European Commission

Research, innovation and economic growth

R&D policy reforms and strategies

Research, innovation and economic growth: R&D policy reforms and strategies

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EXECUTIVE SUMMARY

The Directorate-General for Research and Innovation (DG RTD) seeks to enhance the evidence-base around the impact of policies on research and development (R&D) and innovation and modify QUEST III, DG ECFIN's[1] dynamic stochastic general equilibrium model, with the aim to facilitate its policy-making.

This report is related to Task 3 of the wider project "Study on Econometric modelling support to link R&I to job and growth" and the objectives are twofold.

- **Impact assessment.** Assess the impact of public policies and strategies such as performance-based funding and policies that enhance public-private R&D cooperation on R&D productivity. This is primarily carried out through a review of the empirical literature.

- **Extend QUEST III to facilitate evaluation of R&D policies.** Develop a satellite model that could be integrated within QUEST III to facilitate evaluation of R&D policies on R&D productivity, innovation and other key macro-economic variables. The analysis carried out under the first objective could be used to calibrate the parameters of the satellite model.

The key insights from the literature review are summarised below.

- **Performance-based funding.** Several EU member states have recently adopted a performance-based funding policy whereby research funds to higher education institutions are allocated on the basis of some performance indicators such as the number of publications and citations. The empirical literature that seeks to evaluate the impact of performance-based funding on research productivity is relatively scarce and descriptive in nature and hence should be interpreted with care. Notwithstanding this, the available literature provides mixed results: although some studies document a significant increase in the quantity of university research following adoption of performance-based funding, other studies fail to identify statistically significant effects.

- **R&D specialisation.** R&D specialisation policies seek to incentivise R&D investment in either specific geographical areas, e.g. cluster policies, and/or technology field, e.g. smart specialisation policies. The literature primarily focuses on the evaluation of cluster policies and agglomeration effects, and suggests that R&D productivity is positively related to a firm's geographical proximity to a technology cluster.

- **Public-private R&D cooperation.** There is a lack of empirical evidence that directly assesses the effectiveness of policies that seek to stimulate public-private R&D cooperation. However, there are several studies that look at the impact of some form of public-private cooperation on private R&D productivity. This literature suggests that firms that collaborate with universities or other public research organisations tend to innovate more. Notwithstanding this, the results of the literature should be interpreted with caution due to challenges associated with the identification of causal effects.

- **Research commercialisation**. The available literature primarily focuses on the evaluation Technology Transfer Offices (TTOs) and suggests that research commercialisation proxied by university income from patents and licences is associated with presence, size, and characteristics of TTOs.

[1] Directorate General for Economic and Financial Affairs.

- **R&D tax incentives**. R&D tax incentives such as reduced corporate tax have been found to increase R&D expenditure and innovation. The elasticity of R&D expenditure with respect to tax credits is typically close but less than one suggesting that tax credits considerably stimulate R&D investment without significantly reducing tax revenues.

Finally, a modification of QUEST III is proposed, which amends QUEST's knowledge production function and allows the impact of R&D productivity to vary as a function of the aforementioned policies. The updated model specification could assist the European Commission to quantify the impact of policy interventions on key macro-economic variables and support its policy-making.

1 Introduction

Within the European Commission the responsibility for research and innovation policies primarily lies with the Directorate-General for Research and Innovation (DG RTD), which monitors and analyses national policies and provides recommendations on how member states could improve the quality and quantity of their research and development (R&D). In order to facilitate policy-making, DG RTD uses QUEST III, a macro-economic model developed by the Directorate General for Economic and Financial Affairs (DG ECFIN).The central component of the R&D sector within QUEST III is the knowledge production function according to which innovation is a positive function of the number of high-skilled workers employed in the R&D sector and the international stock of knowledge. The parameters of the knowledge production function have been taken from Botazzi and Peri (2007) and were recently updated as part of Task 1 of the wider project ("*Study on Econometric modelling support to link R&I to job and growth*").[2,3]

Generally, there are two broad types of policies and strategies that can be used to stimulate R&D and innovation (Aschhoff & Sofka, 2008) (EIB Papers, 2009).

1. **Education**. Since the number of high-skilled workers employed in the R&D sector plays a vital role in the generation of new knowledge (as per the knowledge production function), education policies that aim to increase the supply and quality of high-skilled workers would have a positive impact on research activity and innovation. Education policies and their impact on the quantity and quality of education is the subject of Task 2 of the wider project.

2. **Reforms and strategies that seek to increase R&D productivity**. For example, policies that increase public-private R&D cooperation are expected to increase knowledge sharing and circulation and as result R&D productivity. These types of policy reforms and strategies are the focus of this report (Task 3).

In particular, five broad policy reform areas are investigated, as requested by DG RTD.

1. **Performance-based funding policies.** Funding mechanisms that allocate public funding to higher education institutions proportionally to their research productivity, e.g. number of publications.

2. **Specialisation strategies.** Programmes and strategies that target public R&D on specific regions and/or technology fields.

3. **Public and private R&D cooperation policies.** Designing, implementing and governing research programmes to enhance knowledge circulation and cooperation between public and private sectors.

4. **Research commercialisation policies.** Programmes that accelerate the commercialisation of research outputs, such as technology transfer offices; and

5. **R&D tax incentives.** Fiscal incentives provided to R&D companies that seek to stimulate R&D spending and innovation.

Scope of this report

[2] More specifically, task 1 looked at the following. Task 1.1: Update the parameters of the knowledge production function; Task 1.2: Incorporate the impact of scientific and technology diffusion on total productivity and economic growth; and Task 1.3: Allow public and private R&D investment to have a differential impact within the knowledge production function.

[3] Deloitte (2016). Research, innovation and economic growth: Task 1.1: Knowledge production function & Task 1.3: Relationship between public and private R&D.

This report seeks to address two key objectives.

- **Objective 1: Impact assessment.** The first objective is to assess the impact of the five policy areas, as described above, on R&D productivity. This is primarily carried out through a review of the empirical literature although some empirical analysis is also carried out focusing on performance-based funding.[4]

- **Objective 2: Extend QUEST III to facilitate evaluation of R&D policies.** The second objective is to develop a satellite model that could be integrated within QUEST III to facilitate evaluation of the five aforementioned policies on R&D productivity, innovation and other key macro-economic variables. A number of calibration approaches are discussed which primarily draw from the work undertaken within the first objective.

This remainder of this report is structured as follows:

- Section 2 provides the literature review; and
- Section 3 sets out the satellite model.

[4] The available evidence around the impact of performance-based funding is relatively scarce. The motivation of the empirical analysis is to enhance the evidence base. This analysis is presented in the Appendix B.

2 Literature review

This section presents the results of the literature review focusing on the empirical findings of related studies. The key insights obtained from the literature are summarised in Table 1. The next section discusses the approaches used to identify key literature and documentation. Each of the policy reform areas are discussed in detail in the remaining sections.

Table 1: Literature review summary

Reform area	Key insights
Performance-based funding	• Several EU member states have recently adopted a performance-based funding policy whereby research funds to higher education institutions are allocated on the basis of some performance indicators such as the number of publications and citations. • The empirical literature is relatively scarce and most of the studies are descriptive in nature and hence their findings have to be interpreted with caution. • Overall, the evidence around the effectiveness of PBF is mixed.
R&D specialisation	• R&D specialisation policies seek to incentivise R&D investment in either specific geographical areas, e.g. cluster policies, and/or technology field, e.g. smart specialisation policies. • The empirical literature focuses on the evaluation of effectiveness of cluster policies and agglomeration effects primarily in relation to public grant policies, urban redevelopment programmes, promotion of cluster creation, and a firm's proximity to a technology cluster. • Despite the apparent differences in geography, data and methodology used, the available literature suggests that R&D productivity is positively related to a firm's geographical proximity to a technology cluster.
Public-private cooperation	• There is a lack of empirical evidence that directly assesses the effectiveness of policies related to public-private R&D cooperation. • The available empirical studies use firm-level data and seek to quantify the impact of different forms of public-private cooperation on private R&D productivity (e.g. patents, equity partnerships, and contract research). • The available literature suggests that although the magnitude of the impact of public-private cooperation varies, the majority of studies reviewed suggest a positive and statistically significant impact of public-private cooperation on R&D productivity. Notwithstanding this, the results of the literature should be interpreted with caution due to challenges associated with the identification of causal effects.
Research commercialisation	• The available literature focuses primarily on the evaluation of effectiveness and productivity of individual programmes/ interventions related to intermediaries such as Technology Transfer Offices (TTOs). • The studies reviewed typically analyse university-level data and look at the relationship between the presence, size, and characteristics of TTOs as a proxy for university's research commercialisation efforts with the number of patents, number of licences and royalties, and number of start-ups as the main outcome variables. • Although the effect of research commercialisation varies and there are differences between public and private universities, empirical literature suggests that commercialisation strategies tend to lead to increased income

Reform area	Key insights
	from patents and licences, i.e. commercialisation of public research.
R&D tax incentives	• Most literature on R&D tax incentives has focused on their impact on private R&D expenditure and innovation activity, predominantly using firm-level data. • The available empirical studies suggest that fiscal incentives have a positive impact on innovation. • The elasticity of R&D expenditure with respect to tax credits is typically close but less than one suggesting that tax credits considerably stimulate R&D investment without significantly reducing tax revenues.

2.1 Approach to identify key literature and documentation

In order to identify the key literature and documentation, following two approaches were employed:

1. Snowballing technique, and
2. Systematic queries in bibliographic databases

Although there are a few research papers and government reports that seek to discuss and analyse the policy reform areas to stimulate R&D productivity, studies that discuss the outcomes based on quantitative data are relatively scarce. To the extent possible, these publications were used to identify other key sources to be consulted. The snowballing technique involved reviewing citations in these sources to identify additional literature. As the empirical evidence sections for each policy reform areas show, a number of relevant sources on the theme of R&D productivity have been consulted. The existing policy initiatives in the EU member states with regard to the R&D productivity to stimulate research and innovation in the public and private sector have been considered.

As part of the systematic searches in relevant bibliographic databases, queries were conducted in Google, Google Scholar, complemented by specific searches in bibliographic databases such as the National Bureau of Economic Research (NBER), EconLit (from Online Computer Library Center i.e. OCLC/Firstsearch), the Organisation for Economic Co-operation and Development (OECD) databases, World Bank (WB), Web of Knowledge, the Social Science Research Network (SSRN), and other leading academic databases. Table 2 provides some examples of search terms, aligned to the objectives of Task 3.

Table 2: Example search terms for document review

Type of search term	Example search terms
Scoping terms	Performance-based funding; Smart specialisation; Cluster policy; Industrial cluster; Clustering; Agglomeration effects of clusters; Public-private cooperation; University-industry collaboration; University-industry joint venture; Research commercialization; Research transfer; Technology transfer; Technology transfer office; Start-up; Spin-off; Intellectual property; IP.; IP transfer; IP royalty; Tax incentives; Tax credits; Subsidy; User-cost; Research and development; research and innovation; R&D; R&I
Disaggregating and defining terms	Economic modelling; Econometric modelling; Statistical analysis, Frontier analysis; Non-parametric analysis; Implementation analysis; Research institution; University; Elasticity, B-Index

The following sections discuss the main emergent themes of the literature review in the policy background sub-section. The key available studies for the policy reform area are synthesised in the empirical evidence sub-section. For the studies included in the empirical evidence sub-sections, this document uses the following citation index to categorise papers on the basis of their impact and contribution:

- The absence of any stars (i.e. no stars) indicates the study has less than 20 citations;
- * (i.e. 1-star) indicates that the study has 20+ citations; and
- ** (i.e. 2-stars) indicate that the study has 50+citations.[5]

The citation statistics are drawn from Scopus.[6]

2.1 Performance-based funding

2.1.1 Policy background

In Europe, higher education institutions (HEIs) and other public research organisations (PROs) are primarily funded from public science budget and research resources. The public funding mechanisms for HEIs and PROs can be classified at two main levels.

1. **Project funding**. This is defined as the amount of nationally available R&D budget attributed to a research group or individual researcher to perform a certain R&D activity that is limited in time and scope, often based on research proposal submitted to a funding council (van Steen, 2012).[7]

2. **Organisational funding (block funding vs. variable competitive funding).** This is defined as the amount of nationally available R&D budget attributed to a research organisation with freedom to determine the research activities to be performed (van Steen, 2012). Typically, organisational level research funding is in the form of non-competitively allocated block funding which is often used by universities to pay expenditures such as researcher salaries and infrastructure (OECD, 2010). In addition, organisational level funding may also be allocated in a

[5] No study has more than 1000 citations.
[6] https://www.scopus.com
[7] For example, the European Research Council (ERC).

competitive manner and tied to performance indicators such as the number of publications, patents or PhD students. (e.g. JRC, 2015, OECD, 2010).

In recent years the EU members states have increasingly chosen to adopt the so-called performance-based funding (PBF) schemes. The objective of the PBF schemes is to increase research productivity and to enhance the accountability of research performing organisations over their spending of public resources (Hicks 2012).

The amount of funding allocated on the basis of PBF schemes varies significantly ranging from 2% of total funding in Norway to 25% in the UK (Hicks, 2010). In general, the PBF schemes adopted by EU countries can be classified as follows (JRC, 2015; Hicks, 2012).[8]

- **Formula-based non-bibliometric allocation.** Formulae based on assessment of educational (e.g. student and graduation numbers) and research metrics (e.g. number of PhD defences).

- **Formula-based bibliometric allocation:** Formulae based assessment of research output through publication based metrics. This includes for instance the count of publications in international journals, non-weighted and weighted by impact factor (e.g. weighted by the quality of the journal). The formulae may also be based on scientific awards of researchers, patents and revenues from industry co-operations.

- **Peer-review assessment-based allocation.** Similar to a formula-based bibliometric allocation system, some countries base funding allocation decision to universities and groups of universities based on quantitative formulae of research output, such as publications in high-ranked journal, but determined through a peer reviewed assessment. Other performance measures take into account are patents, participation in international research projects or participation in public-private industry co-operation.

The first PBF was introduced in 1986 in the United Kingdom through the Research Assessment Exercise (RAE, now known as the Research Excellence Framework i.e. REF), which is a peer-reviewed process to assess the quality of universities' research performance. Following the UK example, Finland introduced PBF in the 1998s whereas several other countries, including Austria, Belgium, the Netherlands, Italy, France, Poland, Denmark and other member states introduced PBF mechanisms later in the 2000s. The exceptions are Greece, Malta, Cyprus and Luxembourg with no direct PBF in place (e.g. Alexander, 2015). At the EU level, the EC set out to support these strategies, underpinned by an ambition to support research-performing organisations to optimise the use of public research resources and increase accountability.[9] Against this backdrop, the next section discusses the available studies on the impact of PBF schemes on R&D productivity.

A summary of the PBF schemes, including the examples of countries that have implemented those designs, is provided in Table 3. The percentage of PBF funding relative to the total R&D spending for a sample of countries is shown in Table 4, indicating that the PBF intensity varies between the countries that introduced these strategies.

[8] This report focuses on performance-based funding at organisational-level.

[9] This is highlighted by the EC's 2011 communication "Supporting Growth and Jobs – An Agenda for the Modernisation of Europe's Higher Education Systems".

Table 3: Summary of PBF schemes across different countries

Type of PBF scheme	Country	Year of implementation
Formula-based (non-bibliometric)	Austria	2002
	The Netherlands	2012
Formula-based (bibliometric)	Belgium	2003
	Croatia	2013
	Denmark	2009
	Finland	1998
	Poland	2008
	Portugal	2015
	Sweden	2009
	Australia	1995
	Norway	2006
Peer review assessment based	Czech Republic	2013
	Estonia	2012
	France	2008
	Italy	2010
	Lithuania	2009
	Slovakia	2013
	United Kingdom	1986
	Hong Kong, China	1993
	New Zealand	2003

Source: RAND Europe analysis. Formula-based PBF schemes refer to a method of funding allocation which relies on a quantitative method of assessing the funding to be provided to various institutions. The quantitative assessment can be based on research outputs (i.e. bibliometric analysis) or education outputs (i.e. non-bibliometric analysis). For PBF schemes which use formulae based on non-bibliometric allocation, the formulae emphasises solely quantitative parameters such as student and graduation numbers or number of PhD defences. In contrast, PBF schemes, which rely on formula-based bibliometric allocation, can be considered more complex since these schemes may take into consideration weighted and non-weighted impact factors, scientific awards received, and revenues from industry partners.

Table 4: Percentages of PBF across countries[10]

Country	Share of PBF	Country	Share of PBF
Austria	20-60%	Germany	37.2%
Belgium	10-40%	Italy	18%
Croatia	5.6-8.5%	Lithuania	40-50%
Czech Republic	20%	The Netherlands	23%
Denmark	55%	Poland	23%
Estonia	60%	Sweden	10-20%
Finland	34%	United Kingdom	65-70%

Source: Jonkers and Zacharewicz (2015) and OECD (2010)

2.1.2 Empirical evidence

Despite the need to understand the contribution of PBF to research productivity and economic and social return of public research resources, available and reliable empirical evidence in support of PBF schemes remains generally scarce, which is particularly a result of limited data availability. Table 5 summarises the empirical literature that looks at the impact of PBF schemes on research productivity. Research productivity is typically proxied by:

- Number of scientific publications (indexed in the Science Citation Index, the Social Sciences Citation Index, or the Arts and Humanities Citation Index) and quality of publications proxied by a publication impact index; and
- Number of patent applications.

The majority of the empirical literature uses university-level micro data (although Auranen and Nieminen (2010), Cattaneo et al. (2016), and RAND Europe (2016) look at the changes on a country level) and applies the following two types of analytical methods.

1. **Descriptive analysis**. This includes, for example, the study by Moed (2008) which looks at the time-series evolution of annual publications across the UK and associates changes in the quantity and quality of publications to the Research Assessment Exercises in 1992, 1996 and 2001. Similar analysis was done by Butler (2003) who analyses the trends in Australia's presence in the Science Citation Index in relation to the Australian PBF policy.

2. **Econometric analysis**. For instance Smart (2009) uses a linear regression model to investigate the link between the number of publications and PBF in New Zealand whilst controlling for confounding effects such as the number of research staff and university research income. Cattaneo et al. (2016) estimate the effect of

[10] The following countries are without a PBF: Malta, Greece, Cyprus, Luxembourg, Bulgaria, Latvia, Slovenia, Spain, Hungary, Japan, South Korea, and US. The following countries operate a PBF scheme but the PBF percentages could not be reliably identified: France, Portugal, Slovakia, Hong Kong, Australia, New Zealand, and Norway.

PBF introduction in Italy using a Tobit panel and system GMM regressions, including a set of controls.

The review of the literature finds mixed evidence on the effectiveness of PBF mechanisms. Moed (2008) provides a descriptive summary of the increase in aggregate research outputs following changes to PBF policies (although they do not adjust for potential confounding factors) and show that the UK publication output increased by 1.5% over the 1985-2003 period but the world share of UK papers declined by 0.2% at the same time. Cattaneo et al. (2016) investigates the effect of PBF introduction using micro data on 75 Italian universities, showing that PBF increased the number of articles published in scientific journals per faculty member by 0.300-0.387 (pre-PBF average was 0.44). Smart (2009) finds that, *all else equal*, the introduction of PBF in New Zealand improved research output measured by publications of New Zealand's universities by 20 to 34 percent, depending on the timing of the impact measured (short vs. medium term).

Notwithstanding that, Butler (2003) suggests that incorrect PBF schemes may lead to increase in research output at the cost of decline in its quality and several other studies found no statistically significant relationship between PBF and research outputs. Specifically, Auranen and Nieminen (2010) find that although some countries that introduced more competitive public research funding (e.g. the UK, Australia and Finland) appear more efficient overall than countries with lower share of competitive funding, they have not been able to increase their efficiency in publication output. Similarly, Osuna et al (2011) found no significant increase in publications after the introduction of PBF in Spain. Finally RAND (2016; see Appendix B) find no statistically significant effect of PBF on citations and a small negative effect on publications in the 31 analysed OECD countries.

Overall, the empirical literature related to PBF is relatively scarce and most of the studies are descriptive in nature and hence their findings have to be interpreted with caution.

Table 5: Performance-based funding literature review

Paper	Dependent variable	Controls	Methodology	Sample	Results
Auranen and Nieminen (2010)**	Publication counts per higher education R&D expenditure.	N/A	Qualitative and quantitative comparison of different PBF systems in OECD countries.	**Country level data** **Country:** 8 OECD countries (Austria, Denmark, Finland, Germany, Netherlands, Norway, Sweden, UK) **Period:** 1981-2000	Mixed descriptive evidence that countries introducing PBF do not necessarily increase their research efficiency ratios. Even though some countries that introduced more competitive public research funding (e.g. the UK, Australia and Finland) appear more efficient overall than countries with lower share of competitive funding, they have not been able to increase their efficiency in publication output.
Butler (2003)**	Publications indexed in the Science Citation Index, the Social Sciences Citation Index, and the Arts and Humanities Citation Index; and their impact index	N/A	Comparison of research output of two universities that introduced diverse research management or performance (?) strategies.	**University level data** **Country:** Australia **Period:** 1981-1999	Australia saw an increase in the number of research publications but a decline in the citation impact, a result of Australia's PBF aimed at quantity rather than quality of publications. Ever since a shift of formula-based publication assessment towards a stronger quality-focused assessment in 2003, these trends have flattened and the quality of Australian publications has improved.
Cattaneo et al. (2016)	Research productivity (defined as number of articles published in	University characteristics (age, size, student-faculty ratio, average tuition fee,	Estimate the effect of PBF introduction using a Tobit panel and system GMM	**University level data** **Country:** Italy	Introduction of PBF increases the number of articles published in scientific journals per faculty

Paper	Dependent variable	Controls	Methodology	Sample	Results
	scientific journals per faculty member)	indicator of medicine department, international ranking, indicator of private university, region) and legitimacy (public recognition of the university)	regressions to deal with potential endogeneity between research productivity and legitimacy of a university, using data on 75 Italian universities.	**Period:** 1999-2011	member by 0.300-0.387 (pre-PBF average was 0.44)
Jonkers & Zacharewicz (2016)	Publication counts, university autonomy	N/A	Analyse differences in characteristics, implementation and effects of PBF systems in EU member states using qualitative and quantitative methods.	**Country level data** **Country:** European Union member states and selected third countries **Period:** 1984-2000	The nature of systems differs widely across countries; the differences include the share of organisational level funding which is allocated through PBF, the speed within which the system is introduced, the degree of stakeholder involvement, the impact different systems have on the autonomy of research performers, or the criteria on which research outputs are assessed.
Moed (2009)**	Publications indexed in the Science Citation Index and their impact measures	N/A	Perform a longitudinal analysis of UK publication trends amid introduction of Research Assessment Exercise, a regular performance rating system used by higher education funding bodies in determining the main grant for research to the institutions they fund.	**University level data** **Country:** UK **Period:** 1984-2000	Annual publications across all UK Research Assessment Exercises increased. With the shift towards quality instead of pure quantity as performance measure in 1996, the share of UK publications declined, whereas its share of higher impact journals increased.
Osuna et al. (2011)	Publication counts	R&D expenditure and number of	Estimate the number of Spanish scientific	**University level data**	After taking into account level of R&D expenditure

Paper	Dependent variable	Controls	Methodology	Sample	Results
		researchers.	publications from Thomson Reuters using linear time trend regression (before and after treatment) and data on Spanish universities.	**Country:** Spain **Period:** 1980-2005	and number of researchers, there is no significant increase in publications after the introduction of PBF.
RAND Europe (2016)	Publication counts, citation counts	Higher education R&D expenditure, number of researchers, time trend and country effects	Estimate the effect of PBF introduction (a binary variable) using an OLS regression.	**Country level data** **Country:** 31 OECD countries **Period:** 1996-2014	No statistically significant effect of PBF on publications and citations
Smart (2008)	Publication counts	Lagged publication counts, time and institution dummies, and institution level controls.	Estimate total publication counts using linear panel regressions and data from 8 New Zealand universities.	**University level data** **Country:** New Zealand **Period:** 1996-2005	Introduction of PBF results in 20%, 28%, 34% higher research output in 3, 4, and 5 years after its introduction, respectively.

2.2 Public R&D funding targeted to regional strengths

2.2.1 Policy background

This group of policy interventions are linked by their strategic orientation towards targeting and coordinating public funding. The resulting policy interventions can be broadly classified based on two (relatively overlapping) objectives:

1. Capitalising on regional strengths to develop favourable business ecosystems to achieve network spill-overs. This objective is mainly achieved through policies known as cluster policies; and

2. Harnessing and upgrading specific knowledge capabilities including technology capabilities to support innovation-driven economic transformation. Policies known as smart specialisation strategies are employed to address this objective.

Both policies are aimed at increasing R&D productivity. However, in contrast to cluster strategies which are potential drivers of the emergence of a wider regional innovation system or entrepreneurial eco-system, smart specialisation strategies are often aimed at creating the conditions that can transform the regional economy based on a specific set of expertise.

Cluster policies and strategies

Cluster policies and strategies are focussed on local or geographic concentrations (i.e. clusters) of firms, higher education and/or research institutions to facilitate collaboration on research and economic activities. By capitalising on geographical proximity between private firms and universities, cluster policies aim to induce network spill-overs to create agglomeration effects and capitalise on advantages of greater competition and rivalry (Marshall, 1890; Saxenian, 1994; Porter, 1998). Due to these agglomeration effects, the cost of R&D for the cluster-based organisations (universities and private firms) can be lowered. This can result in marked improvement in the innovation output and productivity across the cluster (Porter, 2000; Spencer et al, 2010).

Policy instruments commonly used at the national and regional level to achieve aforementioned network spill-overs include (Uyarra and Ramlogan, 2012):

- Public R&D funding;
- Setting up of intermediary entities;
- Venture capital funds;
- Creation of regional competence centres; and
- Networking or training activities.

Since their emergence in the 1990s, cluster policies have become a standard policy instrument, reaching developed to developing countries alike (Ketels et al., 2006). These approaches are mainly based on a competitive scenario drawing on a Marshallian approach. However, as Uyarra and Ramlogan (2012) observe in their review, although research on clusters has shown them to be important for providing resources and appropriate conditions for innovation there is a weakness in the study of cluster long term performance and impacts in terms of innovation, productivity or employment. Evaluation of cluster policy historically has been rare, and complicated by attribution issues and notably time lags (OECD, 2010).

At European level, Denmark, the Netherlands and Finland started with implementing cluster policies with a focus on innovation, followed by Austria, France and Germany and the United Kingdom (Isaksen and Hauge, 2002). Some countries like the Netherlands, Austria and France have more explicit and in-depth cluster policies in place, either as part of their wider economic strategy or as a tool to promote R&D competitiveness.

An example of a cluster policy is the German cluster strategy of 2006 (termed 'High-Tech strategy') as a result of which the German federal government committed billions of euros annually to the development of cutting-edge technologies as part of a broader policy framework conducive to innovation (Powerhouse Eastern Germany, 2017). As a result of the strategy, Germany increased its expenditure on R&D from €54.4 billion in 2003 to €79.4 billion in 2012 (Legislative Council Secretariat, 2015). In 2012, the value of high-tech exports amounted to €143 billion with Germany performing particularly well in automotive, mechanical, electrical engineering industry, and chemical industry (Legislative Council Secretariat, 2015). As of 2013, the top 15 clusters in Germany (covering automotive, finance, and metal industries among others) provided employment for more than 1 million personnel, an outcome that can be argued to be partly attributable to the cluster policy (European, Commission, n.d.).

Box 1: Becattini school of thought

The other relevant strand of literature is based on Becattini's view of the industrial district which discusses cooperation within clusters and its effects. The concept of technological district is in some ways more advanced than that of clusters as described by Porter (1990), i.e. agglomeration of firms in the same place that exploit some coordination advantages due to proximity. Becattini's industrial district adds the socio-economic effects of networked infrastructure and soft institutions (also known as social capital), the learning element which emerges from division of labour and tends to explain innovation, and industrial dynamics in traditional sectors of the economy. Becattini's view is influenced by Marshall's theory of *Industry and Trade* (1920), as well as the *Third Italy* model of industrial development which emerged in the 1970s-90s. The latter consists of networks of small- and medium-sized firms in traditional sectors in the north-eastern and central parts of Italy, chiefly in traditional manufacturing sectors, such as textile and clothing, glasses, textiles, metalwork, furniture, ski boots and footwear, leather goods, tiles and furniture.

Becattini conceives an industrial district as a 'socio-territorial entity' (1990), which comprises both a community of people and a network of firms *"in one naturally and historically bounded area"*. The district is characterised by *"…self-containment and the progressive division of labour"*. The firms in the district tend to be involved in the same industrial domain (a term not used by Becattini but currently in vogue in the context of the Smart Specialisation debate). In this case, the concept of domain bears a direct relationship with Marshall's definitions of 'main industry' and 'auxiliary industry', which resonates with the concept of *filière de production* or a vertically integrated production chain (Becattini 2002). Interaction among firms is normally characterised not just by a common vision and ethics, but also by a concurrent spirit of competition and cooperation – based on which the term *coopetition* was subsequently coined (Brandenburger and Nalebuff, 1996).

To illustrate his arguments, Becattini (1998) discusses how in the 1980s, many Italian districts emerged thanks to the increased refinement of consumers' preferences – which coincided with a prolonged period of increase of the national GDP and income per capita. However, many of the goods designed and/or produced by *Third Italy* came also to exemplify the essence of the so-called *Made in Italy* – a sort of national trademark that is synonym of high quality and sophistication (Becattini 1998).

Furthering the ideas put forward by the Marshall and Becattini approaches, more recent research has heightened the importance of viewing clusters within a wider context (Asheim et al.,2011; Cooke, 2012; Njøs and Jakobsen, 2016) rather than serving industry specific value chains, such that clusters are viewed as regional constellations of related actors.

Smart specialisation strategies

Smart specialisation strategies are focussed on entrepreneur-led search and discovery and innovation process for new areas of specialisation that build on specific knowledge or technology capability. These strategies tend to affect R&D productivity as a result of spill-overs due to a higher collective pool of specialised knowledge. As a result of smart specialisation strategies the costs of R&D activities can decrease in relation to specific knowledge or technology capability. The focus on a specific capability can enable the participating HEIs, PROs, and private firms to achieve economies of scale that can lead to enhanced R&D productivity.

Smart specialisation is a very recently adopted policy area, promoted by the European Commission since 2010, as part of wider regional and so-called "knowledge-based development" strategies across Europe. Smart specialisation strategies also include technology specialisation strategies which are aimed at specific technology sector (e.g. nanotechnology, biotechnology) based on the revealed technological advantage (RTA) for a region.

A notable example of smart specialisation strategy is the catapult centres establishes by the UK government with £1.5 billion of public and private funding for a period of five years starting from 2015 (Department for Business Innovation and Skills, 2015). Some of the key knowledge and technology capabilities identified by the UK government for smart specialisation through the catapult centres as of 2015 include future cities, energy systems, digital economy, transport systems, and satellite systems.

Around three years from its official launch, the emphasis for smart specialisation has shifted from the analysis of the preconditions for policy design and priority identification, to the actual implementation of the principle and guidelines provided by the European Commission (EC). Above all, the Directorate-General for Regional and Urban Policy (DG REGIO) and the Smart Specialisation Strategy (S3) Platform at the Directorate-General Joint Research Centre (DG JRC) have been placing a significant effort in assisting various regions and countries understand smart specialisation better and so design their strategy and implementation policies.

The main lessons learnt from the analysis of the processes of design and (initial) implementation of smart specialisation strategies from a number of European regions is presented in an EC Handbook "Implementing Smart Specialisation Strategies" (Gianelle et al, 2016). As highlighted in some parts of the EC handbook, to date no hard evidence yet exists as to the actual outcomes of the new strategy. That is, neither in terms of the ability of any specific region to deviate from its current path of technological and industrial specialisation, nor with regard to economic outcomes of the transformative process (e.g. innovation performance, value-added indexes, regional GDP, inward investment, and export performance).[11]

2.2.2 Empirical evidence

Even though many member states have made cluster policies an integral part of their national innovation strategies, it is quite difficult to evaluate their effects at national level, particularly due to the diversity of cluster objectives and application of different instruments. The empirical literature is also quite diverse. However, two principal strands of focus in the literature can be distinguished, as described in Table 6 in detail:

- **Evaluation of cluster policies.** These can be targeted at both creation of an industrial or technological cluster itself (Nishimura and Okamuro, 2011) or at promoting cooperation within already existing clusters (Falck et al., 2010). For instance, the Japanese Industrial Cluster Project policy evaluated in Nishimura and Okamuro (2011) aims to promote cluster creation through offering support in network formation, R&D financing, start-up formation, marketing, management, and fostering human resources.

- **Impact evaluation of firm's presence in a cluster.** For instance, Baptista and Swann (1998) and Beaudry and Breschi (2003) analyse how a firm's proximity to a cluster or other firms from the same industry can affect firm's research outputs.

These studies aim to evaluate the effect of a particular public policy – grant schemes, promotion of cooperation, or promotion of cluster creation – or proximity to a on the propensity to create or apply new inventions.

The range of methodologies used is broad and depends on the particular study objectives.

- **Econometric analysis.** Nishimura and Okamuro (2011) analyse 229 SMEs involved in university-industry partnerships using negative binomial, Poisson, Tobit, and zero-inflated negative binomial regressions. Similarly, Baptista and Swann (1998) analyse 248 British firms and the number of innovations they produced using the OLS, negative binomial and Poisson regressions. These models use additional control variables such as industry fixed effects or firm's market share to control for confounding factors.

- **Differences-in-differences methods with additional controls**. Engel et al. (2013) use a differences-in-differences approach in a generalised linear model framework to allow for different initial regional conditions, comparing firms across all German regions in terms of research outcomes, whereas Falck et al. (2010) uses a differences-in-differences method, comparing firms in target industries

[11] Other studies including Asheim, Grillitsch, and Trippl (2016), Paliokaitė, Martinaitis, and Sarpong (2016), Moodysson, Trippl, and Zukauskaite (2016), Rosiello, Mastroeni, Castle, and Phillips (2015), and Muscio, Reid, and Leon (2015) also provide insights around the design and implementation of Smart Specialisation strategies.

with similar firms in other regions, including a control group drawn from the original region. Particularly the latter study uses an innovative approach to avoid the self-selection bias that may persist in the econometric studies, and thus provide more reliable results.

Despite the apparent differences in geography, data and methodology used, there is a broad consensus on the positive effects of the cluster policy. Policies promoting cluster cooperation as well as presence of a firm in an industrial cluster itself increase the likelihood and number of research outcomes. In particular, Nishimura and Okamuro (2011a, 2011b) find R&D productivity gains from the Industrial Cluster Policy (ICP) in Japan, particularly where policy helps indirect coordination support, such as university-industry partnerships. Falck et al. (2010) find that the German cluster-oriented economic policy increased the likelihood of a firm becoming an innovator in the target industry by 4.7-5.7 percentage points, whereas Baptista and Swann (1998) and Beaudry and Breschi (2003) show that firms located in strong industrial clusters (measured by sector employment) produce more innovations.

Table 6: Overview of available empirical evidence on R&D productivity and/or technology adoption

Paper	Policy instrument	Dependent variable	Controls	Methodology	Sample	Results
Engel et al. (2013)	Cluster-oriented public grant scheme	Number of patent applications	Number of firms, new firm formations, international competitiveness, share of MINT employees, sectoral specialisation and agglomeration.	Evaluate the R&D enhancing effects of two large public grant schemes for the German biotechnology industry offering grants to regions with high expected social return on public funding, using a differences-in-differences approach in a generalised linear model framework to allow for different initial regional conditions, using data on all firms participating in the competition.	**Country:** Germany **Period:** 1991-2006	Winners of public grant schemes generally outperform non-winning participants, suggesting that exclusive funding and the stimulating effect of being a winner have a positive effect on R&D activity in the short-run. Elasticity of patent applications with respect to competition success 0.15-0.72 when comparing winners to non-winners. In the long run the results are ambiguous.
Baptista and Swann (1998)**	Industrial clusters	Number of innovations introduced	Industry fixed effects (indicators for 10 manufacturing industries), firm's market share, industry concentration, region population, dummy for entry knowledge stock	Analyse whether firms located in strong industrial clusters or regions are more likely to innovate than firms outside these regions using OLS, negative binomial and Poisson regressions using data on 248 British firms.	**Country:** UK **Period:** 1975–1982	Firm is considerably more likely to innovate if own-sector employment in its home region is strong. A one unit increase in the regional employment measure (approx. 0.8% change) increases the amount of innovations produced by 0.0098.
Beaudry and Breschi (2003)**	Industrial clusters	Number of patent applications	Regional strength in an industry and in other industries (measured by sector employment), Herfindahl index for employment in all manufacturing sectors, share of regional population	Analyse whether firms located in strong industrial clusters are more innovative than firms located outside of these regions using a negative binomial model using data on 26,055 and 37,724 manufacturing firms in the UK and Italy.	**Country:** UK and Italy **Period:** 1990-1998	Presence of other innovative firms in the industry has a positive and significant effect on the total number of patents produced (a one-point increase in cluster employment of innovative firms in a firm's own industry increases the number of patents produced by a firm by 0.265), presence of non-

Paper	Policy instrument	Dependent variable	Controls	Methodology	Sample	Results
			located in region's main town, firm size, and firm's previous innovative activities.			innovative firms a negative effect (a decrease of -0.350).
Falck et al. (2010)*	Public policy promoting cooperation among organisations	Likelihood of firm becoming an innovator	Industry-specific and state-specific time trends.	Evaluate the impact of a cluster-oriented economic policy aimed at increasing the innovation activity of firms in high-tech industries using a difference-in-difference-in-differences method, comparing firms in target industries with similar firms in other regions, including a control group drawn from the original region on the sample of 1039 German firms.	**Country:** Germany **Period:** 1994-2004	The Bavarian High Technology cluster policy increased the likelihood of a firm becoming an innovator in the target industry by 4.7-5.7 percentage points.
Nishimura and Okamuro (2011)*	Public policy promoting creation of industrial clusters	Number of patent applications	Firm size, industry dummies, collaboration dummies.	Examine the effects of the Industrial Cluster Project – a policy supporting firm creation in Japanese industrial clusters - on the R&D productivity using a sample of 229 SMEs using a negative binomial, Poisson, Tobit, and zero-inflated negative binomial regressions.	**Country:** Japan **Period:** 2003-2005	Being participant in a cluster project with a national university from the same region (a joint effect of *participant x national x same region*) increases the number of patent applications by 0.796 on average, an increase of 9.3% when compared to the baseline of 8.56 patent applications.

2.3 Public-private cooperation

2.3.1 Policy background

In Europe, universities and other PROs are the main beneficiaries of public R&D funding. In order to facilitate effective transformation of research outputs and academic knowledge into better technologies, policy strategies related to public-private cooperation aim to improve the process of knowledge transfer from universities and PROs to industry as well as develop reciprocal interaction to improve overall research performance. The objective is to increase research productivity by avoiding duplication of research efforts, stimulating additional private R&D investment (additionality effect), and exploiting synergies and complementarities of scientific and technological capabilities (Perkmann et al. 2013). Collaboration between universities or PROs and industry has long been regarded as a key driver for skills development (e.g. education and training), the generation and adoption of knowledge in the scientific community, and the promotion of entrepreneurship (e.g. start-ups or spin-offs) (Rosenberg and Nelson, 1993; Cockburn and Henderson, 1998; Zucker et al, 2002).

Typically, the motivation for industry to collaborate with universities or PRO includes access to complementary technical and tacit knowledge (which can include elements of basic research often not pursued by private firms), access to a pool of skilled workers and providing industry relevant training to researchers, access to publicly funded research facilities and equipment, but also sharing costs of R&D. On the other hand, universities benefit from collaboration with industry through access to private funding, reputational enhancement and potentially the improvement of teaching.[12]

Forms of public-private collaboration differ in scope and intensity (Koschatzky and Stahlecker, 2010).

- **Formal vs. informal.** Collaborations can be formal based on equity partnerships (e.g. research joint ventures), research contracts, research projects, or patent licensing. Informal collaborations are characterised by research mobility between universities and industry, sharing of publications or interactions between university researcher and industry representatives at expert groups and conferences.

- **Short vs. long-term.** Short-term collaborations include on-demand assignments for university researchers based on contract research, consulting or licensing. Long-term collaborations associated to joint projects and research partnerships, joint university-industry research centres or research consortia. Long-term collaborations are more strategic and open-ended.

In the EU three relevant policy initiatives are considered to have accelerated in recent years the rate of knowledge transfer from universities or PROs to industry.

- **Legislation to stimulate research joint ventures between universities and firms** (e.g. the EU Framework Programmes, including Horizon 2020). For instance, Horizon 2020 includes a clause that certain projects can only be applied when the proposal is from public-industry consortia. The EU has 3 directives in relation to public private cooperation / partnerships that are relevant here - Directive 2014/23/EU (concession contracts) (PPPIRC, 2016a), Directive 2014/24/EU (public procurement) (PPPIRC, 2016b), and Directive 2014/25/EU (procurement by entities operating in the water, energy, transport and postal services sectors) (European Parliament, 2016). These directives seek to

[12] By including industry relevant content on the curriculum.

transparency in procurement and fostering cooperation between public and private sectors (including universities and the industry).

- **Changes to the intellectual property regime in favour of universities** (e.g. similar to enactment of the Bayh–Dole Act of 1980 in the USA and encouraged by EC policy recommendations[13]). This permits universities, or small business to pursue ownership of an invention rather than writing over property rights to the government. The EC recommendation C(2008)1329 (European Commission, 2008) provides Member States with policy guidelines for the development or updating of national guidelines and frameworks; identifies practices of public authorities that facilitate the management of IP in knowledge transfer activities by universities and other PROs; and provides PROs with a Code of Practice, in order to improve the way they manage IP and knowledge transfer (van Ecke et al., 2009).

- **Strategies and programmes to enhance informal knowledge links**, such as open innovation and open science reforms to open research outputs and data for the use by the industry. As part of the EU Framework Programme for Research and Innovation, the EU created a set of recommendations in 2012 (European Commission, 2012) for the EU member states in relation to funding and development of open science practices. For FP7 and H2020 project, the EU has adopted an open access policy to improve the impact of publicly-funded science research. A key underlying goal being to *"improve the capacity to compete through knowledge"*(European Commission, 2016).

2.3.2 Empirical evidence

There is generally a lack of empirical evidence that directly assesses the effectiveness of policy strategies related to public-private R&D cooperation. However, a number of empirical studies exist in the literature which assess more broadly the impact of different forms of public-private cooperation on private R&D productivity.

Typically, these studies use firm-level data and seek to quantify the impact of a public-private cooperation proxy on an innovation measure. There are three key methodological aspects that differentiate these studies.

- **Measure of cooperation**. The majority of the studies reviewed model firms' R&D productivity as a function of whether a firm is cooperating with a university or PRO using a binary variable that identifies whether there is any form of cooperation. Kaiser and Kuhn (2012) proxies collaboration on the basis of whether a firm participates in an industry-PROs joint venture and Czarnitzki and Fier (2003) by the amount of public public-private cooperation-related subsidies received by a firm or PRO. The latter study captures not only the presence but also the intensity of cooperation.

- **Outcome variable.** Four different outcome variables have been used to measure the impact of public-private cooperation on innovation: (i) patents or patent applications; (ii) product or process innovations; (iii) product sales; and (iv) total factor productivity.

- **Key challenge.** The main challenge in this strand of the literature is the identification of causal effects: firms that decide to cooperate with public organisations may devote more resources on R&D and the potential correlation

[13] Represents legislation that deals with intellectual property arising from federal government-funded research. Before the Bayh–Dole Act, federal research funding contracts and grants obligated inventors and researchers to assign their inventions made using federal funding to the government. The Bayh–Dole Act permits a university, or small business to pursue ownership of an invention it made in preference to the government.

between innovation and cooperation may reflect this association rather the impact of cooperation on innovation. The studies of Lööf and Broström (2008), Harris et al. (2011) and Kaiser and Kuhn (2012) explicitly deal with this issue by using difference-in-difference and propensity score matching approaches. The results of these studies are in principle more reliable than the results of the other studies reviewed.

The results of the empirical literature are summarised in Table 7 and discussed below.

- The three studies mentioned above document significant impact of public-private cooperation on innovation. Lööf and Broström (2008) find that collaboration with university increases a manufacturing firm's propensity to apply for patents by more than 17%. Harris et al. (2011) find that collaborating with HEIs increases a firm's total factor productivity by more than 10%. Kaiser and Kuhn (2012) report that becoming a member of publicly subsidised research joint venture increases a firm's patent applications by nearly 70%.

- Other studies report similar large effects. For example, Becker (2003) finds that firms that cooperate with universities were 45%-54% more likely to create a product innovation, whereas Marotta et al. (2007) find that collaboration with universities increases the probability of introducing a new product by 17%-29%.

- Furthermore, some studies report that the impact depends on industry-specific factors and research quality of PROs. Lööf and Broström (2008) find that effect of university-industry collaboration on sales and patent applications increases the propensity to apply for patents for manufacturing firms but not for service firms. Baba et al. (2009) document that collaboration is only beneficial when it involves 'high-quality' universities or researchers;[14] collaboration with low quality researchers or universities seems to have no productivity enhancing effect. Fritsch and Franke (2004) find cooperation with German public research institutions to be a positive and statistically significant predictor of firms achieving a patent, but other forms of cooperation were not found to be significant.

[14] Quality measured in terms of ex-ante patent activity.

Table 7: Public-private cooperation literature review

Paper	Policy instrument	Proxy variable	Controls	Methodology	Sample	Results
Arvanitis et al. (2008)*	Engagement in knowledge and technology transfer activity	R&D expenditure, sales share of new products, value added per employee	Economy sector, level of human capital, firm age, export activities, reported obstacles to R&D	Estimate firm productivity (patents per R&D employment) using data on 2,428 Swiss firms in a three-equation model starting with the knowledge and technology transfer equation which subsequently serves as an input in an innovation equation.	**Country:** Switzerland **Period:** 2002-2004	Introduction of knowledge and technology transfer activities increases labour productivity by 6.3% on average compared to firms with no such activity.
Baba et al. (2009)**	University-industry collaboration	Patent counts	Total number of publications by the firm's members, number of corporate inventors	Estimate the number of registered patents using a negative binomial regression model applied to a sample of 455 firms active in the photocatalysis industry in Japan.	**Country:** Japan **Period:** 1970-2006	A 1% increase in the number of collaborative patent applications with university researchers involved in many patent applications in addition to authoring many high-quality scientific papers increases the number of patents registered by the university by 0.171%. Collaboration with less productive scientists is not statistically significant.
Becker (2003)	University-industry collaboration	Number of product innovations	Importance of external knowledge, firm size, market concentration, different forms of R&D cooperation, degree of product diversification	Estimate a set of simultaneous equations using a dataset of 2,048 German firms, with the R&D expenditures to sales ratio (measuring firms' investments in the development of new products) and indicator variable for realisation of product innovations in the 1990-1992 period as the main input/output dependent	**Country:** Germany **Period: 1990-1992**	Firms in R&D cooperation with universities were 45%-54% more likely to create a product innovation.

Paper	Policy instrument	Proxy variable	Controls	Methodology	Sample	Results
				variables.		
Belberbos et al. (2004)**	University-industry collaboration	Sales from innovative products per employee	Type of collaborator (competitor, supplier, customer, university and research institutes), proxy for spill-over effects, firm size, firm innovation intensity, lagged productivity and industry fixed effects.	Estimate a linear regression model with productivity growth measured by value added per employee or sales generated by new to the market products per employee as the dependent variable using data on 1,360 Dutch firms.	**Country:** Netherlands **Period:** 1996-1998	Firm's R&D cooperation with university increase sales growth from innovative products per employee by 37%. No effect on labour productivity was found.
Czarnitzki and Fier (2003)	Subsidies for R&D collaboration	Patent (application) counts	Firm size, R&D capacity, firm age, region, industry and time trend	Estimate the likelihood of at least one patent application made in the last three years using a probit model and estimate the number of patent requests using negative binomial regression model, based on data on 3,568 German firms.	**Country:** Germany **Period:** 1993-2001	Firms collaborating with public research institutions exhibit 26%-35% higher probability to submit a patent application and get it granted than non-cooperating firms. The effect is higher for publicly funded and subsidised cooperation (43%-59%) and is not significant if a single firm receives the R&D grant (i.e. if it does not collaborate with anyone).
Harris et al. (2011)	University-industry collaboration	Total factor productivity, measured using the gross value added and factor inputs from companies' financial statements	Firm employment, capital stock, firm age, human capital (workforce with university degree), industrial diversification, Herfindahl index , foreign-ownership dummy, single plant enterprise dummy, industry, region, and knowledge sourcing	Compare firm-level total factor productivity by looking at firms that collaborate with universities (a self-selected group) and a counterfactual created using propensity score matching on the total of 14,872 UK firms.	**Country:** UK **Period:** 2004-2006	Collaborating with HEIs increases firm's total factor productivity by 11.3%-11.9% on across all industries (9.2%-15.1% for the production sector and 10.4%-14% for the non-production sector) compared to firms that do not collaborate with universities.

Paper	Policy instrument	Proxy variable	Controls	Methodology	Sample	Results
			strategy dummies.			
Kaiser and Kuhn (2012)	Public-private research joint ventures	Patent application counts	Lagged patent applications, lagged patent stock, firm age, dummy for private ownership, sales concentration, time trend, stock market listed, region	Compare patent stocks of firms participating in public-private research joint ventures (a self-selected group) to a counterfactual created using propensity score matching on the total of 27,798 Danish firms.	**Country:** Denmark **Period:** 1990-2004	Becoming a member of publicly subsidised research joint venture increases the number of patent applications by 0.00387 in the short-run and by 0.01615 three years after joining the research joint venture. If the baseline of average annual patent applications of 0.0056 is used then the short-run effect corresponds to a 69% increase in the patent applications on average.
Lööf and Broström, (2008)**	University-industry collaboration	Patent application	Innovation input (e.g. R&D expenditure, training, market introduction and other preparation related to innovation), firm size, export ratios, export ratio, human capital (employees with university degree), focus on the global market, foreign ownership	Assess the effect of university-industry collaboration on sales and patent applications using propensity score matching of participating firms with similar organisations not in cooperation with universities, using the sample of 2,114 Swedish firms.	**Country:** Sweden **Period:** 1998-2000	University collaboration increases the propensity to apply for patents for manufacturing firms by 17%-32%, whereas no such association can be found for service firms.
Marotta et al. (2007)	University-industry collaboration	Patent application counts	Human capital indicators (e.g. knowledge of supervisors and workers), firm size, firm age, export behaviour, existence of	Estimate propensity to introduce product or process innovation patenting using a probit model using dataset on 706 and 6,221 firms from Chile and Colombia,	**Country:** Chile and Colombia **Period:** 1998-2000	Collaboration with universities increases the probability of patent activity in the firm by 37%/44% and the probability of introducing a new product by 29%/17% for Chile/Colombia, respectively. Internal

Paper	Policy instrument	Proxy variable	Controls	Methodology	Sample	Results
			R&D department, innovation intensity (innovation expenses/number of employees), industry fixed effects	respectively.		collaboration does not seem to have a statistically significant effect on the outcome measures.
Robin and Schubert (2013)*	Industry collaboration with public research institutions	Sales from new products	Firm size, R&D expenditures, sales, relative size of competitors, industry and region dummies, concentration of universities, and indicator of openness of the company.	Estimate the change in share of total sales due to new products and propensity to introduce a product innovation using a Heckit regression (Tobit with Heckman selection) on the sample of 20,672 French and 5,200 German firms.	**Country:** France, Germany **Period:** 2002-2008	Cooperating with a public research institution entails an increase in the share of sales from new products (France: 2 percentage points; Germany: 5 percentage points). In contrast, R&D cooperation does not seem to have positive impact on process innovation.

2.4 Research commercialisation

2.4.1 Policy background

The process of conversion of scientific outputs into new technologies is referred to as research commercialisation. Public policy support for research commercialisation is aimed at addressing shortcomings of publicly funded R&D in producing new, marketable technologies. This is because universities and PROs, the organisations usually engaged in public R&D, emphasise basic (as opposed to applied) research[15]. Although part of this research is commercialised or used by the private sector as input to other R&D projects, in case of some research projects, significant part of the research is either underutilised or in some cases not utilised at all.

As outlined by Cervantes and Meissner (2014), the low rates of research commercialisation for public R&D are mainly due to the following four types of challenges.

1. **Asymmetric information**. Potential users in the industry may not be aware of university inventions.

2. **Lack of clarity on IP rights**. Due to lack of clarity over ownership of university inventions, industrial partners may not be prepared to engage in commercialisation process. Hence, industry may be reluctant to invest if there is a lack of legal framework securing IP rights.

3. **Coordination challenges**. Incentives for universities and industry may be misaligned, e.g. the industry has stronger focus on applied research and the universities emphasise basic research.

4. **Financial challenges**. Often there are insufficient funds available at universities and PROs for developing prototypes and demonstration projects that can subsequently attract private finance from industry.

The policies and strategies for research commercialisation are intended to address these challenges, and improve the pace and effectiveness through which research outputs are transformed. This transformation is in the form of new products and processes where the transfer of technologies is centred on patenting and licensing[16] of academic inventions and the promotion of academic start-ups[17]. Policies to enhance the commercialisation of public R&D mainly focus on (OECD, 2013):

- **Legislative initiatives related to commercialisation and patenting.** These initiatives are intended to address the challenge of asymmetric information i.e. the industry's lack of awareness about the research conducted at the universities. Most European countries have moved to a system of institutional ownership (Geuna and Rossi, 2011) as part of which the universities and research organisations manage the IP on behalf of the researchers. In contrast to the individual researcher, the universities can build on economies of scale and establish long-term institutional relationships with the industry. This mechanism provides certainty and clarity in the legal framework, improves management of the use of IP and thus provides better opportunities commercialisation.

[15] Private firms are generally unwilling to invest in early stage R&D (and basic research) because of the difficulties of appropriating private returns, although social returns can be high. This is the main justification for public R&D. See Becker (2015).
[16] Licensing income streams are usually measured as total university royalties from all types knowhow and IP (e.g. patents, copyrights etc.)
[17] Public research spin-offs are seen as a mechanism for the exploitation and commercialisation of publicly developed R&D. They are often defined as venture between public research institutions and industry.

- **Encouraging industry engagement by granting licences on IP rights free of charge.** This mechanism is intended to address the lack of clarity regarding ownership and transfer of IP rights and lower the perceived risk of legal disputes. Exchange of knowledge is embedded in IP documents and contracts between universities and industry to enhance commercialisation. This is driven by the IP policies of universities.

- **Intermediaries and bridging organisations**. In order to address the coordination challenges, the universities have established intermediaries in the form of Technology Transfer Offices (TTO) in order to reduce search costs between actors involved in the commercialisation process. Other intermediaries to improve coordination between universities and the industry include science parks or technology hubs.

- **Pre-commercial innovation procurement.** As part of this policy, the public sector purchases inventions from academic research to reduce the financial challenges of developing prototypes or demonstration projects. The inventions purchased from academic research are almost market ready but with initial low scale (of production or manufacturing) in order to stimulate innovation and accelerate the pathways to market through private firms.

2.4.2 Empirical evidence

The available literature focuses largely on the evaluation of effectiveness and productivity of individual programmes/interventions related to intermediaries or bridging organisations such as TTOs at the micro level of a firm or institution. Due to legislation favouring commercialisation of research inputs through strong intellectual property rights, most of the studies are focused on the US universities, where TTOs are relatively more effective than in other countries, which also generally lead the world rankings for the highest amount of patents, licenses, royalties, and start-ups.

Working with university level data, the studies look at the relationship between the presence, size, and characteristics of university TTOs, which broadly serves as a proxy for university's dedication to research commercialisation, and mainly one of the following outcome variables.

- **Number of patents.** For instance Anderson et al. (2007) assess the efficacy in producing research outputs given R&D spending, arguing that given the relatively high patent application fee and complex process of patenting, not all invention disclosures are subsequently used for patent applications. Universities focused on commercialisation and those with better administrative/legal support are more likely to apply for patents.

- **Number of licences and royalties.** Since universities generally do not profit from patent protection through production or services (unless a start-up is formed – see below), most of the patent-related income comes from licensing. Transforming patent grants into licenses is thus essential step in the commercialisation process. Looking at both the number of licenses and amount of royalties allows assessment of both quality and quantity of licensing, e.g. Carlsson and Fridh (2002) look at both licenses and patents as outputs of a research process with R&D spending as inputs.

- **Number of start-ups.** As an alternative to licensing, an innovation can be commercialised directly through a spin-off company. Caldera and Debande (2010) consider a full set of production equations based on a theoretical model starting with an R&D budget that is subsequently transformed into patents, which serve as explanatory variables for the number of licenses or start-ups.

While some of the studies look at only a specific subset of the outcome variables (e.g. Chapple et al., 2005, considers only the number of licenses and licensing outcome), others evaluate the full range of relevant measures (e.g. Thursby and Kemp 2002 looks at the number of licenses, industry supported research, new patent applications, invention disclosures, and amount of royalties received). Further, two principal strands of methodological approach in the empirical literature can be identified:

- **Methodology.** The main methodology used is standard Ordinary Least Squares (OLS) regression (e.g. Caldera and Debande (2010) estimate a series of performance equations where technology transfer outcomes are expressed as a function of the TTO size, TTO age, and TTO specialisation in R&D contracts), but also more complex models such as the zero-inflated negative binomial regression estimating the number of agricultural biotech patents produced as in Foltz et al. (2000).

- **Key challenge.** Universities that have established a TTO may have more and better resources than universities that do not have a TTO. In order to quantify the marginal impact of TTO on innovation the quality and quantity of R&D resources need to be controlled for. Caldera and Debande (2010), for instance, controls for university characteristics (university size and type), Carlsson and Fridh (2002) for differences in R&D expenditure, Thursby et al. (2001) for the quality of faculty and Thursby and Kemp (2002) for the type of faculty (biological sciences, engineering, physical sciences) and its quality rating.

The results of the empirical literature can be summarised as follows.

- **Commercialisations strategies tend to lead to increased income from patents and licences**. Almost all the empirical studies are in agreement that the various forms of commercialisation promotion (mainly creation and expansion of a university TTO) are beneficial. Almost all the empirical studies are in agreement that the various forms of commercialisation promotion (mainly creation and expansion of a university TTO) are beneficial. In particular, increasing licensing activity from existing intellectual property is likely to generate greater revenue in the short term compared with higher risk and uncertain income prospects from encouraging spin outs activity (Barjak et al., 2015). Patenting activity is also important to create opportunity for future licensing income. However, the challenge is to identify policy approaches to support patenting and licensing activity which also support increased spin-out activity (Berbegal-Mirabent et al., 2015; Barjak et al., 2015).

- **The effect sizes vary across studies**. Assessing the performance of UK TTOs, Chapple et al. (2005) find that a 1% increase of staff increases the income from licensing by about 0.37% and the number of licences by about 0.13% leading to the suggestions that hiring more staff in TTOs may lead to higher numbers of licences and larger revenues thereof. Furthermore, Caldera and Debande (2010) show that university internal factors such as university policies and incentives, tend to have an important impact on the knowledge transfer performance. For instance, the study's findings suggest that an increase in the size of the TTO by one staff member is associated with a rise in R&D contract income of about 44 to 60 percentage points. Similarly, Foltz et al. (2000) estimate the effect of one additional TTO staff member (approx. 30% increase in the TTO employee count) increases the number of agricultural biotech patents by 29.2% and Thursby et al (2001) estimates that an additional TTO staff member increases the number of licences by 36.5% on average.

- **Differences between private and public universities (including external factors)**. According to Anderson et al. (2007) there are substantial differences between public and private universities in the effectiveness of transforming research funding across into licensing income, start-up companies, and patents. More recently, Berbegal-Mirabent et al, (2015) and García and Ribeiro-Soriano (2015) identify factors such as the capabilities of TTO staff as a more important influence on TTO activity than increasing the number of TTO technical staff. Both studies found that TTOs that generate greater R&D contract income have more accumulated experience, larger budgets and better international social networks than average TTOs. Berbegal-Mirabent et al. (2015) also found that the presence of science parks boosts the number of R&D contracts, whereas being a polytechnic university increase R&D contract income.

Table 8: Research commercialisation literature review

Paper	Policy instrument	Outcome variable	TTO characteristics (where applicable)	Controls	Methodology	Sample	Results
Anderson et al. (2007)**	Intra-university commercialisation strategies	Number of invention disclosures, patent applications, license and option agreements.	N/A	Public/private ownership, medical school status	Estimate the effectiveness of university technology transfer using Data Envelopment Analysis with total research spending as the input variable. The method compares selected universities in terms of their outputs given inputs (R&D spending) and ranks them according to their effectiveness.	**Country**: US **Period:** 2001-2004	Private universities are not any more efficient than their public counterparts in terms of technology transfer. Substantial differences exist in effectiveness of transforming research funding into licensing income, start-up companies, and patents. Universities at the productivity frontier are up to 6.19 times more efficient than the least effective universities.
Caldera and Debande (2010)**	University technology transfer office (TTO), established policies and procedures for the management of technology transfer	Licensing income and number of licenses, R&D income and number of R&D contracts, number of spin-offs	TTO size (number of staff), age, specialisation	Science park dummy, inventor royalty share, rule on copyrights dummy, rule of invention dummy, control for university characteristics (university size, university type)	Estimate a series of performance equations where technology transfer outcomes are expressed as a function of the TTO size, TTO age, and TTO specialisation in R&D contracts using OLS regression on the data from 52 Spanish universities	**Country**: Spain **Period:** 2001-2005	One additional TTO staff member (approx. 10% increase in the TTO size) increases licensing income by 60.1%-66.3% and the number of R&D contracts by 26.1%-50.3%.
Carlsson and Fridh (2002)	University technology transfer office (TTO)	Number of invention disclosures, patents, start-ups, licenses and the	TTO size (number of staff)	Total R&D expenditure	Analyse the technology transfer process from an R&D budget to licensing and creation of spin-offs, using invention disclosures and patents both as inputs and	**Country**: US **Period:** 1991-	One additional TTO staff member (full-time equivalent, approx. 20% increase in the TTO size) increases the number of patents by 29.1% and the number of invention disclosures by 36.1% on average;

Paper	Policy instrument	Outcome variable	TTO characteristics (where applicable)	Controls	Methodology	Sample	Results
		amount of licensing income			outputs of a set of linear equations estimated through OLS regression on the data from 12 US universities, 55 US hospitals and research institutes and 28 Canadian research institutes.	1996	not significant in explaining the number of start-ups.
Curi et al. 2012	University technology transfer office (TTO)	Patent applications, software applications, number of patents with submitted extension requests, number of extensions required.	Number of full-time equivalent employees in the TTO	Number of publications, university size, presence of a university-related hospital and disciplinary field.	Analyse the average efficiency of French TTOs over the period 2003–07 using by using a Simar and Wilson (2007) two-stage DEA estimation based on the bootstrap procedure. The first stage estimates technical (in)efficiency and is then regressed on a set of external factors	**Country**: France **Period:** 2003-07	French TTO score lower efficiency (51%) than that found in studies of US (82%) and UK (71%). Age of the TTO has an impact on efficiency as well as scale economies related to university size, and the local intensity of industry (and public) R&D.
Chapple et al. (2005)**	University technology transfer office (TTO)	Number of licences or licensing income	TTO size (number of staff), age	Medical school indicator, regional GDP, regional R&D intensity	Evaluate relative efficiency of 122 UK universities in transforming research inputs into outputs using non-parametric Data Envelopment Analysis with invention disclosure, total research income, number of TTO staff, and external legal IP spend as the input variables.	**Country**: UK **Period:** 2002	One unit increase in University TTO staff results in 13.6%-18% increase in licensing agreements and 23.4-36.7% in licensing income.

Paper	Policy instrument	Outcome variable	TTO characteristics (where applicable)	Controls	Methodology	Sample	Results
Curi et al. (2015)	University technology transfer office (TTO)	Patent applications, software applications, number of patents with submitted extension requests, number of extensions required)	Number of full-time equivalent employees in the TTO, age	Number of publications, presence of a university-related hospital and industry	Study examines productivity change in French TTO through a Malmquist productivity index approach based on efficiency measures computed through the nonparametric estimator of the efficient frontier, Data Envelopment Analysis (DEA) following the introduction of two policies, the July 1999 innovation law, aimed at enhancing technology transfer processes between universities and industry, and the new public management oriented reform was introduced in 2001 to accelerate and improve the quality of the technology transfer process.	**Country**: France **Period:** 2003-06	Following the two policy changes 50% of TTOs improved their productivity through improvements in technology and efficiency, although TTO where more responsive to efficiency improvement than technical change (business model improvement). In the short-run the presence of younger TTO and a university hospital constrained efficiency improvement.
Foltz et al. (2000)	University technology transfer office (TTO)	Number of agricultural biotech patents	TTO size (number of staff)	Ratio of gross state product in agriculture, dummy for land grant institutions and research money from federal and local government sources.	Develop a consistent theoretical methodology for understanding the university patent production process and then estimate the model using a zero inflated negative binomial regression using data on 142 US universities.	**Country**: US **Period:** 1991-1998	One additional TTO staff member (approx. 30% increase in the employee count) increases number of agricultural biotech patents by 29.2%.
Lautenschläger, Haase	Support programme	Number of spin	TTO size and	University potential, size and	Tobit estimation of factors influencing spin out	**Country**:	Institutes taking part in the EXIST programme to support spin outs

Paper	Policy instrument	Outcome variable	TTO characteristics (where applicable)	Controls	Methodology	Sample	Results
and Kratzer (2014)	to support university spin offs	outs	characteristics	strategy	production in 54 higher education institutions in Germany using the EXIST programme to understand impact of public support on spin out activity	Germany **Period:** 2009-2010	from public institutions were found to produce between 10.3 to 11.2 more spin outs than those outside the programme, although results did not control for participation in EXIST so potential endogeneity was not controlled for.
Link and Siegel (2005)**	Organisational incentives to university/industry technology transfer (UITT)	Number of licensing agreements, invention disclosures, and amount of licensing outcome.	TTO size (number of staff), age	External legal expenditures on UITT, medical school indicator, average industry R&D intensity and real output growth in the university state, percentage of royalty that is allocated to faculty members, indicator of centralised licensing	Evaluate the impact of organisational incentives and research inputs on the effectiveness of university management of intellectual property portfolios using parametric stochastic frontier approach using data on 113 US universities.	**Country:** US **Period:** 1991-1998	A 1% increase in UTTO staff member increases average annual number of licensing agreement by about 0.467% and average annual licensing revenue by 0.392%. Universities that allocate a higher percentage of royalty payments to faculty members tend to be more efficient in technology transfer activities.
Siegel et al. (2008)	University technology transfer office (TTO)	Number of licensing agreements, amount of licensing outcome, number of spin offs	TTO size (number of staff), age	Research income, expense on IP, presence of university hospital, science park, quality of faculty, incubator	The paper measures relative efficiency of university TTOs using multiple outputs to estimate a stochastic, multiple-output distance function to capture the efficiency of both university licensing and spin-off generation.	**Country:** UK, US **Period:** Pooled data for 2001-2003.	Evidence of constant or decreasing returns to scale (0.68 to 0.92) for TTO size (coefficient 0.38 to 0.5) and expenditure on IP (coefficient 0.23-0.44). With technical efficiency scores on average 0.71, indicating scope for improvement of close to 30%.
Thursby et	University	Number of	TTO size	Percentage of	Assess the relationship	**Country**	Additional TTO staff member

Paper	Policy instrument	Outcome variable	TTO characteristics (where applicable)	Controls	Methodology	Sample	Results
al. (2001)**	technology transfer office (TTO)	licenses, patents, amount of sponsored research tied to license.	(number of staff), indicator of licensing importance to TTO	licensed disclosures in early stage of development, number of inventions disclosed, quality of faculty, indicator for presence of medical school	between licensing outcomes and the characteristics of TTO using an OLS regression using data on 62 surveyed US research universities.	**:** US **Period:** 1994-1996	increases number of licences by 36.5% on average.
Thursby and Kemp (2002)**	University technology transfer office (TTO)	Number of licenses, industry supported research, new patent applications, invention disclosures, and amount of royalties received	TTO size (number of staff)	Type of faculty (biological sciences, engineering, physical sciences) and its quality rating in the Ph.D. granting departments of program area	Evaluate relative efficiency of 113 UK universities in transforming research inputs into outputs using non-parametric Data Envelopment Analysis with TTO size and federal government support as the input variables.	**Country:** US **Period:** 1991-1998	Faculty quality and number of TTO staff positively correlated with technology transfer outputs and probability of being at the research efficiency frontier. Private universities more efficient than public universities
Toole and Czarnitzki (2005)*	Public policy fostering academic entrepreneurship	Indicator of at least one patent application, number of patent applications, patent stock.	N/A	Patent stock, region dummies.	Estimate the effect of early-stage funding for university-based biomedical technology firms using data on 3,360 scientist-linked firms and 36,466 non-linked firms in probit regressions.	**Micro data** **Country:** US **Period:** 1972-1996	Full-time scientist-linked university-based technology firms receiving grants through the public policy have 22.7% higher probability of being granted a patent relative to their non-linked counterparts. University researchers choose to commercialise through the programme since the funds are

Paper	Policy instrument	Outcome variable	TTO characteristics (where applicable)	Controls	Methodology	Sample	Results
							available earlier and cost less in terms of risk and return.

2.5 R&D tax incentives

2.5.1 Policy background

R&D tax incentives are fiscal incentives[18] provided to businesses designed to promote greater R&D investment and innovation by reducing the cost of R&D inputs or increasing the expected profit of R&D spending[19,20]. In a report for the European Commission, CPB Netherlands Bureau for Economic Policy Analysis (2014) classifies R&D tax incentives into four categories.

- Tax credits i.e. decrease the corporate income tax rate a firm has to pay
- Enhanced allowances i.e. decrease the base amount that is taxed.
- Accelerated depreciation i.e. permit depreciation of purchased fixed assets at higher rates in the first years of the asset's life, which decreases the overall taxable income in the specific periods.
- Corporate tax rate i.e. reduce the corporate tax rate on intellectual property income (e.g. Patent Box).

There are two channels through which tax incentives could promote R&D and innovation.

- Direct channel which increases the resources available for R&D, i.e. the inputs in the R&D production function; and
- Indirect channel which increases the productivity of R&D inputs. For example, tax incentives could decrease the cost of fixed capital investment, increase capital utilisation and make R&D labour more productive.

From a policy perspective, the tax incentives provided through the above channels can lead to following two main outcomes.

1. Higher R&D expenditure; and
2. Greater innovation[21].

From the perspective of tax incentivised R&D productivity, it may be useful to consider the example of the Irish corporate tax rate.[22] In 1998, the Irish government introduced a

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[18] In addition to tax incentives, another policy instrument commonly used to promote R&D investment is a subsidy, which is financial aid commonly provided by the government via direct (cash grants, interest-free loans) or indirect (low-interest loans, accelerated depreciation, or rent rebates) means. Under the EU rules, subsidies for R&D are also subject to state aid rules. Unless expected under De Minimis Aid or General Block Exemption Regulations (GBER), participating universities need to comply with EU rules on state aid in case they receive the subsidies. For further details see Reid et al. (2016)

[19] Similar to tax incentives, direct subsidies (grants) also aim to encourage R&D innovation by reducing the cost of R&D inputs faced by the firm. However, tax incentives are considered to have several advantages over direct subsidies:

- Tax incentives reduce the tax burden automatically, usually based on the level of R&D expenditures and are project independent. However, the data required to claim tax deductions may discourage the participation of smaller firms.
- Direct subsidies are generally only paid once a project has been evaluated. They are associated with higher administrative costs and increased uncertainty of being funded. Governments also face an information disadvantage as regards which projects will succeed or generate the highest social returns.

[20] For a detailed review of the effects of subsidies and tax credits see Becker (2015)

[21] The link between R&D, productivity and growth has been long established in the economic literature since the seminal works of Arrow (1962), Romer (1986), and Grossman and Helpman (1991).

[22] Fiscal policy remains a national prerogative and, although most EU Member States offer some form of R&D tax incentives, these differ considerably across countries, according to their type, the costs covered, whether specific organisations are targeted, and the organisation of the scheme. As a result, at the EU level, the focus

tax rate of 12.5%[23] on trading income which resulted in increased inward investment in the Irish technology sector and is considered to be one of the key factors in the Celtic Tiger phenomenon (The Irish Independent, 2004). A further evolution of this policy is the Irish corporate tax policy 'knowledge development box' (O'Reilly, 2016) announced as part of Budget 2016. Under this policy, companies can qualify to pay half the designated corporate tax rate (i.e. 6.25% against the stipulated 12.5%) if they demonstrate that their earnings are linked to patents and copyrighted software created by R&D carried out in Ireland (Sirmans, 2016)

2.5.2 Empirical evidence

The impact of tax incentives on R&D has been extensively studied in the literature. The literature can be classified in terms of the following methodological aspects.

- **Outcome variables.** The impact of tax incentives has been analysed on either R&D investment or innovation, e.g. patent applications and introduction of new products.

- **Measures of tax incentives.** The main focus has been on tax credits although some studies have looked at the impact of tax subsidies, e.g. research grants.

- **Estimation method.** A range of methods have been used including OLS, Difference-in Difference, propensity score matching, logit/probit and Instrumental Variables.

The main findings from the literature are summarised in Table 9 and discussed below.

- **R&D expenditure.** Tax credits have been found to have a positive and statistically significant effect on R&D investment. However, the estimated elasticity substantially varies in size. For example, Montmartin & Herrera (2015) report an elasticity of 0.20, Guceri and Liu (2015) document an elasticity of 1 and Rao (2016) an elasticity of 1.1%. In a meta-analysis, Castellacci and Lie (2013) document an elasticity which is close but lower than 1 suggesting that tax credits considerably stimulate R&D investment without significantly reducing tax revenues. Furthermore, the recent survey of the relevant literature by Becker (2015) also suggests that the elasticity of R&D expenditure with respect to tax incentives is around 1.

- **Innovation.** Fiscal incentives have a positive impact on innovation. For example, Cappelen et al. (2012) find that firms receiving tax credits are 24% more likely to apply for a patent and Czarnitzki et al. (2011) document that the introduction of tax credits increases the number of new products introduced to the market by 12.2%. Apart from tax credits, subsidies also have a significant impact on innovation, for example, Knoll et al. (2014) show that a one unit decrease in the B-index[24] increases the firm patent applications by 40.5%.

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has been on developing guidelines for good practices in relation to tax treatments and incentives e.g. COM(2006)728. A recent study for DG-TAXUD (CPB, 2014) identifies widely adopted practices such as volume based incentives and simple one-stop, online application systems.

[23] Corporate tax rates across the EU vary dramatically. France and Germany are at the relatively high-end with 33% and 30% respectively. In Austria, Denmark, and Spain it is 25%, 23.5%, and 28% respectively. Ireland, Cyprus, and Bulgaria are at the lower end with 12.5%, 12.5%, and 10% respectively.

[24] The B-index is a measure of the level of pre-tax profit a representative company needs to generate to break even on a marginal, unitary outlay on R&D (Warda, 2001).

Table 9: Overview of available evidence of R&D tax incentives and their links to R&D productivity and/or technology diffusion

Paper	Policy instrument	Dependent variable	Controls	Methodology	Sample	Results
Berger (1993) **	R&D tax credit	R&D intensity	Cashflow, industrial R&D, tobins Q, capital expenditure	Test the credit's effect on qualified R&D spending using several versions of a spending model. Using pooled OLS with fixed effects. Dataset of 231 firms with 14 years of available data during 1976-89	**Country:** US **Period:** 1976-1989	R&D elasticity of 1.0 to 1.5.
Bloom et al (2002)**	R&D tax credit	R&D investment	Lagged R&D investment, user cost	Model of R&D investment is estimated using a panel of data on tax changes and R&D spending in nine OECD countries over a 19-year period, Approach similar to stochastic form of the demand equation for R&D capital derived from a CES production function where, in steady state, R&D capital is proportional to the flow of R&D investment.	**Country:** Nine OECD countries **Period:** 1979-1997	Results indicate a 10% fall in the cost of R&D stimulates just over a 1% rise in the level of R&D in the short-run, and just under a 10% rise in R&D in the long-run. R&D price elasticity of 0.16-1.1; long run price elasticity of approximately unity.
Bronzini & Prizelli (2016)	R&D tax subsidies (grants covering up to 25% of the costs for research projects)	Number of patent applications	Firm financial statement variables (sales, value added, assets, gross operating margin, cash flow, labour costs, total capital stock, intangible capital stock), industry indicator	Evaluate the effect of public subsidy programme on the number of patent applications using regression discontinuity design	**Country:** Italy **Period:** 2004-2005	Receiving subsidy increases the number of patent applications by 1.8 (from average of 0.5) per firm. The percentage of firms with at least 1 patent increases by 10 percentage points (from 14%) when receiving subsidy.
Cowling (2016)	R&D tax credits	Product, service and process	Firm size, age, indicator of international sales,	Using a business Survey on 5,723 British firms, asking whether take-up of tax credits	**Country:** UK	No statistically significant effect was found between taking tax credits and change in product,

Paper	Policy instrument	Dependent variable	Controls	Methodology	Sample	Results
		innovations	growth orientation, strategic planning, firm capability index	actually led to an increase in product, service, or process innovation, using a probit model.	**Period:** 2012	service, or process innovation.
Dechezleprêtre et al. (2016)	R&D tax subsidies	Number of patent applications	Firm financial statement variables, industry indicator	Evaluate the effect of R&D tax subsidies on the number of patent applications using regression discontinuity design.	**Country:** UK **Period:** 2006-2011	The effect of tax subsidies on R&D outcomes is higher for small companies, a tax-price (user cost) elasticity of about 2.6. (i.e. 10% fall in the price generates about a 26% increase in the volume of R&D)
Hall (2003)**	R&D tax credits	R&D investment	Sales, R&D capital, lagged R&D investment	GMM estimation of investment demand equations at the firm level using a Cobb-Douglas form for the production function with R&D capital and adjustment cost.	**Country: US** **Period: 1981-1991**	R&D price elasticity of 1.0 to 1.5.
Montmartin & Herrera (2015)	R&D tax credits	R&D investment	Interest rates, ratio of public and private expenditures on R&D	Determine the effect of R&D tax credits on R&D investment using spatial dynamic panel data methods, data from 25 OECD countries over 20 years.	**Country:** 25 OECD countries **Period:** 1990-2009	A 1% decrease in the B-index (increase in tax incentives) leads to 0.198% increase in R&D expenditures funded by the private sector (as a percentage of GDP).
Cappelen et al. (2012)	R&D tax credits	Propensity to apply for patent and introduce new product or production process	R&D capital stock, R&D capital intensity, indicator of cooperation with another firm, university, or research institution, human capital (proxied by education), firm size, industry and geographic indicators	Estimate the causal effect of tax credits on the various types of innovations using a logit model and a sample of 1,689 firms.	**Country:** Norway **Period:** 1999-2004	Firms receiving tax credits are 24% more likely to apply for a patent. The propensity to patent increases by 31% if they also collaborate with other firms.

Paper	Policy instrument	Dependent variable	Controls	Methodology	Sample	Results
Castellacci and Lie (2013)	R&D tax credits	R&D investment	Time, industry, and country indicators, type of data used in the original study.	Meta-analysis to assess the impact of effect of fiscal incentives on R&D investment using data from 34 peer-reviewed scientific papers.	**Country:** various **Period:** various	For every dollar foregone in tax, the additional expenditure on R&D is less than a dollar on average. This result varies with firm size and industry.
Guceri and Liu (2015)	R&D tax credits	R&D investment	Profits, revenues, sector-, year- and firm-fixed effects.	Difference-in-differences and panel regression methods using a sample of UK 30,056 UK.	**Country:** UK **Period:** 2002-2012	For each dollar foregone in corporation tax revenue, an additional dollar is spent in private R&D.
Rao (2016)	R&D tax credits	Research intensity (R&D spending/sales ratio)	Tax regime dummies, total assets, net income	Analyse the effect of R&D tax credits on R&D spending using data from corporate tax returns for around 19,900 US companies. The econometric estimation uses an instrumental variable strategy based on tax law changes that addresses potential simultaneity between R&D spending and its user cost.	**Country:** US **Period:** 1981-1991	Results indicate a 10% reduction in the user cost of R&D leads the average firm to increase its research intensity—the ratio of R&D spending to sales—by 19.8% in the short-run. The long run elasticity slightly smaller (1.94 vs 1.98). However the finding indicate that not all firms respond to tax credits in the same way, although on average firms will increase R&D spending immediately and over the long term in response to tax credits, young and small firms may reverse their subsidy related spending increases.
Knoll et al. (2014)	R&D tax subsidies	Number of quality-adjusted patent applications	GDP per capita, enrolment rates in tertiary education, R&D spending relative to GDP, FDI flows, quality of governance	Assess the impact of R&D tax subsidies on R&D activity in the host country as well as in neighbouring jurisdictions using data on 16,644 firms from various countries in a	**Country:** Several European countries **Period:**	A one unit decrease in the B-index increases a firm's patent applications by 40.5%.

Paper	Policy instrument	Dependent variable	Controls	Methodology	Sample	Results
			indicator	linear regression.	1998-2006	
Cerulli & Poti (2010)	R&D tax subsidies	R&D investment	Size, past experience in R&D, cash flow, labour cost, equity, capital intensity, sector, region, and year indicators	Analyse the effect of R&D subsidies on R&D investment by comparing 853 Italian companies receiving R&D subsidies with 3,147 firms that did not receive a subsidy	**Country:** Italy **Period:** 2000-2004	Receiving a subsidy increases a firm's R&D expenditure beyond the subsidy amount. This increase in R&D expenditure is by 40% on average.
Czarnitzki et al. (2011)**	R&D tax credits	Number of new products, originality of innovation, sales from new products	Size, dummy for outsourcing of R&D, price-cost margin, intensity of R&D, profitability, domestic and international market share, industry indicator	Evaluate the effect of R&D tax credit policy on firm's innovation output using a propensity score matching approach and a sample of 3,562 Canadian firms.	**Country:** Canada **Period:** 1997-1999	Introduction of tax credits increases the number of new products introduced to the market by 12.2%.

2.6 *Summary of empirical estimates across policy areas*

The findings from the empirical literature are summarised in Table 10 below, providing a range of relevant estimates for each of the five policy areas.

Table 10: Summary of relevant empirical estimates across policy areas

Policy area	Range of effects
Performance-based funding (PBF)	The empirical evidence of the impact of PBF on research productivity is mixed. The most positive results are reported by Smart (2009) who finds that the introduction of PBF increased research publications of New Zealand's universities by up to 34%. Other studies find no statistically significant impact on either the quantity or quality of publications.
Public R&D funding targeted to regional strengths	Empirical studies focus mainly on cluster effects, including the evaluation of cluster policies (incentivising firms to locate near or within a cluster) or a firm's proximity to a cluster. The empirical literature finds consistently positive and significant effects of cluster policies or proximity to a cluster on R&D productivity: participating in a cluster increases a firm's innovativeness from 0.7% to 9.3%.
Public-private cooperation	Empirical studies investigate forms of cooperation between private firms and universities, focussing on product innovations and patent applications as outcome variables: • **Product innovation**: cooperation with university leads to increase in probability to create innovation from 45% to 54%. • **Patent application**: cooperation with university leads to increase in probability of patent application from 17% to 44%.
Research commercialisation	Empirical studies investigate associations between Technology Transfer Office (TTO) capacity (proxy for commercialisation) and number of patents and licensing income as outcome variables: • **Patents**: a 1% increase in TTO staff members leads to an increase in number of patents from 1% to 1.5%. • **Licensing income**: each additional TTO staff member leads to an increase in income from 23.4% to 66.3%.
R&D tax incentives	Empirical studies investigate associations between reductions in the user cost of capital induced by tax incentives, either in form of tax credit or subsidy, and R&D expenditure as outcome variable. The elasticity of R&D expenditure with respect to tax incentives (user cost of capital) varies across studies but on average is around -1.

3 Satellite model

This section sets out a satellite model that could be incorporated within QUEST III to facilitate evaluation of the impact of policy strategies and reforms on innovation and other key macro-economic variables.[25]

The satellite model builds around the following knowledge production function:

$$\Delta Z_{t+1} = \chi(.)(L_t^s)^\rho + \sigma(.)\chi_P(.)(L_{Pt}^s)^\rho - (1-\phi)Z_t \qquad (1)$$

where Z is the stock of knowledge, L^s is the R&D employment in the private sector and L_P^s is the R&D employment in the public sector.

This generalises the QUEST III knowledge production function by incorporating the following features:[26]

- Private and public R&D activities have a differential impact on the creation of new ideas. The first term in (1) captures the contribution of private R&D to the growth of knowledge, while the second term measures the impact of R&D carried out by public institutions. The last term suggests that the creation of new ideas depends on the stock of knowledge in the previous period.

- Private R&D productivity is a function of public-private cooperation. This feature is captured by the $\chi(.)$ function.

- The σ(.) function captures the private sector propensity to take technologies developed by public R&D and use them to improve production methods. This parameter is affected by policies that foster the commercialisation or transfer of public technologies.

- The χP(.) function captures the efficiency of public R&D in developing new technologies. This can be impacted by policies that introduce performance-based incentives in public R&D institutions and universities.

These features are discussed in detail in the remainder of this section.

The function χ

The function $\chi(.)$ reflects the productivity of R&D activities. There are many factors that may impact the productivity of private R&D. Two formulations are considered in the model, capturing two distinct factors: public-private R&D cooperation and the stock of public knowledge.

Public-private cooperation

A significant strand of the empirical literature on R&D policies has explored how the cooperation in R&D between public and private organisations enhances the productivity of private R&D. In these studies, the independent variable is a binary variable that takes the value of 1 if there is a form of cooperation and 0 otherwise.

The formulation of $\chi(.)$ described below is motivated by the empirical literature. Consider χ(C) where C is a binary variable that takes the value of 1 if there is private-public

[25] The model has been designed considering primarily the five policy reforms and strategies discussed in the previous sections of this report.

[26] The current version of the knowledge production function within QUEST assumes that innovation is a function of two variables: R&D employment and international stock of knowledge. It also assumes that the impact of private R&D on innovation is the same as the effect of public R&D.

cooperation and 0 otherwise. In this setting, $\chi(0)$ is the steady state value for the productivity of private R&D. In particular, equation 1 implies that:

$$\Delta Z_{t+1}^{Pr} = \chi(0)\,(L_t^s)^{\rho} \quad (2)$$

where Z^{Pr} is the stock of privately developed technologies. Equation (2) implies that:

$$\chi(0) = \frac{\Delta Z_{t+1}^{Pr}}{(L_t^s)^{\rho}} \quad (3)$$

Hence, $\chi(0)$ can be computed using the estimate of ρ from Task 1 (elasticity of domestic stock of knowledge with respect to R&D employment) and/or information on (i) the number of private patents, and (ii) the number of researchers engaged in private R&D activities.

Table 11 provides estimates of $\chi(0)$ computed as per equation (3) for various countries.[27]

Table 11: Estimates of $\chi(0)$

Country	X(0)	Country	X(0)
Australia	2.60	Iceland	0.45
Austria	2.20	Israel	2.35
Belgium	1.77	Italy	3.03
Canada	1.92	Japan	9.05
Switzerland	3.68	Luxembourg	0.35
Czech Republic	0.35	Latvia	0.27
Germany	8.01	Netherlands	4.73
Denmark	2.16	Norway	1.84
Spain	1.24	New Zealand	1.65
Estonia	0.31	Poland	0.49
Finland	2.89	Portugal	0.27
France	3.64	Slovak Republic	0.32
United Kingdom	4.13	Slovenia	0.56
Greece	0.35	Sweden	3.83
Hungary	0.83	Turkey	0.80
Ireland	1.17		

[27] For each year from 2002-2011 the ratio of the number of patent applications divided by number of R&D personnel powered to 0.6 is computed. Then the average ratio and is divided by the ratio of private to total patents.

Source: OECD, Eurostat, Deloitte/RAND analysis

The empirical studies on the impact of cooperation on various innovation metrics provide estimates of ((χ(1)- χ(0))/ χ(0)). In particular, the literature suggests a mid-point value of 0.69 (see Table 7).

The role of public knowledge

More generally, the productivity of private R&D may be affected by the stock of public knowledge. Public R&D is typically directed to basic research and in theory the greater the stock of basic research output, the easier it may be by private companies to develop new products.

This feature is taken into account by allowing the productivity of the public R&D to be a function of public stock of knowledge. In particular, χ_t is defined as:

$$\chi_t = \frac{\varepsilon Z_t^P}{Z_t^P \ + Z_t^{Pr}} \quad (4)$$

where Z_t^P is the stock of public knowledge and ε is a parameter that measures the sensitivity of private R&D productivity to the ratio of public to private knowledge (Z_t^P / Z_t^{Pr}).

To close the model, the law of motion of public knowledge needs to be specified. It is assumed that the stock of public knowledge evolves as follows:

$$Z_{t+1}^P = \phi Z_t^P + (L_{Pt}^S)^\rho \quad (5)$$

where $Z_{Pt}(L_{Pt}^S)^\rho$ is the number of new public technologies.

Unfortunately, the available empirical literature does not provide the estimates required for the calibration of the parameters of interest, therefore the implementation of this extension is constrained.

The function σ

Since public organisations tend to focus on basic research as opposed to development of new products, there should be a significant gap between a patent granted to a public institution and the commercialisation of that patent. The term σ(.) captures this gap. This feature is captured with the following formulation:

$$\sigma(L_c) = \sigma_0 L_c^{\rho c} \quad (6)$$

where $\sigma(.)$ is the probability of commercialising a new technology , Lc is the number of staff employed in commercialising new ideas, σ_0 describes the average commercialisation rate of public innovations and ρ_c is the elasticity of commercialisation with respect to the number of people employed at the commercialisation sector.

Optimal hiring of commercialisation staff is defined by the following first order condition:[28]

$$\sigma'(L_c) \frac{E_t[V_{t+1}]}{R_t} = W_t^s \quad (7)$$

where V_{t+1} is the value of a commercialised technology at t+1.

[28] See Task 1.2 report.

To calibrate the two parameters (σ_0 and ρ_c), estimates of the average commercialisation rate and of the elasticity of commercialisation with respect to commercialisation staff are used. In the US, one third of the patents developed by universities and the public sector are commercialised (Morgan et al., 2001). The estimates of the elasticity of the probability of commercialising a public technology with respect to the number of staff employed in technology transfer offices range from 0.05 in Spain to 0.4 in the US (see Table 8). These estimates together with conditions (6) and (7) are used to pin down σ_0 and ρ_c.

The function χP

The function $\chi_P(.)$ determines the productivity of public research activities. The steady state value $\chi_P(0)$ can be calibrated in an analogous way to the calibration of $\chi(0)$. In particular, the calibration requires information around the number of public R&D researchers (government and academic institutions) as well as the share of patents produced by public researchers.

As with $\chi(.)$ and σ(.), χ_P could be calibrated by using estimates from the micro literature. However, as discussed in previous sections, the quantity and quality of these estimates is relatively poor.

An alternative approach could rely on a structural model. The remainder of this section sets out two versions of a model (private information and private action) that could be used to measure the impact of a particular policy (performance based funding) on the public sector R&D productivity.

Private Information

In the private information model, agents' differences in productivity of R&D depend on some intrinsic worker attribute that is exogenous. The ability of researcher *i* is defined by η_i. In the absence of performance-based compensation, workers are indifferent between working in public research and other occupations regardless of their research ability. Therefore, the average research ability of researchers is equal to the average ability in the population:

$$\chi P = \chi_0 \int_1^\infty \eta_i dF(i) \,/ \int_1^\infty dF(i) = \chi_0 \zeta/(\zeta - 1) \qquad (8)$$

where the distribution F(.) is assumed to be a Pareto distribution, with floor normalised to 1, and curvature ζ>1.

If performance-based compensation is introduced, the researchers employed in public R&D would be those with higher ability. In particular, the average skill of researchers will be:

$$\chi P = \chi_0 \int_{\hat{\eta}}^\infty \eta_i dF(i) \,/ \int_{\hat{\eta}}^\infty dF(i) = \chi_0 \zeta/(\zeta - 1) * \hat{\eta} \qquad (9)$$

where $\hat{\eta}>1$ is the ability of the marginal researcher.

The free entry condition pins down the value of $\hat{\eta}$:[29]

$$W_t^S = \hat{\eta}\chi_0 * E_t[(L_{Pt}^S)^{\rho-1} J_{t+1}/R_{t+1}] \qquad (10)$$

where W_t^S is the wage of skilled workers, J is the value of a new technology and R is the discount rate.

[29] See Task 1.2 report.

The model has two parameters to calibrate: ζ and χ_0. The latter can be pinned down by the productivity of public R&D in the absence of performance based funding policies, these parameter estimates are shown in Table 12 and 13. The former can be pinned down by the variance of the distribution of skills in the population. In particular, variance of ability in population is given by:

$$Var(\eta_i) = \frac{\zeta}{(\zeta-1)^2(\zeta-2)} \qquad (11)$$

This variance can be proxied by the dispersion of the logarithm of the Pisa scores in the country.[30]

[30] Academic publications could provide an alternative source of information to calibrate skills or ability.

Table 12: Variance of Pisa score and implied

Country	Variance of (log) Pisa score	ζ	Country	Variance of (log) Pisa score	ζ
Austria	0.23	4.00	Hungary	0.24	3.90
Belgium	0.30	3.70	Ireland	0.20	4.10
Bulgaria	0.39	3.50	Italy	0.25	3.90
Czech Republic	0.23	4.00	Lithuania	0.24	3.90
Germany	0.27	3.80	Luxembourg	0.31	3.70
Denmark	0.27	3.80	Latvia	0.18	4.20
Spain	0.23	4.00	Netherlands	0.25	3.90
Estonia	0.15	4.50	Poland	0.18	4.30
Finland	0.24	3.90	Portugal	0.27	3.80
France	0.30	3.70	Romania	0.25	3.90
United Kingdom	0.26	3.80	Slovakia	0.35	3.60
Greece	0.29	3.70	Slovenia	0.28	3.80
Croatia	0.24	3.90	Sweden	0.30	3.70

Source: PISA DATA

Table 13: Variance of Pisa score and implied

Country	χ_0	Country	χ_0
Austria	5.04	Latvia	0.44
Belgium	2.92	Lithuania	0.22
Bulgaria	0.16	Luxembourg	0.56
Croatia	0.07	Malta	0.12
Cyprus	0.13	Netherlands	5.37
Czech Republic	0.56	Norway	1.26
Denmark	3.24	Poland	0.77
Estonia	0.17	Portugal	0.26
Finland	4.81	Romania	0.26
Germany	12.44	Slovakia	0.17
Greece	0.20	Slovenia	0.81

Hungary	0.67	Spain	1.40
Iceland	0.38	Sweden	7.62
Ireland	1.23	United Kingdom	3.45
Italy	3.80		

Source: Eurostat, RAND Europe analysis

Private Action

In the private action model, workers have a priori the same skill, but their productivity increases with effort which is assumed to be observable. Exerting effort is costly for the worker. In particular, the cost of exerting effort level *e* is $C(e)=b_t*e$, where b_t is the marginal cost of effort and grows at the same rate as the economy in steady state.

Workers can be induced to exert high effort by offering them a compensation scheme with the compensation being a positive function of effort.[31] It is assumed that $\chi_P(e)$ is an increasing concave function.

The optimal effort level solves:

$$\text{Max } \chi(e)\ (L_p)^{\rho-1} E_t(J_{t+1}/R_{t+1}) - (W^S + b_t\, e) \quad (12)$$

where public research managers take as given the flow of total public R&D in the economy, L_p.

The optimal effort level, e* is implicitly defined by:

$$\chi'(e^*)(L_p)^{\rho-1} E_t(J_{t+1}/R_{t+1}) = b_t \quad (13)$$

Managers can ensure the exertion of optimal effort by offering the following scheme to workers:

$$W(e) = \begin{cases} 0 \ if\ e \neq e^* \\ W_t^S + b_t e^* \ if\ e = e^* \end{cases} \quad (14)$$

Once the compensation scheme offered to public researchers ensures they will exert the optimal level of effort, public research organisations need to determine the number of scientists working on public R&D activities. There are two ways to proceed at this point. One possibility is to assume that L_p is determined exogenously by the policy maker. In this case, the model can be used to explore the impact of performance based funding on R&D activity conditional on an exogenous path for L_p , for example, the path observed in the last decade. A second alternative is to consider a free entry condition into public R&D similar to the condition in private R&D. In this case, scientists will flow into public R&D until the cost of hiring a new scientist that exerts the optimal level of effort equals the cost of hiring this scientist and induce him/her to exert e*. This free entry condition is:

$$\chi(e)(Lp)^{\rho-1} E_t(J_{t+1}/R_{t+1}) = W(e^*) \quad (15)$$

[31] In the case where effort is not observable, a high effort can be induced by making the compensation contingent on the number of technologies developed.

Specialisation strategies

Specialisation strategies try to incentivise R&D activity in sectors/regions with highest productivity. To consider the impact of such policies, it is necessary to extend equation (1) to introduce heterogeneity.

In particular, consider an environment where the flow of newly created technologies is given by:

$$\Delta Z_{t+1} = \sum_{i=1}^{N} \Delta Z_{it+1} \qquad (16)$$

where *i* denotes a sector or region.

To simplify the analysis, the focus is on the case where technologies are developed only by the private sector. In this case, the increase in the number of patents developed in sector/region *i* is:

$$\Delta Z_{it+1} = Z_{it}^{\gamma} Z_t^{-\gamma} \chi_i (L_{it}^s)^{\rho} - (1-\phi) Z_{it} \qquad (17)$$

In this formulation, γ captures the magnitude of local spill-overs and Γ>0 implies that local stock of knowledge affects the return to private R&D.

An extension of (17) with also public R&D would be:

$$\Delta Z_{it+1} = Z_{it}^{\gamma} Z_t^{-\gamma} (\chi_i (L_{it}^s)^{\rho} + \chi_{iP} (L_{iPt}^s)^{\rho}) \quad - (1-\phi) Z_{it} \qquad (18)$$

In equation (18), the productivity of both private and public R&D activities is a positive function of the local stock of knowledge.

In both of these formulations, there are efficiency gains associated with making R&D policy region specific. In particular, R&D subsidies and policies that stimulate R&D investments in regions where Z_i is greater will be welfare enhancing.

The calibration of χ_i we can carried out as in Section 0. In particular, equation (17) implies that:

$$\chi_i = \frac{\Delta Z_{it+1}^G}{\left(\frac{Z_{it}}{Z_t}\right)^{\gamma} (L_{it}^s)^{\rho}} \qquad (19)$$

where $\Delta Z_{it+1}^G$is the (gross) number of new innovations developed.

A calibration of χ_i is provided in Table A-1 in the Appendix A. This has been computed by using the following data and assumptions;

- The ratio of regional to national stock of innovations is proxied by the average share in the total number of national patent applications over the period 2002-2008;
- A value of γ equal to 0.5 is assumed;
- For each year, ΔZ_{it+1}^G is proxied by the number of patent applications;
- L_{it}^s is measured by the number of R&D full time equivalents (FTEs); and
- A value of ρ equal to 0.6 is assumed.

Once the model is calibrated, there are at least two types of specialisation policies that can be explored.

- **Targeted R&D subsidies.** These seek to reduce the cost of conducting R&D that may vary by region.
- **Public infrastructure.** The second policy that could be considered is around the effect of local public infrastructure, e.g. labs, better internet connectivity, funding of university research. These infrastructures are complementary to private R&D and as a result they could have a greater impact on regions that have a comparative advantage in R&D.

R&D Subsidies

Several countries use R&D subsidies to reduce the cost of R&D (costs related to R&D infrastructure and/or R&D labour).

The free entry condition in the presence of an R&D subsidy of τ is: [32]

$$(1-\tau)W_t^S = E_t[\chi(L_{Pt}^S)^{\rho-1}J_{t+1}/R_{t+1}] \qquad (20)$$

In response to R&D subsidies, companies increase the resources invested in R&D, in a way consistent with the empirical evidence presented in Section 2.6. The estimated implied R&D subsidy rates are shown in Table 14.

Table 14: Implied R&D subsidy rates

Country	Large, profitable firm	SME, profitable firm	Large, loss-making firm	SME, loss-making firm
Austria	0.15	0.15	0.15	0.15
Belgium	0.11	0.11	0.10	0.10
Bulgaria	0.00	0.00	0.00	0.00
Cyprus	0.00	0.00	0.00	0.00
Czech Republic	0.21	0.21	0.15	0.15
Denmark	-0.01	-0.01	-0.01	-0.01
Finland	-0.01	-0.01	0.00	0.00
France	0.26	0.43	0.22	0.43
Germany	-0.02	-0.02	-0.02	-0.02
Greece	0.11	0.11	0.08	0.08
Hungary	0.30	0.20	0.09	0.11
Iceland	0.22	0.22	0.22	0.22
Ireland	0.29	0.29	0.23	0.23

[32] See Task 1.2 report.

Italy	0.09	0.09	0.09	0.09
Latvia	0.31	0.31	0.25	0.25
Lithuania	0.32	0.32	0.26	0.26
Luxembourg	-0.01	-0.01	-0.01	-0.01
Netherlands	0.21	0.21	0.20	0.21
Norway	0.08	0.22	0.08	0.23
Poland	0.05	0.06	0.04	0.04
Portugal	0.36	0.37	0.29	0.29
Romania	0.08	0.08	0.07	0.07
Slovak Republic	0.11	0.11	0.09	0.09
Slovenia	0.19	0.19	0.15	0.15
Spain	0.36	0.36	0.29	0.29
Sweden	0.05	0.05	0.05	0.05
Switzerland	-0.01	-0.01	-0.01	-0.01
United Kingdom	0.10	0.29	0.10	0.29

Source: OECD. Corresponding year of data included is 2016.[33]

Multi-country extension

The formulation used in equation (1) corresponds to a closed economy setting. There are two ways to extend this setting into a multi-country environment.

Following the current formulation in QUEST III, equation (1) can be modified by introducing an externality in R&D from the technology in the world, Z^W. The elasticity of this term can be calibrated using the estimates from Task 1 (elasticity of innovation with respect to international stock of knowledge).

An alternative approach could link equation (1) to the QUEST modification proposed in Task 1.2: the total stock of developed technologies is the sum of the technologies developed in each country. That is, the sum of the Z's in (1) across countries. Country-level variation in used technology arises exclusively from country-level differences in the adoption rate.

Overall, the proposed modification presented in this section could be integrated into QUEST III, either assuming a single or multi-county setting, and could be used to quantify the impact of policy reforms that seeks to improve the R&D productivity on innovation, economic growth and employment.

Summary of calibration parameters

[33] See http://www.oecd.org/sti/rd-tax-incentive-indicators.htm

Table 15 presents a summary of potential parameter values to be used for calibration and implementation of the models.

Table 15: Summary of parameter values for calibration and implementation

Symbol	Parameter	Value
$(\chi(1) - \chi(0))/\chi(0)$	Productivity of R&D activities	0.69 (Kaiser and Kuhn, 2012)
σ_0	The average commercialisation rate	0.33 (Morgan, Kruytbosch, Kannankutty , 2001)
ρ	Elasticity of commercialisation with respect to commercialisation staff	0.0015-0.00467 (Link and Siegel, 2005; Chapple et al., 2005)
ζ	Curvature of a distribution function describing the average research ability of researchers	See Table 12.
χ_0	Productivity of public R&D in the absence of performance based funding	See Table 13.
χ_i	Productivity of R&D activities in different countries	See Table A-1.
τ	R&D subsidy rate	See Table 14.

4 Appendix

A Regional productivities

Table A-1: R&D Productivity at the Regional level

Region	X_i	Region	X_i	Region	X_i
Austria	0.2	Spain	0.05	Lithuania	0.02
Burgenland (AT)	1.65	Galicia	0.22	Luxembourg	0.1
Niederösterreich	0.5	Principado de Asturias	0.39	Latvia	0.03
Wien	0.2	Cantabria	0.57	Netherlands	0.14
Kärnten	0.61	País Vasco	0.19	Groningen	0.65
Steiermark	0.29	Comunidad Foral de Navarra	0.34	Friesland (NL)	1.28
Oberösterreich	0.36	La Rioja	0.69	Drenthe	1.52
Salzburg	0.73	Aragón	0.3	Overijssel	0.55
Tirol	0.46	Comunidad de Madrid	0.1	Gelderland	0.37
Vorarlberg	0.85	Castilla y León	0.22	Flevoland	0.99
Belgium	0.11	Castilla-la Mancha	0.45	Utrecht	0.42
Région de Bruxelles-Capitale / Brussels Hoofdstedelijk Gewest	0.28	Extremadura	0.42	Noord-Holland	0.31
Prov. Antwerpen	0.26	Cataluña	0.12	Zuid-Holland	0.3
Prov. Limburg (BE)	0.67	Comunidad Valenciana	0.17	Zeeland	1.38
Prov. Oost-Vlaanderen	0.29	Illes Balears	0.61	Noord-Brabant	0.35
Prov. Vlaams-Brabant	0.27	Andalucía	0.14	Limburg (NL)	0.55
Prov. West-Vlaanderen	0.48	Región de Murcia	0.31	Norway	0.08
Prov. Brabant Wallon	0.39	Canarias (ES)	0.29	Oslo og Akershus	0.11

Region	X_i	Region	X_i	Region	X_i
Prov. Hainaut	0.59	Finland	0.1	Hedmark og Oppland	0.44
Prov. Liège	0.41	Länsi-Suomi	0.23	Sør-Østlandet	0.27
Prov. Luxembourg (BE)	2.1	Pohjois- ja Itä-Suomi	0.23	Agder og Rogaland	0.31
Prov. Namur	0.62	Åland	4.56	Vestlandet	0.21
Bulgaria	0.02	France	0.1	Trøndelag	0.19
Severozapaden	0.09	Île de France	0.17	Nord-Norge	0.24
Severen tsentralen	0.07	Champagne-Ardenne	1.17	Poland	0.02
Severoiztochen	0.06	Picardie	0.84	Lódzkie	0.1
Yugoiztochen	0.06	Haute-Normandie	0.82	Mazowieckie	0.04
Yugozapaden	0.02	Centre (FR)	0.61	Malopolskie	0.07
Yuzhen tsentralen	0.07	Basse-Normandie	0.96	Slaskie	0.08
Switzerland	0.17	Bourgogne	0.93	Lubelskie	0.1
Cyprus	0.06	Nord - Pas-de-Calais	0.68	Podkarpackie	0.18
Kypros	0.06	Lorraine	0.73	Swietokrzyskie	0.22
Czech Republic	0.03	Alsace	0.7	Podlaskie	0.16
Praha	0.05	Franche-Comté	0.77	Wielkopolskie	0.08
Strední Cechy	0.1	Pays de la Loire	0.6	Zachodniopomorskie	0.14
Jihozápad	0.13	Bretagne	0.54	Lubuskie	0.23
Severozápad	0.25	Poitou-Charentes	0.95	Dolnoslaskie	0.09
Severovýchod	0.11	Aquitaine	0.55	Opolskie	0.2
Jihovýchod	0.09	Midi-Pyrénées	0.38	Kujawsko-Pomorskie	0.11
Strední Morava	0.13	Limousin	1.41	Warminsko-Mazurskie	0.14
Moravskoslezsko	0.14	Rhône-Alpes	0.32	Pomorskie	0.1
Germany	0.16	Auvergne	0.73	Portugal	0.03

Region	X_i	Region	X_i	Region	X_i
Stuttgart	0.5	Languedoc-Roussillon	0.52	Norte	0.06
Karlsruhe	0.67	Provence-Alpes-Côte d'Azur	0.4	Algarve	0.22
Freiburg	1.11	Corse	3.44	Centro (PT)	0.07
Tübingen	0.87	Croatia	0.03	Área Metropolitana de Lisboa	0.04
Oberbayern	0.45	Jadranska Hrvatska	0.08	Alentejo	0.15
Oberfranken	2.06	Kontinentalna Hrvatska	0.03	Região Autónoma dos Açores (PT)	0.15
Mittelfranken	1.02	Hungary	0.05	Região Autónoma da Madeira (PT)	0.18
Unterfranken	1.4	Közép-Magyarország	0.06	Romania	0.01
Schwaben	1.77	Közép-Dunántúl	0.2	Nord-Vest	0.05
Berlin	0.65	Nyugat-Dunántúl	0.21	Centru	0.06
Brandenburg	1.36	Dél-Dunántúl	0.21	Nord-Est	0.04
Bremen	1.42	Észak-Magyarország	0.23	Sud-Est	0.05
Hamburg	1.02	Észak-Alföld	0.16	Sud - Muntenia	0.03
Darmstadt	0.63	Dél-Alföld	0.16	Bucuresti - Ilfov	0.02
Gießen	1.61	Ireland	0.09	Sud-Vest Oltenia	0.05
Kassel	1.97	Border, Midland and Western	0.21	Vest	0.06
Mecklenburg-Vorpommern	1.54	Southern and Eastern	0.09	Sweden	0.13
Braunschweig	0.69	Iceland	0.06	Stockholm	0.23
Hannover	1.09	Ísland	0.06	Östra Mellansverige	0.34
Lüneburg	2.75	Italy	0.11	Småland med öarna	0.7
Weser-Ems	2.02	Piemonte	0.35	Sydsverige	0.34
Düsseldorf	0.82	Valle d'Aosta/Vallée d'Aoste	2.94	Västsverige	0.28

Region	X_i	Region	X_i	Region	X_i
Köln	0.65	Liguria	0.63	Norra Mellansverige	0.61
Münster	1.62	Lombardia	0.27	Mellersta Norrland	1.43
Detmold	1.3	Abruzzo	0.78	Övre Norrland	0.61
Arnsberg	1.02	Molise	1.78		
Koblenz	2.46	Campania	0.38		
Trier	4.62	Puglia	0.56		
Rheinhessen-Pfalz	1.09	Basilicata	1.44		
Saarland	2.13	Calabria	1		
Dresden	0.94	Sicilia	0.45		
Sachsen-Anhalt	1.41	Sardegna	0.8		
Schleswig-Holstein	1.31	Provincia Autonoma di Bolzano/Bozen	1.68		
Thüringen	1.1	Provincia Autonoma di Trento	0.96		
Denmark	0.11	Veneto	0.46		
Hovedstaden	0.13	Friuli-Venezia Giulia	0.71		
Sjælland	0.55	Emilia-Romagna	0.37		
Syddanmark	0.41	Toscana	0.43		
Midtjylland	0.35	Umbria	0.94		
Nordjylland	0.55	Marche	0.82		
Estonia	0.03	Lazio	0.24		
Eesti	0.03				
Greece	0.03				
Attiki	0.04				
Voreio Aigaio	0				
Notio Aigaio	0.22				
Kriti	0.12				

Source: Eurostat (2016) - *Research and innovation statistics at regional level*. *Data inputs represent the average values from 2002-2008*.

B.1 Motivation

This section sets out the data, methodology, and results of the econometric analysis that seeks to quantify the potential association between the introduction of PBF systems on R&D outcomes such as publications and citations. As highlighted in section 2.2.2, the empirical evidence on the effects of PBF on public R&D productivity is scarce and only a handful studies apply more in-depth econometric methods to assess the effects of PBF. Against this backdrop, the objective of this analysis is to bridge further this gap in the empirical literature.

Section 2.2.1 above outlined that there is large heterogeneity across countries regarding the implementation of PBF systems. For instance, some countries have implemented PBF at different points in time, whereas some countries have no PBF system in place at all. Exploiting the heterogeneity across countries, this analysis investigates the associations between PBF and research performance at country level, exploring potentially different effects of PBF systems (e.g. formula-based vs. peer reviewed). That is, the analysis is similar to the studies by JRC (2015) and Auranen and Nieminen (2010), which were mainly descriptive studies, but goes beyond by trying to assess any statistically significant effects using econometric methods.

B.2 Methodology

B.2.1 Data

A large dataset, primarily sourced from the OECD, Eurostat and Scopus has been compiled. This dataset includes the key outcome variables on publications and citations, as well as a set of controls including Higher Education R&D expenditure (HERD) and the number of researchers as measures for R&D input. The estimation sample encompasses 31 OECD countries[34] spanning over a maximum of 19 years (1996 to 2014).

Following previous empirical studies, this analysis have used both scientific publications and citations to measure the quantity and quality of scientific outputs. The former is a proxy of research output quantity and the latter a measure of research quality.

A summary of the variables used together with definition and sources is provided in Table B-1.

Table B-1: Data summary

Variable	Source	Note
Publications	Scopus/ Scimago	Number of all scientific publications published during the selected year. It is usually called the country's scientific output.
Citations	Scopus/Scimago	Number of citations by the documents published during the source year, --i.e. citations in years X, X+1, X+2, X+3... to documents published during year X

[34] The included countries are: Austria, Australia, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Greece, Hong Kong, Hungary, Italy, Japan, Korea, Latvia, Lithuania, Luxembourg, Malta, Netherlands, New Zealand, Norway, Poland, Portugal, Slovakia, Slovenia, Spain, Sweden, and United Kingdom.

Variable	Source	Note
Higher education R&D expenditure (HERD)	OECD/Eurostat	Higher education R&D expenditure (HERD) is total intramural expenditure on research and development for higher education sector during a given period
Number of researchers	OECD/Eurostat	Number of researchers employed by higher education sector

B.2.2 Descriptive Statistics

Figures B-1 to B-4 report the number of publications over time for four countries that introduced a PBF system (year of introduction marked with vertical red line). In all four countries, the number of publications has increased over the time period considered, especially after 2002. This may reflect either unobserved factors which affect all countries in a similar way (e.g. higher propensity to publish) or increased R&D spending. This highlights the importance of controlling for common country factors that vary over time (as discussed below this is done by including time dummies in the model) and factors that vary over time and across countries (research spending and number of researchers).

Figure B-1: Austria - publications

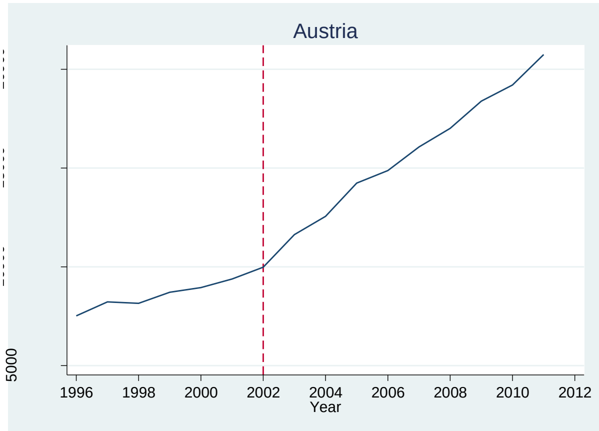


Figure B-2: Norway - publications

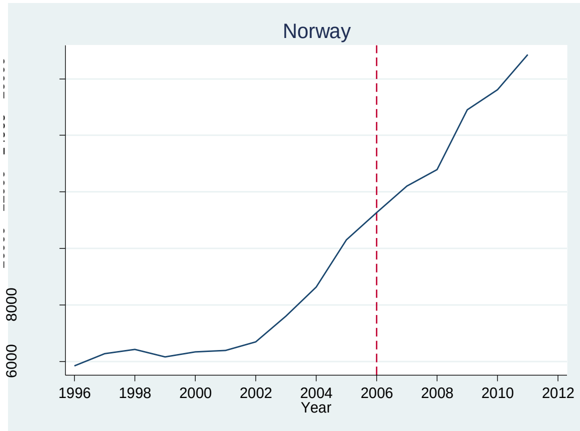
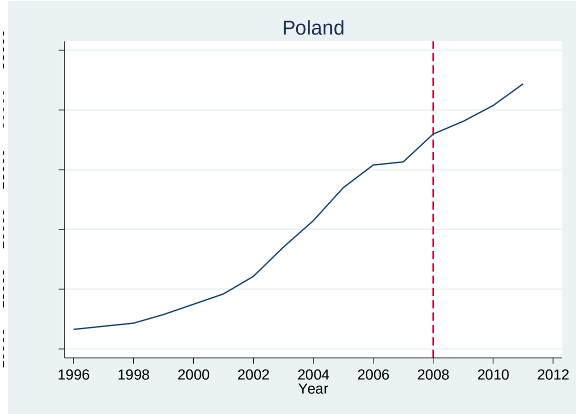
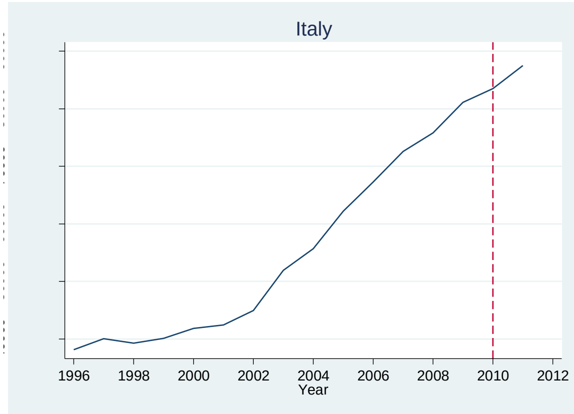


Figure B-3: Poland – publications **Figure B-4: Italy - publications**





Source: Scopus/Scimag, RAND Analysis 2016

B.2.3 Model specification

The model used to quantify the impact of PBF is shown below.

$$Y_{ct} = \beta_0 + \beta_1 X_{ct} + \beta_2 P_{ct} + \gamma_c + \gamma_t + \epsilon_{ct}$$

where Y_{ct} is a measure of R&D outcome in country c at time t; X_{ct} is a vector of controls; P_{ct} is a dummy variable that takes value 1 if a country c has implemented PBF; γ_c is a country fixed effect, γ_t is a time fixed effect; and ϵ_{ct} is an idiosyncratic error term. The coefficient of interest is β_2, which measures the overall impact of the implementation of PBF on R&D performance.[35]

B.3 Results

Table B-2 reports the coefficient estimates (and standard errors) for the model that uses the number of publications as the dependent variable. Overall, the analysis is conducted over two samples: (1) 31 OECD countries; and (2) 25 EU OECD countries. The results suggest that the introduction of a PBF system reduces on average the publication output by about 4.4 per cent. The coefficient is larger when only including EU countries and statistically significant at 10% level, suggesting a 5.3 per cent reduction in the number of publications. The results from column (2) and (4) indicate that this negative association between PBF and publications stems from the introduction of a formula-based PBF system, rather than a PBF system based on peer-reviewed assessments. The peer-reviewed PBF system does not have statistically significant effect on the number of publications, while there is a negative and significant effect of formula based PBF on publications, with the number of publications decreasing by around 8 per cent.

Table B-3 reports the results for models using citations as the dependent variable. Overall there seems to be a slightly negative effect of PBF on citations, amounting to around 4 to 5 per cent. When separating the effect for formula or peer-reviewed based

[35] While the analysis takes into account within country-variation, time trend and relevant (observed) confounding factors, omitted variable bias may still be a problem for the analysis. Such factors include the availability of other R&D resources, the passing of particular laws or acts that affect R&D activities, unobserved R&D productivity shocks and so on. The analysis' findings need to be interpreted as associations rather than necessarily causal effects.

systems, there is a negative and significant effect on citations for the formula based PBF while a positive but small effect for the peer-reviewed based PBF.[36]

Overall, the results of the analysis presented in this section suggest that PBF has no significant impact on the quality of research output and negative impact on quantity of research output. The findings are generally in line with Auranen and Nieminen (2010) and Osuna et al. (2011). Different from previous literature that found a positive association between PBF and growth in scientific papers or the improvement of research quality, this paper employs in-depth econometric analysis that takes into account of time-varying confounders, time trend and country-level difference. Thus, the analysis here contributes to a better understanding of the impact of PBF on scientific outputs.

The small and insignificant result may be due to the fact that most PBF systems include metrics not only based on publications, but on some other quality based measures as well. These metrics may help create incentives for researchers to improve research and publication quality, rather than increase the number of research publications. In fact, some systems such as the RAE and REF in the UK limit the number of publications per researcher that can be submitted to each assessment process. Therefore the introduction of PBF systems may encourage all researchers to pursue a high quality publication strategy, rather than a volume based one.[37] In addition, formula based PBF systems generally rely heavily on citations and journal metrics and therefore support a research strategy of concentrating on high quality publications. In contrast, under the peer-reviewed based system there is no statistically significant effect, suggesting the peer-reviewed system has less impact on the overall publication strategy of researchers.

The results may also cast doubt on the use of PBF to improve research productivity. The introduction of PBF may introduce too much competition and even have negative impact on research production by distracting researchers' time and energy from research to funding competition. Policy makers need to carefully consider the unintended impact of the PBF and aim for the long-term improvement of the research system by promoting talent and creativity instead of playing performance controls of a bureaucratic profession.

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[36] Sensitivity analysis was conducted with PBF policy dummy lagged by 3 or 5 years to take into account time lags between the introduction of the policy, changes in behaviours and the time required to convert research efforts into published output. The results of the sensitivity checks are similar to the baseline results.

[37] Furthermore, as the PBF system is likely to provide greater resource to those able to optimise their outputs according to the assessment process, over time funding would then be concentrated towards those researchers who on average produce less quantity but higher quality research outputs compared to those with more general, or high volume publication strategies. A greater concentration of resources may also reduce the overall publication level. Other strategies to improve the quality of research, such as larger research teams, that allow individuals to collectively achieve high quality outputs than would otherwise be possible, may also contribute to a reduction in the overall number of publications.

Table B-2: Econometric results – effect of introduction of PBF policy on scientific publications

	(1)	(2)	(3)	(4)
	Sample: all		Sample: Europe only	
Outcome variable	**log(publications)**			
PBF	-0.0438		-0.0532	
	(0.027)		(0.029)*	
PBF – formula-based only		-0.0797		-0.0861
		(0.024)***		(0.026)***
PBF – Peer-review only		0.0034		-0.0051
		(0.048)		(0.049)
Number of researcher (ln)	0.2410	0.2473	0.2159	0.2222
	(0.068)***	(0.069)***	(0.067)***	(0.067)***
R&D expenditure (ln)	0.2201	0.2138	0.2131	0.2070
	(0.053)***	(0.053)***	(0.052)***	(0.052)***
Constant	5.9503	5.9659	7.1242	7.0499
	(0.404)***	(0.403)***	(0.470)***	(0.477)***
Observations	494	485	438	438
R-squared	0.9920	0.9920	0.9918	0.9918

Source: RAND analysis

Table B-3: Econometric results – effect of introduction of PBF policy on citations

	(1)	(2)	(3)	(4)
	Sample: all		Sample: Europe only	
Outcome variable	**log(citations)**			
PBF	-0.0408		-0.0541	
	(0.031)		(0.032)*	
PBF – formula-based only		-0.0928		-0.1072
		(0.032)***		(0.032)***

PBF – Peer-review only		0.0389		0.0237
		(0.053)		(0.053)
Number of researcher (ln)	0.2325	0.2458	0.1995	0.2103
	(0.073)***	(0.072)***	(0.071)***	(0.070)***
R&D expenditure (ln)	0.2550	0.2424	0.2388	0.2283
	(0.056)***	(0.055)***	(0.054)***	(0.053)***
Constant	9.0056	9.0125	10.3522	10.2320
	(0.441)***	(0.439)***	(0.514)***	(0.520)***
Observations	494	485	438	438
R-squared	0.9918	0.9919	0.9921	0.9922

Source: RAND analysis

C Approach to estimating the R&D subsidy rate across countries

To calibrate the QUEST model for government support for industry R&D, specifically to estimate the R&D subsidy rate across countries, using the publicly available data from the OECD is proposed:

- The government-funded Business enterprise Expenditure on Research and Development (BERD) and
- The B-index (a measure of the before-tax income needed by a "representative" firm to break even on USD 1 of R&D outlays, in other words a measure of account provisions in the tax system that allow for special treatment of R&D expenditures). The higher the B-index is the higher are the allowances and credits applying to R&D outlays.

The OECD data overcome the problem with data consistency as the R&D subsidies are often linked to specific local programmes and it would be extremely challenging to give a complete picture of subsidies in a consistent manner across countries using data from national sources (and data is scarce for most countries).

Government-funded BERD is a measure of direct support as it includes grants, loans and procurement which immediately affect the funds available for a firm to spend on R&D. It can be broadly understood as direct R&D subsidies. On the other hand, the B-index is a measure of indirect support, representing various tax incentives that lower the tax liability *after* the R&D outlays are made. As per the OECD definition, 1 minus B-index can be understood as implied subsidy rate.

The following table shows both measures of direct and indirect support as % of GDP and in USD million per country. Alternatively, the indirect support can be directly reported using the 1 minus B-index measure (final column on the right) while government-funded BERD can be reported relative to BERD funded by companies, giving a rough estimate of a share of the total R&D expenditure financed by the government. Detailed R&D subsidy data (expressed as 1 minus B-index) are also shown in Table 14.

Table C-1: Measures of direct and indirect support as % of GDP

Country	Direct government funding of BERD as % of GDP	Indirect government support through R&D tax incentives as % of GDP	Average R&D subsidy rate (1-B index)
Austria	0.15	0.12	0.15
Belgium	0.1	0.2	0.105
Czech Republic	0.12	0.06	0.18
Denmark	0.06	0.06	-0.01
Estonia	0.08	0	0
Finland	0.06	0.01	-0.005
France	0.11	0.26	0.335
Germany	0.08	0	-0.02
Greece	0.02	0.04	0.095
Hungary	0.19	0.13	0.175

Country	Direct government funding of BERD as % of GDP	Indirect government support through R&D tax incentives as % of GDP	Average R&D subsidy rate (1-B index)
Ireland	0.07	0.16	0.26
Iceland	0.1	0.06	0.22
Italy	0.05	0.0004	0.09
Netherlands	0.02	0.15	0.2075
Norway	0.08	0.05	0.1525
Poland	0.04	--	0.0475
Portugal	0.04	0.09	0.3275
Slovak Republic	0.02	0	0.1
Slovenia	0.25	0.09	0.17
Spain	0.08	0.02	0.325
Sweden	0.14	0	0.05
Switzerland	0.02	0	-0.01
United Kingdom	0.08	0.08	0.195

Source: OECD. Corresponding year of data included is 2016.

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Introduction

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Satellite Model

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The Directorate General for Research and Innovation of the European Commission commissioned Deloitte and RAND Europe to undertake a study with the aim to better understand the impact of public policy on innovation. In particular, the objective of the study is twofold: enhance the evidence base around the impact of public policy on research and innovation; explore possible modifications in QUEST III to evaluate a number of innovation policies and reforms.

This report focuses on the assessment of the impact of public policies and strategies such as performance-based funding and policies that enhance public-private R&D cooperation on R&D productivity. Furthermore, a satellite model is developed that could be integrated within QUEST III to facilitate evaluation of R&D policies on R&D productivity, innovation and other key macro-economic variables.

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