented, the new knowledge created from R&I is non-rival 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 below socially desirable 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 be the case 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 private R&I investments closer to 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 *et al*, 2009). For example, Griliches (1958) found that the social rate of return to research in hybrid corn between 1910 and 1955 was between 35 percent and 40 percent. 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 percent against a median private rate of return of about 25 percent. Jones and Williams (1998) argued 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) found, 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 spillovers, one can also look at the evidence on spillovers 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) reviewed 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) used regional R&I and patent data for Europe to find that *"spillovers are very localised and exist only within a distance of 300 km."* Bottazzi and Peri (2007) used OECD data to study the dynamic relationship between R&I employment and patent applications.

[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 at reducing private R&I investments.

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 Why R&I policies may not work: government failure

Innovation policies are designed to address the potential market failures and distortions we have discussed, 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 cost, including the cost of administering the policies and the cost of failure to reach goals. 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 public funding may indirectly crowd-out private R&I by increasing the demand for 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 stated that, because of this wage effect, conventional estimates of the effectiveness of R&I policy may be 30 percent to 50 percent too high. Wolff and Reinthaler (2008) found for 15 OECD countries that an increase in the R&I subsidy rate increases expenditure for business research more than R&I employment by roughly 20-30 percent, 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 percent 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 are notoriously difficult, particularly *ex ante*. And finally there is the problem of political capture, resulting in the selection of the wrong projects.

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

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 tax incentives (like R&I tax credits), subsidies (like research grants), research loans and public venture capital, public R&I and public-private partnerships, 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 through tax-credits, 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 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 depth of this type of policy.

A major benefit of R&I tax credits relative to R&I subsidies is that they allow firms choose the projects and foot part of the bill. It is also a more predictable, reliable scheme, as all firms qualifying for the criteria can use it, thus economising 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 being non-discriminatory, tax credits can be specifically targeted towards selected sectors, firms (such as SMEs or young firms) and different types of R&I projects (eg R&I collaboration with universities). To allow firms to 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. R&I tax credits involve administration costs for government and implementation costs for recipients, 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 shortage 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, reducing the gap between private and social returns to R&I and alleviating financial frictions is through direct support in the form of grants and subsidies. Direct subsidies are used by every EU country as one of their major innovation policy instruments. Certain projects are selected 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 subsidy programmes are designed and targeted at promoting excellence in research; promote the emergence of new technological paradigms (like robotics); promote research cooperation between top universities/research centres and the leaders in the private sector; and promote research in areas of fundamental relevance for society (environment, digitalisation, 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 guaranteed financing from government. Such government financial support schemes vary in three main ways: (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 start-up firms, the so-called public venture capital. Not only is financing provided but also management guidance and network connections, to give innovative projects the best chance to succeed.

3.3.4 Public R&I and public-private partnerships

Instead of just subsidising or participating in the financing of R&I, a government 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, such as space exploration or the production of nuclear energy. Examples of publicly funded research labs are the German Max Planck Institute or the CNRS in France. Bloom *et al* (2019) in their *toolkit for innovation policymakers* ranked direct public funding at the very top. Public R&I can also be done jointly with the private sector, where both sides co-finance projects, and 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 associated with investing in R&I. Demand can also be encouraged by giving subsidies to private consumers of new products (eg photovoltaic panels) or by encouraging the adoption of new products through information campaigns or by regulations.

3.3.6 Patents

Patents are used to protect innovation from copy and imitation, thus raising 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, patents can be adjusted in various ways to bring monopoly rents close to their optimal level (for example by adjusting the length of the patent protection period). 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.

[7] For a historical analysis of patent protection, see Lerner (2002). Boldrin and Levine (2013) argued against patent protection. In the same direction, Bessen and Maskin (2009) argued 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) studied the relative importance of secrecy versus patents using the European Community Innovation Survey (CIS). He found 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 the 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 with high compliance costs and red-tape burdens may hinder innovation activities.

3.4 The main R&I policies deployed in the EU

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

3.4.1 EU R&I policy: Framework Programmes

The EU's main policy instrument is the Framework Programmes, its multi-annual (seven-year) 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.

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

The currently running Framework Programme is **Horizon Europe**, the Framework Programme 9 (2021-2027). Horizon Europe is the largest ever Framework Programme, including novelties compared to its predecessor, Horizon 2020 (2014-2020). These include EU-wide missions, ie time-bound and specific goals on issues (eg cancer) on which Europe needs to deliver, the European Innovation Council (EIC) as a major tool to support Europe's transition into the next wave of digital, artificial-intelligence and deep tech innovation, and more emphasis on partnerships that respond to strategic priorities of EU countries and stakeholders, including industry and civil society (such as *Alliances* and *IPCEIs*).

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.

Horizon Europe's planned budget is about €94 billion. Its major components are:

- **Global Challenge Pillar and Industrial competitiveness (56 percent of the Horizon Europe budget):** directly supports research related to societal challenges reinforcing technological and industrial capabilities[9]. Within this pillar, about 30 percent of the budget goes to digital and industry, 30 percent to climate, energy and mobility, 15 percent to health.
- **Open Science Pillar (27 percent):** Supports research through European Research Council grants, Marie Curie Fellowships, and investments in infrastructures, ie mostly basic research, selected from investigator-initiated proposals.
- **Open Innovation Pillar (14 percent):** Supports market-creating innovation, breakthrough ideas, and scaling-up innovative enterprises through the European Innovation Council (€10.5 billion) and the European Institute of Innovation and Technology, to foster the integration of business, research, high education and entrepreneurship (€3 billion)

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 about €11 billion through

[9] Most notably, €7.7 billion is foreseen for Health, €2.8 billion for Inclusive and Secure Society, €15 billion for Digital and Industry, €15 billion for Climate, Energy and Mobility and €10 billion for Food and Natural Resources. Finally, €2.2 billion goes to non-nuclear direct actions of the European Commission's Joint Research Centre.

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

market-based instruments (such as guarantees), which are expected to leverage €200 billion in the private sector.

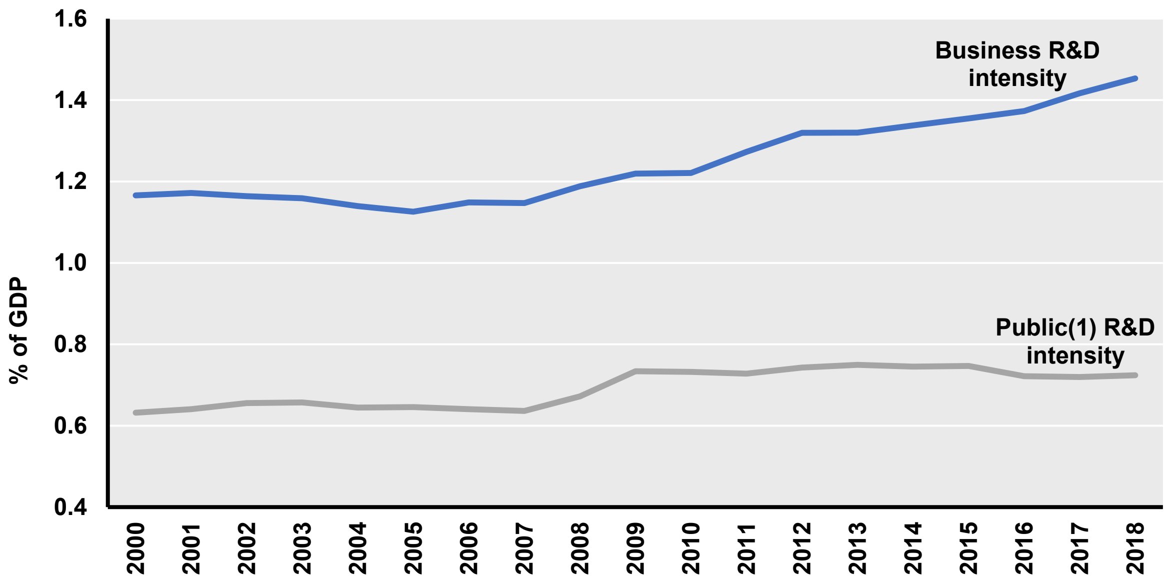
3.4.2 Major R&I Policy instruments at the EU and its member states

In this section we look at the major policy instruments deployed in the EU and its member states, following the characterisation of R&I policy instruments, as reported above. Furthermore, regional governments and stakeholders are key actors when it comes to R&I policy interventions[11].

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 percent of GDP, as Figure 1 shows. There is therefore little catching up to the 1 percent 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 percent target.

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



Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on Eurostat (online data code: rd_e_gerdtot). Note: (1) Public equals GOVERD plus HERD.

[11] Consistent 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-.

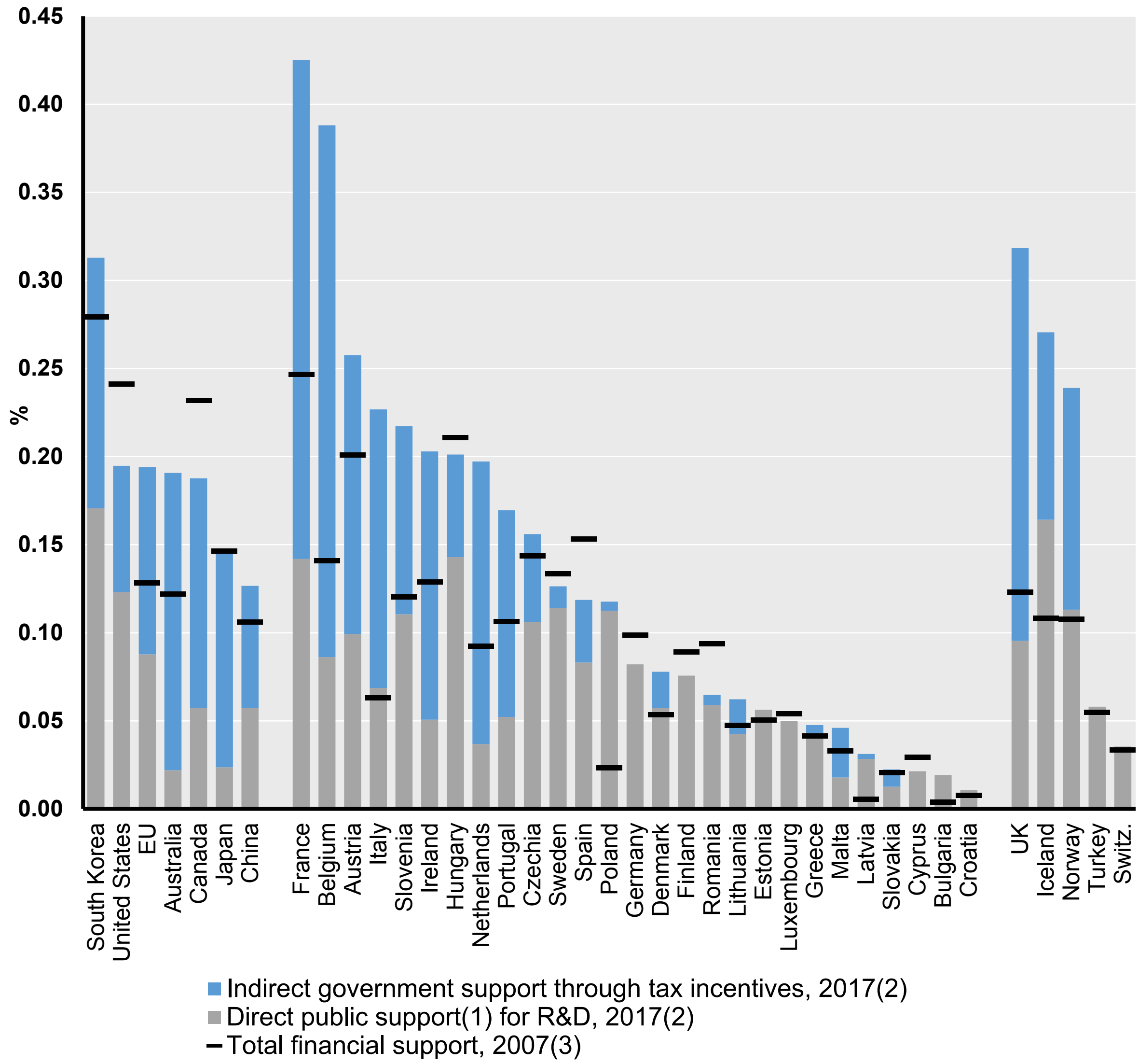
Public R&I spending varies greatly between EU countries. Denmark scores >1 percent, Germany is at 1 percent, Italy only spends around 0.5 percent, Romania and Bulgaria only 0.2 percent. Furthermore, there is little evidence of convergence, as Denmark and Germany are forging ahead with above-EU-average growth rates in public R&I spending, while Italy shows no growth, and Romania and Bulgaria are decreasing (EU-RTD-SRIP, 2020).

However, public public support for business R&I has increased substantially in the EU, from 0.13 percent of GDP in 2007 to 0.2 percent 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 priority in the Bloom *et al* (2019) S&I policy toolkit. Public support for business R&I has grown in most EU countries, but particularly in France, Belgium and Italy (Figure 2).

R&I tax incentives and grants

The two major instruments for delivering public support to business R&I 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 the most marked increase. By 2017, grants and R&I tax incentives had become about equally sized as R&I policy instruments (Figure 3). R&I tax incentives in the EU almost tripled from 0.04 percent of GDP in 2007 to 0.11 percent in 2017. The OECD's 2020 STI outlook confirmed that this shift in the policy mix towards tax incentives has continued more recently, with tax support doubling in the EU over ten years, from 26 percent of total government support for R&I in 2006 to 57 percent in 2018.

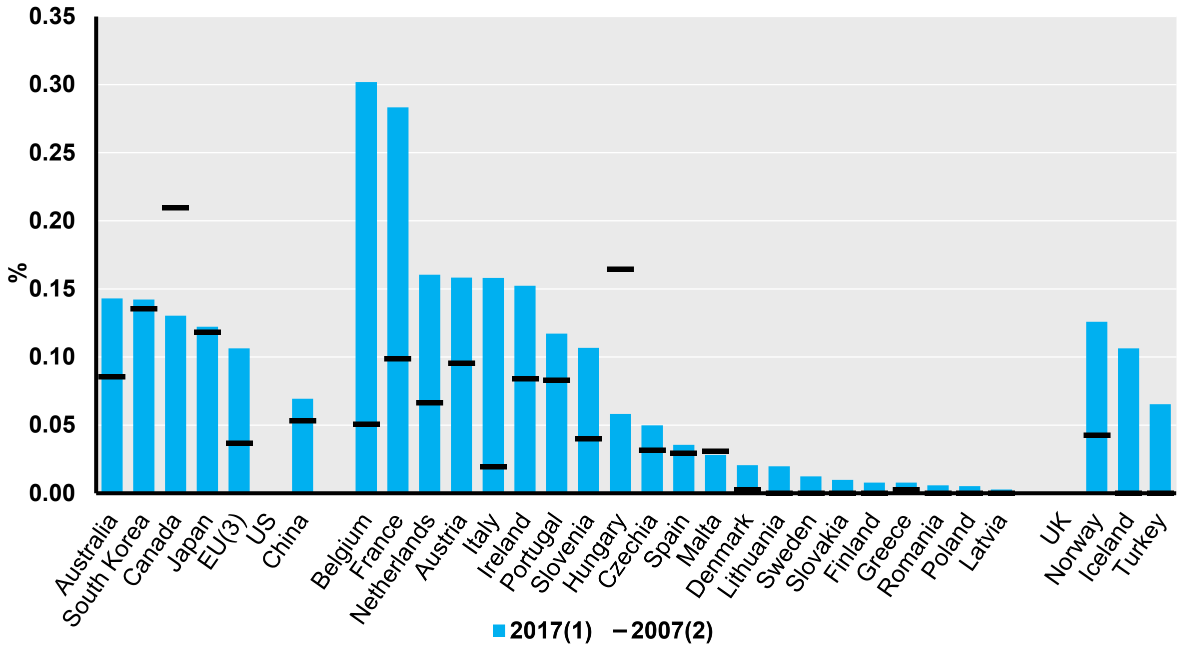
Figure 2: Public support for business R&I (as %GDP) (2007 & 2017)



Source: DG Research and Innovation, Chief Economist - R&I Strategy & Foresight Unit based on Eurostat (online data code: rd_e_gerdfund) and OECD (R&D tax expenditure and direct government funding of BERD). Notes: (1) Estimated direct public support for business R&D includes direct government funding, funding by higher education and public sector funding from abroad. (2) US: 2014 for tax incentives only; AU: 2015; FR: 2016 for tax incentives only; RO, UK: 2016; EL: 2015. (3) CH, TR: 2008; CN, MT: 2009; DE, EL: 2011. (4) The following countries have no tax incenitves for R&D: BG, DE, EE, HR, CY, LU, CH. (5) Elements of estimation were involved in the compilation of the data.

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

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



Source: OECD (R&D tax expenditure and direct government funding of BERD). Notes: (1) US: 2014; FI: 2014; EL, FR: 2016. (2) CN: 2009; EL: 2011. (3) EU was estimated by DG Research and Innovation. (4) BG, DE, EE, HR, CY, LU, CH have no tax incentives for R&D.

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 accounted for around 33 percent of total R&I expenditure in 2018, of which two-thirds was 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 remained close to 0.7 percent of GDP in 2018.

Public-private partnerships

At the EU level, European Partnerships provide a framework for programme-level collaboration. They allow translation of 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 partipants, including research funders and organisations, universities, industry, bodies with a public service remit at local, regional, national or international level, and civil society.

Public procurement

Public procurement aims to directly create demand for innovation. According to OECD (2017), around 80 percent of OECD countries have developed a strategy to support innovative outcomes through the use of public procurement. In the EU, 14 percent of GDP is spent every year on public procurement (European Commission, 2020). Yet only a few EU countries have in place public procurement programmes for research and innovation. Examples include Belgium, France, Austria and Italy. For an assessment of the effectiveness of the public procurement instrument, see 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 can providing public guarantees to enable access to credit, such as in Italy (*Cassa Depositi e Prestiti*). There are also instances of public venture capital, eg 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, such as the last economic crisis in 2008, public venture capital has been resilient and has increased its share of total funding from 13 percent in 2007 to 22 percent in 2018.

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

- **VentureEU** the EU will provide funds of €410 million for the period 2021-2027 (€200 million from Horizon 2020) aiming to raise up to €2.1 billion of public and private investment.
- **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 to be invested in companies operating in innovative sectors covered by Horizon 2020.

Regulation

At the European level, there is the EU Single Market Programme (SMP), which aims 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 incentivises private R&I investment by creating 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 policymakers achieve EU policy objectives by ensuring that legislation is designed to create the best possible conditions for innovation to flourish. In particular, the innovation principle implies that future initiatives undertaken by the European Commission, eg 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 of whether R&I policies lead to innovation and growth. 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 of 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 (Figure 3), 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 their 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 variation in the findings on tax price elasticities. In a review of the literature, Hall

[12] A first exercise when evaluating R&I credits is to assess 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.

and Van Reenen (2000) reported econometric estimates ranging from 0.1 to 2, concluding that the most plausible estimates of 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 concluded 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."* 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 indicating 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 there are caps on the tax credits 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 because 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, R&I tax credits that are too general miss their 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 for firms facing financial constraints, such as small, early-stage and first-time R&I-performing firms. Dechezleprêtre *et al* (2016) showed that in the UK, young firms among the small firms are more responsive to R&I tax credits because they are credit constrained. Greater additionality for small firms compared to 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 variability of R&I tax credits, Busom *et al* (2014) reported 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, unlike large firms, prefer tax credits over direct support because they are easier to obtain without having to reveal any information about the amount and the kind of research that is being performed.

[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.

More recent literature has looked at the specific case of patent boxes, ie special tax regimes that apply lower taxes to patent revenues. Bloom *et al* (2019) argued forcefully 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 flags up a warning on its general effectiveness. To improve effectiveness, tailoring of the instrument is needed.

4.1.2 Direct subsidies

A growing body of econometric work has been produced that evaluates 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 aspects 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 as a result of the policy that would not have been achieved without the public intervention (eg number of patents, new products, enhanced productivity). Finally, behavioural additionality refers to the changes that occur in firms' behaviour and strategies 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 *et al* (2000) concluded that *"the findings overall are ambivalent"*, although on average there is more evidence in favour of positive effects. Also Garcia-Quevedo (2004) found 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 firm level than among those carried out at 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) warned 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 because better firms are selected for subsidies, rather than because 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) found evidence of partial additionality. For manufacturing in Israel in the 1990s, he estimated that an extra dollar of R&I subsidies increased 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) synthesised the evidence into what they refer as a *toolkit for innovation policymakers*. They ranked 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 for skilled labour, while human capital policies have the opposite effect.

Akcigit *et al* (2016) studied the optimal design of corporate taxation and R&I subsidies in an endogenous growth framework of heterogeneous firms with heterogeneous innovation capacities, knowledge spillovers and private information. The model was estimated using firm-level data matched to patent data. In this framework, they showed 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 aspect 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 specialisation 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 effects 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 and 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].

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 (eg 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 finance ministries 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 was pioneered by Romer (1990) and Aghion and Howitt (1998), among others. 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 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 model used by the Directorate-General for Economic and Financial Affairs (DG ECFIN), and NEMESIS, the model used by DG Research and Innovation (DG RTD). A third model used at the European Commission is RHOMOLO, a Dynamic General Equilibrium model covering the EU at the regional level. It was developed by the Joint Research Centre (JRC-IPTS) together with the Directorate-General for Regional and Urban Policy to assess the impact of EU cohesion policy. As RHOMOLO is a DSGE model in which the effects of R&I investments are modelled as exogeneous TFP shocks, we do not discuss this model here[15].

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

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 realised by sectors to knowledge accumulation and diffusion between production sectors and countries, and to the profit maximisation behaviour of 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: ie one euro of extra subsidies generate 0.74 euros of new R&I expenditures. This number is based on past econometric work, as reported in the previous sections of this paper. (ii) *The knowledge spillovers across sectors and countries* that describe all the positive externalities induced by an R&I increase to capture the 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 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.

subsequently, a TFP equation is estimated to model the increase in TFP resulting from R&I, reflecting the time it takes for an investment in R&I to be turned into innovation and consequently a productivity improvement.

4.2.1.2 EU R&I policy assessment with NEMESIS

DG RTD uses NEMESIS regularly to analyse the impact of its policies. For instance, the NEMESIS model has been used to provide an *ex-ante* assessment of the impact on GDP and employment of a step increase in the FP7 (Seventh Framework Programme) 2013 budget of €8 billion.

A first step to assess the impact of this shock on public R&I expenditures is to assess its impact on overall R&I investments. The allocation of the extra FP7 funding to EU countries 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, ie proportionate to the level of R&I expenditure in each sector. This does not necessarily accord with the actual allocation of funds. The exercise furthermore assumes 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 unlikely to hold 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 €8 billion of FP7 in 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 €8 billion shock amounts to €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, enjoying it requires patience. The effect is cumulated over time with four identifiable phases. 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 realised 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 materialise. 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 in which most benefits are reaped. There is however also knowledge depreciation, with the value of the innovations spurred by the one-off shock slowly evaporating, being replaced by other newer innovations. In a fourth stage this depreciation effects start to become more powerful, slowly killing off the positive effect of the shock on GDP and jobs. Similar results have been obtained for the first Horizon 2020 call. The cumulative wealth from this shock, in terms of GDP after 15 years is €119 billion. Each year, 49,000 extra jobs are created on average over this 15-year period.

Using the NEMESIS model to study the impact of more public R&I investment on GDP growth and jobs in Europe shows the potential for a considerable impact, which could reach a multiplier of about 10. But these positive effects are realised over a long period, with the stimulus effects initially being absorbed by higher wages for researchers and resulting in job destruction from increased labour productivity. Only in the longer term is the endogenous growth power of the additional private investments in R&I 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 policy initiatives and reform proposals in terms of their short and long-run growth and employment impacts. QUEST III includes explicit modelling of *knowledge creation* and *technology adoption,* which allows the evaluation of *R&I policies*. To this end, QUEST III adopts a *semi-endogenous growth* framework in line with Romer (1990).

4.2.2.1 The QUEST III model specifications for R&I

The QUEST III model economy is populated by households, firms that produce final and intermediate goods, a research industry, and 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 TFP of R&I and the elasticity of R&I with respect 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. Because of 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 intervention are looked at: a tax credit for private R&I and a subsidy for wages of researchers in the R&I sector.

Roeger *et al* (2008) worked out a scenario of an *R&I tax credit* of 0.1 percent of GDP on income from intangible capital given to the non-liquidity constrained households. These R&I tax credits are financed in a budgetary neutral manner through an increase in lump-sum taxes on 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 percent of the total increase in R&I spending is due to higher wages in these simulations.

The alternative scenario considered is a *subsidy on top of 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 points. 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 was used to analyse the effects of various structural reforms in Southern European countries (Italy, Spain, Portugal and Greece). Reforms were 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 largest for Greece and Italy, the countries with the lowest current R&I tax credits, but still are only about 1.4 percent for Greece and 0.9 percent for Italy. For Spain it is even lower: 0.1 percent. In comparison, the structural reforms that yield the most significant results in the long run are education policies that decrease the share of low-skilled workers. This gives an increase of 15 percent in GDP for Italy and Spain, an increase in employment of 11 percent for Italy, 10 percent 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 percent of GDP. Also in Spain, product market reforms generate a substantial long-run increase in GDP: 16 percent 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. Major obstacles 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 gives 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 talent. Furthermore, the results from R&I serve 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].

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

The lower scope for positive effects in QUEST III holds particularly for the effect on jobs. This is because in the QUEST III model, support for 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 QUEST III 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, leads to a positive answer with caveats. 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 realised 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 needed are studies with a (quasi-) experimental design to nail down the causality effect of public funding. More data and analysis are needed to underpin 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 can offer positive effects, especially at a coordinated international level, but only if they are targeted at firms that are impeded from developing R&I projects where social rates of return substantially exceed private rates of return. That leaves a substantial challenge for policy to identify and select projects with higher social rates of return. Apart from subsidies for basic research 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 enable an explicit and sufficiently rich modelling of the R&I growth process. Those that do, treating either R&I as semi-endogenous (like the QUEST III 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 and before they 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 large intervals before long-term effects are seen on GDP growth and jobs, depending on how R&I is modelled and calibrated within these models. Further work is needed to test the robustness of the results from variations in modelling. 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 significant differences between countries in terms of the effects from R&I (policies).

Where the macro-models are as yet under-exploited 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. In particular, 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; the role of the public R&I sector; and the heterogeneity and dynamics of the population of innovative firms. All models require further development 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 aspects on 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 measures 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 aspects of the model.

So on the question of whether public R&I can serve 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.

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