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A literature review on the impact and effectiveness of government support for R&D and innovation

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Abstract

This paper examines the empirical evidence on the impact and effectiveness of government support for R&D and innovation. It covers findings for EU and OECD countries, China and Taiwan. The period covered is 1960 till 2017. The review of the literature shows a great variety of empirical evaluations that focus on effects of either direct government support in the form of grants, subsidies and loans or indirect support in the form of tax incentives, on input additionality, output additionality, behavioural additionality and welfare. The review is structured according to this set of outcomes and effects.

The report notes a great heterogeneity of empirical studies, a wide range of empirical estimation approaches, and variety of definitions of studied outcomes. Further, there is a relative abundance of studies evaluating the effect of government support on R&D expenditure compared to the number of studies evaluating output additionality on a firm and macroeconomic levels, behavioural additionality or evaluating impact on welfare. The report concludes with the overview of main findings indicating that government support for R&D and innovation, either in the form of grants, subsidies and loans, or in the form of tax incentives on input, output and behavioural additionality as well as on welfare may have a positive impact but not always. The overall conclusion leans towards complementarily of public and private R&D expenditures and a positive but modest impact on innovation at the firm level. However, the magnitude of the effect varies with firm size, generosity of support, size of the project supported, sectors, the type of tax system, etc. The government support seems to be the most effective when targeting an innovation input –R&D expenditure. We suggest that to gain better understanding of the impact of government support for R&D and innovation to firms and to come to a more conclusive view of the nature and the magnitude of its impact and effectiveness, more studies evaluating the impact of government direct and indirect support on innovation output at the firm and macroeconomic levels as well as on welfare are needed and that due to a host of methodological issues, the pure econometric estimations of the impact and effectiveness of government support needs to be complemented by long-term ex-post evaluation studies and qualitative in-depth case studies.

Keywords: Government R&D subsidies, grants, tax credits, input, output, behavioural additionality, welfare

JEL codes: O3, O5, O30; O38; D22, E62, E62, H21, H40, H54, L10

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Introduction

Government policy measures to stimulate private sector to increase investment in research and development have always been an important part of traditional industrial policy and even more so of more recent innovation policy, notably in the EU member states and OECD countries.

The rationale for government support is based on the assumption that R&D conducted within firms, will directly or indirectly stimulate innovation that leads to the production of new marketable products, processes or services, the assumption on which public industrial policies are based. The classical argument for government support for R&D conducted in firms is derived from the public good characteristic of knowledge creation. Since firms are not able to appropriate all the external benefits of their investment in knowledge, and R&D spending is investment in new knowledge, the overall investment rate in the creation of new knowledge is lower than optimal - firms are not ready to undertake R&D projects that would be socially valuable. Public good characteristics of knowledge creation, the intangible character of knowledge and its risky nature and information asymmetries between borrowers and lenders, lead to a form of market failure that calls for government policy measures to stimulate private sector to increase investment in research and development by reducing the cost of risky investment and thus increasing the firms' expected returns to R&D projects.

In addition to the classical argument justifying government intervention, several other have been put forward, such as, competitive edge of firms engaged in international markets, "catching up" with global productivity, and protecting 'infant industries', (Cunningham, P., et al., 2013; Furtado, C., 1964; Mozzoleni, R. and Nelson, R., 2007). To Bozeman, B., and Deitz, J.S., 2001 public intervention is justified by three paradigms: the market failure paradigm, the mission-oriented paradigm and the cooperation paradigm[1].

The above justifications became the foundation of innovation policies adopted by governments worldwide. Governments, already within the past half-century up to the present, direct a large sum of public funds towards expanding the base of scientific and technological knowledge to reduce uncertainty, to substitute inefficient markets by sharing risks and costs and to devise ways to overcome inappropriability (Cunningham, P., et al., 2013, p. 29). A variety of tax and subsidy measures were introduced with the intention of encouraging private firms to undertake R&D projects at their own expense (David, P., et al., 2000). During the 2000 to 2013 period, for example, government financial support instruments to promote R&D have accounted for nearly 70% of all R&D cost performed in OECD countries (Appelt, S., et. al., 2016, p. 6) in the form of grants, purchase of R&D services and R&D tax incentives.

While it is generally believed that government support for R&D investment in firms has a positive effect on innovation, the issue at stake is: how effective the public support for private firm R&D activities really is? Does public funding of private R&D induce firms to increase their own R&D expenditure, or the opposite; it crowds out private firm investment in R&D? Do government R&D support measures have a

[1] Support for producing and delivering 'public' or 'collective' goods falls into mission oriented paradigm, while supporting collaboration between public research and industry, suppliers and knowledge providers, the facilitation of the flow of knowledge between the actors involved to support structural change in the national innovation system falls into cooperation paradigm.

positive impact upon innovation activities other than R&D at the firm level – new product and process development, productivity and growth? Do they stimulate private spending on research and/or development activities at the firm level? Do they have a positive impact upon the quality of R&D done at the firm level? Do they have an impact upon firm's R&D investment plans – inducing behavioural changes at the firm level? This information is no doubt a crucial input to good policy making.

Empirical investigations found in the literature seek to understand the causal effect of policy intervention and to establish its cost effectiveness. The assessment of the impact and effectiveness can be categorized into three different levels: 1) R&D expenditure, 2) innovation and 3) effects on macroeconomic level. The first level refers to input additionality, the degree to which firm R&D expenditures have increased because of the government support, the second refers to output additionality, the degree of changes in innovation behaviour of firms measured by product and process innovation, increased number of patents, improved organization and management of the firm, and third level refers to effects on economic outcomes such as increased productivity and economic growth that may be induced by government funding of R&D investments in firms.

Most of the empirical analysis of surveyed literature concentrates on the first level, input additionality, testing the crowding-in and crowding-out hypothesis, i.e. on the nature of the effect of government funding of R&D on private firms own R&D expenditure. Empirical studies on output additionality and or those evaluating effects on macroeconomic level are more limited, in spite of the fact that this evidence would have been highly important for judging the effectiveness of government innovation policy. In the interest of public intervention in R&D are not private rates of return but its effect on the overall economic outcome.

Within these three levels, government support for R&D can be direct or indirect. Grants, subsidies and loans are instruments of so-called direct government support, while tax incentives, especially tax credits are instruments of so-called indirect government support. These are also the most common proxies for government support in empirical evaluations of the causal impact of policy intervention. Namely, a government can influence R&D activities also by public investments, or by funding private sector research through loans and contracts. Nevertheless, there is no clear-cut opinion regarding the effectiveness of direct compared to indirect government support or which is a preferential measure of its effectiveness. However, it is widely accepted that direct support in the form of grants, subsidies and loans compared to indirect support in form of tax incentives, is more appropriate especially for R & D projects having the largest gap between social and private rate of return. In these cases government targeting compared to firms' choice in allocating tax incentives into different R&D project could be more effective because of the tendency of private firms to allocate tax incentives into those projects that yield the highest private rests of return.

According to Eurostat (2017) the public share in R&D activities from 2004 to 2014 within the EU-28 was between 32% and 35 %, of which relatively high amount is used to subsidies R&D activities undertaken by private firms. The major argument by economists to justify the government support of R&D (direct or indirect or both) was presented already in the previous section. There are many who put arguments specifically in favour of grants, subsidies and loans as proxy for government support to firms' R&D

expenditure and innovation activities against fiscal incentives.[2] Often quoted arguments against fiscal incentives, particularly tax incentive is that to generate the socially desirable level of R&D expenditures a huge tax change would be necessary, and further that in case of frequent changes of tax incentives, firms' planning of R&D investment becomes difficult, which can marginalize the effect of tax incentives and that raising private R&D expenditure by tax incentives could be inefficient if the user cost of R&D elasticity is low.

The impact of direct and indirect government measures for R&D support on all three levels has been studied since the early 1960-es. In this paper the literature published between 1960-es and 2017 is reviewed based on findings of individual articles and studies as well as on the findings of survey articles and studies. Empirical evidence that will be presented is not restricted to the European counties, although the bulk falls into this context. The research was done using both dikul.si database and Google search engine. Dikul.si data base revealed more than 480 articles. After eliminating those that were not relevant for the study, 79 articles and studies remained for analysis and 28 using Google search. It includes 107 articles and studies, of which the empirical evidence of 57 articles and studies evaluate effectiveness and impact of government support in the form of subsidies and grants on input, output, behavioural additionality and welfare, and 41 articles and studies evaluate effectiveness and impact of government support in the form of tax incentives. In each of the levels of analysis also studies based on meta-regression analysis and studies with systematic review of empirical studies are included, so that the total number of estimates greatly exceeds the total number of articles and studies.[3]

The paper is organized as follows. In the first chapter we present empirical evidence of the effects of government direct support (grants, subsidies and loans) for R&D on private R&D expenditure, innovation, and macroeconomic outcomes, including welfare. In the second chapter we present empirical evidence of effects of indirect government support (fiscal incentives) at the same four levels of evaluations. Finally, we discuss the implications, along with the limitations of the reviewed literature.

1 An overview of empirical evidence on the impact and effectiveness of government direct support for R&D and innovation

1.1 Empirical findings on input additionality

Presentation of the evidence of the reviewed studies on the effectiveness and impact of direct support to R&D expenditure is organized in historical order, starting with the earliest representative studies. The data reveal great heterogeneity of empirical studies. Till 1990s the majority of studies were performed using US data, some including also data from UK and Canada (See David, P., B., and Toole, A. 2000). Later on, most studies used data from the EU/OECD countries. See Appendix Table A.1 to A.4.

[2] However, in practice, it is difficult for the government to make a proper targeting due to uncertainty of knowledge creation and due to selection bias, pressure of lobbyist and preference of bureaucrats.

[3] For example, among articles and studies evaluating the impact of government direct support for R&D conducting in firms on R&D expenditure (input additionality) 7 articles included present meta-regression analysis and systematic review of empirical studies, altogether covering 226 articles and studies.

The reviewed studies differ in the industries considered: most focus on manufacturing and very few include also services or other sectors. Considering the size distribution of companies, the effect of government direct support for R&D investment on SMES and within them the young high-tech companies were most often studied. The surveyed studies have a high degree of heterogeneity with respect to the periods analysed as well the level of aggregation. Few used longitudinal approach, mostly a short run or point in time evaluations. Besides national statistics, many base their estimation on using Community Innovation Surveys (CIS) data[4]. The researchers mostly used firm-level data, few also used plant level data or aggregate data on the level of industry or countries. Analyses were performed using time series, cross-section data or panel data. Econometric methods used show that the traditional empirical approach relied on the least squares (OLS) estimation of linear regression models, regressing R&D intensity of private firms i.e. R&D expenditures relative to sales (the most common measure used) on public support measured by either public grants, subsidies or contracts (used especially in US studies) or on total government funding of firm R&D activity. In most of surveyed articles till 2000 private R&D expenditure is regressed on the government R&D funding with some control variables such as firm, time and location specific characteristics. Positive coefficient on public expenditure is interpreted as revealing the predominance of complementarity (crowding-in) between public and private expenditure, while negative coefficient indicates the predominance of substitution (crowding-out). The traditional approach has been criticized, most notably by David P., B., and Toole, A., 2000, Klette, T.J. et al., 2000, and more recently Cerulli, G. 2010 for largely ignoring endogeneity problems as well as selection bias both in the model construction as well as in the estimation phase (Cerulli, 2010, p. 432-434). Due to the selection bias, results may be more biased towards substitution effect (David, P., B., and Toole, A. 2000). After the 2000s and especially in the last years, scholars increasingly have used a 'non-structural' models, such as control-function allowing also for fixed effects (Streicher, G., 2007), matching and difference-in-differences (DID) and conditional DID estimator (e.g. Aerts, K., and Schmid, T., 2008) combining the matching and DID estimators to eliminate some of the disadvantages, depending on the availability and type of data. Among them matching and DID became preferred techniques used to evaluate the impact of government direct support to private firm R&D investment in the recent studies thus enabling a more reliable evaluation of the causal effect between public support to private R&D investment and consequently more reliable policy recommendations. Propensity score matching (PSM) addresses the problem of "selection on observables" and parametric regression analysis is carried out to address the potential bias associated with the "selection on un-observables".

What follows is the review of the evidence on input additionality, the empirical studies testing crowding-in and crowding-out hypotheses, i.e. the positive or negative impact of direct government support on private R&D expenditure of firms receiving grants, subsidies or loans.

Table A.1 in the Appendix presents the findings on input additionality of 25 published articles and studies, covering the period from mid 1960s till 2017. Three of them used meta-evaluation and four of them systemic reviews. In several studies depending on the sub-sample of firms both complementarity

[4] Community Innovation Surveys (CIS) are a series of surveys conducted in EU member states, EFTA countries and EU candidate countries by the national statistical bodies in cooperation with EUROSTAT. The Community Innovation Survey (CIS) based innovation statistics are part of the EU science and technology statistics. Surveys are carried out with two years' frequency by EU member states and a number of ESS member countries. Compiling CIS data is voluntary to the countries, which means that in different surveys years different countries are involved. The first CIS took place in 1992, and subsequently in 1996, 2001, 2005, 2007 and 2009 up to 2016.

and substitutability was found. Therefore, the total number of results is greater than total number of studies.

1.1.1. Empirical findings of meta-evaluations and systematic/critical review of studies

In Table 1 below we present the summary of findings of this section

Table 1: Summary of the distribution of the econometric evidence of meta-regression analysis and systematic reviews of empirical studies

Study	**Complementarity**	**Insignificant**	**Substitutability**	**Mixed results**	**Total**	**Publication period**
David, P., B., and Toole, A. 2000	16	3	11	3	33	Pre-2000
Garcia-Quevedo, J., 2004	38	19	17		74	Pre-2002
Correa, P., 2013	predominantly					2004-2011
Cunningham, P. et al., 2013	12	3	2	7	24	2000-2012
Zuniga-Vicente, J. A., et al., 2014	48	14	15		77	Pre-2011
Becker, 2015	predominantly					Post-2000
What Works Centre for Local Economic Growth, 2015	8	1	1	8	18	2000-2015
TOTAL	122	40	46	18	226	

David, P., B., and Toole, A. 2000 found that 11 studies out of 33 reported substitution effect. The US based studies tend to find more substitution effects than non-US based studies.

Garcia-Quevedo, J., 2004 found that out of 74 studies 38 indicated complementarity, 17 substitutability and 19 were insignificant. Crowding-out is more common in firm-level studies compared to industry and country level studies.

Correa, P., 2013, found that the effect of public investment on research and development is predominantly positive and significant. Public funds do not crowd out but incentivize firms to revert funds into research and development. The coefficient of additionality impacts on research and development ranges from 0.166 to 0.252, with reasonable confidence intervals at the 95 percent level. The results are highly sensitive to the method used. The high heterogeneity of precision is explained by the wide variety of methodologies used to estimate the impacts and model characteristics.

Cunningham, P. et al. 2013, reports the summary of 24 studies testing crowding-in and crowding-out hypotheses. Twelve of them found complementarity or positive effect, two substitution effect, seven mixed effect (mainly depending on the size of the firm and on the volume of support, more positive effect on SME as well as of small grants and more negative on large firms as well as in the case of large grants) and three insignificant or zero effect. A number of reviewed studies calculated the project additionality around 70%. Many of them reported that smaller firms, firms in relatively low technology sectors and firms from less advanced regions tend to exhibit more input additionality. The analysis of the literature reviled that the results were usually exceedingly sensitive to methodology applied, confirming the already discussed effect of methodology used on results obtained.

Zuniga-Vicente, J.A., et al., 2014 reviewed 77 studies. They found that 60% of studies reported crowding-in effect, 20% crowding out and 20% obtained insignificant results.

Becker, B., 2015 found that empirical results before 2000 are inconclusive with respect to crowding-in and crowding-out hypotheses. More recent research rejects substitution effect and tends to find additionality effect.

What Works Centre for Local Economic Growth, 2015 provides the most rigorous research. Based on the systematic review of 1,700 programmes from GB and other OECD countries of which only 18 R&D expenditure studies were included in the analysis of which the analysis of the evidence reviewed met the standard 3, 4 or 5 levels of SMS[5]. Eight studies found complementarity effect, another eight mixed effects and one substitutability effect and one reports insignificant result. The study based on these findings concludes that the evidence whether public support crowds out private investment is inconclusive. The mixed findings, positive and negative effects indicate that grants, loans, subsidies may positively impact R&D expenditure, but not always. They also found that effects are bigger on SMEs R&D expenditure than for large firms. Programs that target particular sector appear to be slightly worse in terms of increasing R&D expenditure compared to those that are sector neutral.

1.1.2 Empirical findings of individual studies

In Table 2 we present the summary of findings for this section.

Individual studies accumulated over the period from 2003 till 2016 of which the majority are of most recent dating i.e. from 2011 on. Out of 18 analysed, 13 report complementarity effects, one substitutability effect, four mixed and one insignificant result. Total number of results is greater than the total number of studies due to different results obtained regarding the sub-samples included in the study. Most of these studies were performed on firm level data a preferred level of analysis in order to account for the firm's heterogeneity which is hidden on the higher level of aggregation.

[5] Ranking according to The Scientific Maryland Scale (SMS) the level 3 refers to comparison of outcome in treated group after an intervention, with outcomes in the treated group before the intervention and comparison group used to provide a counterfactual (e.g. difference in difference), level 4 to comparison of outcome in treated group after an intervention, with outcomes in the treated group before the intervention, and comparison group used to provide a counterfactual (e.g. difference in difference). Careful and credible justification provided for choice of a comparator group that is closely matched to the treatment group and level 5 refers to research designs that involve randomisation into treatment and control groups (What Works Cetre for Local Economic Growth, 2015, p. 17).

Table 2: Summary of the distribution of the econometric evidence of individual articles published in the period 2003 - 2016

Complementarity	**Insignificant**	**Substitutability**	**Mixed results**	**Total**	**Publication period**
13	1	1	4	19	2003-2016

The empirical results of authors such as Kaiser, U., 2004, Hewitt-Dundas, N., and Roper, S. J., 2009, Carboni, 2011, Bloch, C., and Graversen, E.K., 2012, Arque-Catells, P., 2013, Jaklic, A., et al., 2013, Aristei, D. et al., 2015 and Czarnitzki, D., and Delanote, J., 2016, largely confirm insights of the input additionality prevailing in the literature on this topic, i.e., public subsidies complement private R&D investment.

Mixed results were found by several researchers. Clausen, T.H., 2007 when analysing the effect of public subsidies on Norwegian firms in the period 1999-2002, obtained a significant input additionality of subsidies for research on firm R&D investment budget, but substitution effect for firms' development activities. His findings also support the theoretical argument that subsidies stimulate the best private R&D expenditure where the gap between the social and the private rate of return to R&D is high. Dai, X., and Liwei, C., 2015 found E-shaped relationship and inverted-U correlation with the firm's total R&D and private investment with different levels of public subsidies using a large sample of Chinese manufacturing firms. They found saturation point beyond which further increase in public subsidies does not yield an increase in firm's total R&D investment but would partially or completely crowd out a firm's private R&D investment. Similarly Marino, M. et al., 2016 found crowding-out effect to be more pronounced at higher level of public subsidies for a sample of French firms during the period 1993-2009. This finding is in line with Guellec, D., and Van Pottelsberghe de la Potteries, B., 2003, who found, based on econometric analysis of 17 OECD countries, that while government funding of R&D performed by firms has a positive effect on business financed R&D, the stimulating effect varies with respect to its generosity. It increases up to a certain threshold (about 10% of business R&D) and then decreases beyond.

Few researchers were interested to find out the sign of the effect of subsidies on firm R&D expenditure when firms are receiving government support from different sources. Czarnitzki, D., and Lopes-Bento, C., 2013 reviewing the effects of a specific government-sponsored commercial R&D program in Flanders from various policy aspects found that the policies are not subject to full crowding-out, the treatment effects are stable over time, and receiving other subsidies in addition to the programme under evaluation does not decrease the estimated treatment effects. The same authors, Czarnitzki, D., and Lopes-Bento, C., 2014 also report the co-existence of national and European polices as complementary in case of Germany. Marino, M., et al., 2016 in addition to results presented above found no evidence of additionality or substitution effect between public and private R&D expenditure for the analysed period 1993-2009 for a sample of French firms.

Some authors looked at input additionality specifically for SMEs and young high tech companies. Czarnitzki, D., and Delanote, J., 2015 when evaluating the merit of EU policy focusing on SMEs and young independent firms in high-tech sectors, found no full crowding out effect for all firms, however, the treatment effect is the highest for high-tech firms. Hud, M. and Hussinger, K., 2015 analysing the effect of public support to German SMEs during 2006-2010 have found crowding-out effect caused by reluctant innovation investment of subsidies for the crisis year 2009, and a positive effect for the whole period. They conclude that public subsidies have positive overall effect; this prevented discontinuation of R&D spending that would otherwise be the case. Radicic, D., and Pugh, G., 2016 found large treatment effect for European SMEs with respect to input additionality from national and international programmes separately as well as for firms supported by both sources relative to the firms supported only by national programmes.

Yu, F., et al., 2016, the only author out of the reviewed ones in this section found crowding-out effect of government support to R&D firms' expenditure. He found that government grants have a significant crowding-out effect on firms' R&D investment in China, while

Comparison of these results with the results of meta-analysis considering the publication period pre-2000 shows that in the recent publications post 2000-2017 results are more in favour of crowding-in hypothesis. The difference in obtained results between pree-2000 period and post-2000 period may well be explained by different methodological approaches used in two periods. As already discussed, most of the empirical work in pree-2000 studies did not use techniques to control for endogeneity, selection bias and unobservable heterogeneity. Therefore, the endogeneity of subsidies as well as selection bias may have biased the results, leading to a higher frequency of a substitutability effect.

The more recent empirical work very seldom reports crowding out effect between public subsidies and private R/D expenditure, disregarding whether the analysis was performed on a firm-level, industry and aggregate level data. Most of these studies, as can be seen from Table A.1 in the Appendix, used statistical techniques to control endogeneity and/or selection bias, and dealt with unobserved heterogeneity. They have used complex empirical technics such as matching, non-parametric matching estimator, treatment effect analysis, estimation of close-response function, the fixed effect model, CDM model, first difference, difference-in-difference estimator, control-function regression, propensity score matching, treatment effect analysis, combining difference-in-difference (DID) with propensity score and matching methods. This reinforces the argument that methodological design applied makes a great difference: the more sophisticated econometric techniques are used the more crowding-in hypothesis is confirmed and complementary of private and public funds for R&D becomes a prevailing outcome. In addition, the findings obtained are more reliable as in the case in which empirical testing was based on a traditional approach.

The overall summary of studies examining input additionality indicates a positive impact of public support on firms' R&D expenditure. The impact seems to be stronger for SME companies, stronger during the recent financial crisis disregarding the size of the companies while the impact of government support diminishes at the higher levels of subsidies. On the country level, in some cases the co-existence between national and European policies, i.e. complementarity effect was found but this evidence is rather scare and cannot be generalized. However, the evidence whether public support crowds out private investment is inconclusive. The mixed findings, positive and negative effects indicate that government direct support may positively impact R&D expenditure, but not always.

1.2 Empirical findings on output additionality

This section reviews studies evaluating the impact of direct government support (grants, subsidies, loans) on innovation outcomes such as production and sales of better, more innovative products, and or improved production processes of recipient firms as well those that were evaluating its impact on macroeconomic outcomes, such as on productivity, employment and economic growth.

Table A.2 in the Appendix presents the findings on output additionality of 22 published articles and studies, over the period from 2000 till 2017. Three are using meta-regression analysis and systemic reviews, and 19 are individual articles and/or studies, evaluating output additionality at the firm level as well as the effect of government direct support on macroeconomic outcomes. Compared to input additionality fewer studies looked at economic effects of R&D support beyond immediate impact on R&D expenditures in spite of the fact that the ultimate goal of the policy is to encourage an increase of firms' innovation outputs and macroeconomic outcomes – productivity, employment and growth.

1.2.1 Impact on innovation at the firm level

In Table 3 we present the summary of findings of this section.

Table 3: Summary of output additionality at the firm-level

Study	**Complementarity/Positive effect**	**Insignificant/ No effect**	**Substitutability/ Negative Effect**	**Mixed results**	**Total**	**Publication period**
Cunningham, P., et al., 2013	7	2	4	4	17	2004-2012
What Works Centre for Local Economic Growth, 2015	11*	3*		2* 3**	16* 3**	2000-2015
Sub-total	18	5	4	9	36	
Individual studies	8		3	4	15	2003-2017
Total	26	5	7	13	51	

* Measuring the effect on patents or self-reported product or process innovation.
**Measuring the effect on other innovation outcomes – impact on the quantity and quality of academic publications, on the innovation process, and on collaboration.

Findings of studies based on meta-evaluations and systemic/critical review of surveyed articles are the following.

Cunningham, P. et al., 2013 in their survey of studies assessing output additionality include those evaluating the impact of government direct support on a firm level as well as on macro outcomes. Out of 24 surveyed studies only 17 of them, those that report results on the firm level, will be reviewed here.

Seven studies obtained additionality effect, four substitution effect, four mixed results and two insignificant results. Empirical studies are based on EU and other OECD countries and CIS data; they also include evaluations of government supported innovation programmes and specifically their effect on young high-tech firms. Most of them focus on manufacturing while very few focus on services. Authors used quite different measures for output additionality: the number of patent applications, appropriability (patents, models/designs, trademarks and copyrights, trade secrets, design complexity and lead time), new products and services, propensity to innovate, number of innovations, world-first innovations and sales. Among them, the number of patents was the most commonly used measure of output additionality.

What Works Centre for Local Economic Growth, 2015, is based on a systematic review of 1,700 programmes from GB and other OECD countries. Only 19 studies which met the standard of 3, 4 or 5 level of SMS[6] were included in the final review. Sixteen evaluations considered patents or self-reported innovation (in terms of new/improved products or processes) and the remaining three considered less standard measures of innovation, such as the effect on quality of academic publications on innovation process, and or, collaboration. Out of 16 studies ten found consistently positive effect of the programme, one on at least one of the various innovation outcomes, but zero effect on others, two studies found mixed results for the particular innovation outcome considered[7], while three studies found that the programme had no effect on innovation. Three studies out of 19 considered alternative measures of innovation outcomes with mixed results on innovation outcome. These results indicate that grants, loans, and subsidies may positively impact innovation outcomes but not always. The effects differ across types of innovation and are weaker for patents than for self-reported measures of process or product innovation. The effect of public R&D targeted to a particular sector appear to be slightly worse in terms of increasing innovation compared to those that are sector neutral and appear to be higher in the case of SMEs compared to larger firms.

Donselaar, P. and Koopmans, P., 2016 performed meta-analysis of the effect of R&D on productivity at the micro, meso and macro level of 38 studies. Two important results emerged: 1) a substantial part of the differences in results between studies can be explained by study characteristics such as econometric method used, the specification of the estimated equations, the output variable used as a dependent variable, the definition of the R&D input variable etc., and 2) assuming "optimal" study characteristics, the meta regressions were used to compute "best guess" estimates of the output elasticities of business R&D capital and public R&D capital in non-G7 countries. For domestic business R&D capital the best guessed output elasticity was found to be 0.06, for domestic public R&D capital 0.03 but the latter is subject to much uncertainty because of diverging results in a small number of studies.

Individual studies evaluating the impact of direct government support on a firm level in this report include the most recent publications (between 2007 and 2017). Out of 19 studies four evaluated output

[6] Ranking according to The Scientific Maryland Scale (SMS) the level 3 refers to comparison of outcome in treated group after an intervention, with outcomes in the treated group before the intervention and comparison group used to provide a ounterfactual (e.g. difference in difference), level 4 to comparison of outcome in treated group after an intervention, with outcomes in the treated group before the intervention, and comparison group used to provide a counterfactual (e.g. difference in difference). Careful and credible justification provided for choice of a comparator group that is closely matched to the treatment group and level 5 refers to research designs that involve randomisation into treatment and control groups. What Works Centre for Local Economic Growth, 2015, p. 17.

[7] For example, results may vary across different econometric specifications, acrross different samples or across firm size. (What Works Centre for Local Economic Growth, 2015, p. 26.

additionality on macroeconomic level. Here findings of only the remaining 15 studies evaluating additionality on a firm level are reviewed.

Out of 15 studies 8 found positive effect of government support of R&D on innovative firms' activities (output additionality), three found that access to government funds had a negative influence on innovation output, and four found mixed results.

A positive output additionality effect of all public R&D schemes in Eastern Germany was found by Almus, M., and Czarnitzki, D., 2012. Czarnitzki, D., and Lopes-Bento, C., 2014 found that subsidy recipients in Germany are more active with respect to patenting. A citation analysis of patents revealed that the subsidy recipients file patents that are more valuable (in terms of forward citations) than those filed in the counterfactual situation of receiving no public support. Similarly, Czarnitzki, D., and Delanote, J., 2016 found a positive effect on innovation output in case of Belgium using CDM model, Guo, D., et al., 2016 in the case of Chinese government Innovation Fund for SME support generated higher number of patents and sales from new products and exports. Bronzini, R., and Piselli, P., 2014 in the case of Northern Italy innovation programme during early 2000s found a significant impact on the number of patent applications, particularly in the case of smaller firms. It also increased their likelihood of applying for a patent. Czarnitzki, D., and Delanote, J., 2015 evaluated the current focus of EU policy on independent young SMEs in high tech sectors, and found that current policy focus is not ineffective. Positive effect of R&D subsidies was also found by Radicic, D., and Pugh, G., 2016 who performed analysis of treatment effect on a wide range of innovation output in European SMEs. They found positive effects of innovation support programmes, typically increasing the probability of innovation and its commercial success by around 15%. Huergo, E., and Moreno, L., 2017 examined the impact of Spanish R&D programmes on firms' R&D activities. Their results indicate that direct aid clearly increases the probability of conducting R&D activities, the full crowding out of private R&D is rejected for all types of support – low interest loans and national and EU subsidies. They also found that the impact of the support is greater for SMEs while for large firms a substitution effect between subsidies and loans cannot be ruled out.

Zemplinerova, A., and Hromadkova, E., 2012 based on a Czech sample of large firm dataset found that bigger firms are less efficient in transforming the innovation input into output and that access to subsidies has a significant negative influence on innovation output. A negative effect of subsidies on innovation output was found also by Hong, J., et al., 2015 in Chinese high tech industries but positive and significant effect of private R&D funding. Montmartin, B., and Herera, M., 2015, in the case of high tech industries of 25 OECD countries found a substitution effect between R&D subsidies and fiscal incentives.

Several authors report mixed effects, positive and negative, of government R&D funding on innovation output. Herrera, L., and Sanchez-Gonzalez, G., 2013, based on a sample of Spanish firms found that regardless of the size of the firm size, public funding stimulates firm's investment into applied research and technological development but not also into basic research. In small firms they increased the expansion of the sale of products new to the firm while in large subsidized firms they improved the sales of products new to the market. Radicic, D., and Pugh, G., 2016 have studied the effect of national and EU R&D programmes on output additionality on the sample of 28 EU countries. They found no evidence of innovation output additionality from national programmes and crowding-out from EU programmes could not be rejected. Radicic, D. et al., 2015 report positive impact of national and international programmes on innovative behaviour of European SMEs - positive treatment effect was found for the propensity for patent application, but not on innovative sales. Szczygielski, K., et al., 2017 examining the efficiency of innovation policies by looking at data from 2010 innovation surveys found that government aid for R&D activities contributed to better innovation performance by firms in Turkey and Poland. However, EU-funded grants for physical and human capital upgrading in Poland were inefficient in fostering innovation, and have actually impeded innovations.

In summary, the evidence presented on output additionality at the firm level suggests that direct government support such as grants, subsidies and loans may positively impact innovation outcomes: increased number of patents, sales of new product and introduction of new processes, but not always. The greater impact on firm innovation output is generally found for SMEs. The effect of public R&D targeted to a particular sector appears to be slightly worse in terms of increasing innovation compared to those that are sector neutral. Out of the 51 studies reviewed, 26 report positive impact, while 7 report negative, 13 mixed and 5 insignificant impacts. This indicates the existence of a modest positive impact of direct government support for R&D on firm output additionality. It should be noted, that these results are even more imprecise compared to input additionality due to problems associated with the definition of innovation output. For example, are patents which are the most common definition of innovation output, an adequate measure of innovation output? Further, the impact of government support might take longer to materialize and therefore it is not captured by econometric evaluation. Finally, how to take into account that R&D investment is usually associated with high uncertainty.

1.2.2 Impact on macroeconomic level

In Table 4 below we present the summary of findings in this section.

Findings of studies of systemic/critical review of surveyed articles are presented first.

Cunningham et al., 2012 in their survey present the results of seven studies that were evaluating the effect of direct government support for R&D on macroeconomic level measured by the impact on total factor productivity, productivity, aggregate efficiency, technical and scale efficiency. Three of them reported a positive and significant effect of grants on total factor productivity, aggregate efficiency, technical efficiency and scale efficiency while one study reported productivity increases due to spillover of publicly financed R&D and estimated social gain in output to be 16%. Another three studies analysing the impact of government supported R&D projects on firm productivity or innovative performance found in general positive effect which, however, was not found for young, small highly innovative companies.

What Works Centre for Local Growth, 2015, reviewed 19 evaluations of which the analysis of the evidence reviewed met the standard of 3, 4 or 5 levels of SMS[8]. Out of 19 studies 17 evaluations considered the impact of grants and loans on productivity, employment and firm performance (sales,

[8] Ranking according to The Scientific Maryland Scale (SMS) the level 3 refers to comparison of outcome in treated group after an intervention, with outcomes in the treated group before the intervention and comparison group used to provide a counterfactual (e.g. difference in difference), level 4 to comparison of outcome in treated group after an intervention, with outcomes in the treated group before the intervention, and comparison group used to provide a counterfactual (e.g. difference in difference). Careful and credible justification provided for choice of a comparator group that is closely matched to the treatment group and level 5 refers to research designs that involve randomisation into treatment and control groups. What Works Centre for Local Economic Growth, 2015, p. 17.

turnover or profit), ten found consistently positive effects of the programme on at least one or two of these outcomes. A further five studies found mixed results. Two found that the programme had no effect, and the two studies that looked at the impact on exports showed positive effect. These findings suggest that R&D grants and loans can positively impact macroeconomic outcomes: productivity, employment or firm performance. The review of these studies also revealed that support is more likely to increase employment than productivity.

Table 4: Summary of output additionality on macroeconomic level

Study	**Complementarity/positive effect**	**Substitutability/ Negative effect**	**Mixed results**	**Insignificant /No effect**	**Total**	**Publication period**
Cunningham, P., et al., 2012	4		3		7	2004-2012
What Works Centre for Local Economic Growth, 2015,	10 2*		5	2	17 2*	2000-2015
Sub-total	16		8	2	26	
Individual studies	2	1	1		4	2013-2015
Total	18	1	9	2	30	

*Measuring the impact on export sales

Individual studies evaluating the impact of direct government support on macroeconomic outcome presented below report the following findings:

Brautzsch, H.K., et al., 2015 found that R&D subsidies provided by the German Central Innovation Programme for SMEs in the period 2008-2009 had a substantial leverage effect on employment, value added and production in the business cycle that amounted to at least twice the initial financing and counteracted the decline of GDP by 0.5% in the year 2009.

Becker, L., 2015 evaluated the effectiveness of public innovation support on firms' labour productivity, turnover and on employment by cross-section analysis based on the Eurostat's CIS harmonized data 2008 for 15 EU countries, using the set of 29.451 firms (unbalanced panel). She found positive impact of public innovation support on labour productivity, and a negative one for employment and turnover. Private R&D investment on the contrary increases firms' competitiveness measured by the same innovation indicators.

Karhunene, H., and Huovari, J. 2015, analyzing a sample of Finish SMEs in the period 2000-2012 found no significant positive effect on labour productivity over the five-year period after a subsidy was granted, but found positive employment effect.

Czarnitzki, D, and Lopes-Bento, C., 2013, present microeconomic evidence of grants for R&D on employment obtained from different sources in Germany. They conclude that policies are not subject to full crowding out and that treatment effects are stable over time. Receiving subsidies from different government-sponsored commercial R&D programmes does not have a substitution effect.

In summary, a direct government support as reported in the surveyed studies on macroeconomic outcomes can have a positive impact. The effects on output additionality differ across different types of measures of innovation: productivity, employment, and firm performance (profit, sales or turnover) and the support more likely increases employment than productivity. However, due to the rather limited empirical evidence, it is difficult to come up with unambiguous conclusions.

1.3 Empirical findings on behavioural additionality

This section presents the evidence of the potential effects of public R&D subsidies on the composition of R&D expenditure, especially on the decision to improve firms' innovation processes. As stated by Afcha, C. S., and Lopez, G. L., 2014, the leading hypothesis argues that public subsidies affect the composition, explicitly favouring the combination of internal and external R&D expenditure. In this way public subsidies influence the innovative performance of the company. Behavioural additionality complements the more traditional evaluation of the impact of public support to firms' innovation, i.e. input and output additionality, with information on changes in firm behaviour. In short, behavioural additionality focuses on assessing the influence of public funding on dynamic capabilities for change of firms receiving government support (changes in management, changes in organization, etc. that would better support firms' innovation activities).

The review of behavioural additionality includes a systematic survey of empirical studies in the period from 2003 to 2010 from EU and other OECD countries as well as findings of 6 individual articles published in recent years. The summary of findings is presented in Table 5 below. For more detailed information see Table A.3 in the Appendix.

Table 5: Summary of empirical evidence on behavioural additionality

Study	Complementarity/ Positive effect	Substitutability/ Negative effect	Mixed results	Insignificant/ No effect	Total	Publication period
Cunningham, P. et al., 2012	7				7	2003-2010
Individual studies	5	1			6	2009-2016
Total	12	1			13	

Cunningham, P., 2013 reviewed 7 articles on behavioural additionality; all of them report a positive impact.

All of the recent studies reviewed, except one, also report a positive impact of government funding on firms' decisions regarding the allocation of R&D expenditure into innovative activities, except one.

Positive impact was found also by Afcha, C. S., 2011 based on the study of the impact of regional and national public funding schemes during 1998-2005 on Spanish manufacturing firms. Both were effective in stimulating firms for R&D cooperation with universities and technology centres. Afcha, C. S., and Lopez, G. L., 2014 t based their empirical results on the surveys on business strategies in Spain, 1991-2008. They confirm a positive impact of public funding on internal R&D expenditure, in particular the encouragement of companies to combine their expertise internally with sources of information produced by third parties through external R&D expenditure. Wanzenboeck I. et al., 2013 examined on the sample of Austrian firms in 2006 how the impact of R&D funding schemes led to the realisation of behaviour additionality. They found a significant impact which is especially pronounced in the case of technologically specialized firms. Clarysse, B., et al., 2009 when examining the impact of R&D grants of the IWT in Flanders during 2001 and 2004 found that congenital and inter-organizational learning increases behaviour additionality but it decreases with the number of subsidized projects that are undertaken by the company. Radas, S. et al., 2015 found that subsidies and tax incentives to some degree have strengthened the R&D orientation of SMEs towards innovation and output.

The negative impact of public funding for R&D was found by Yu, F. et al., 2016, for the renewable energy sector in China. Government subsidies had a significant crowding-out effect on firm's R&D investment behaviour.

The measures of behavioural additionality are quite heterogeneous. They include dimensions such as project additionality (project launch), acceleration additionality (accelerated schedule), network additionality (more collaboration), challenge additionality (more challenging research) and management additionality (improved management) [9] dimensions which are difficult to quantify.

In summary, due to rather scarce empirical evidence and estimation problems how to define as well as quantify behavioural outcomes it is difficult to reach a decisive conclusion of the effect of government direct support on behavioural additionality. Quite often the measures that are used to evaluate output additionality on a firm level are used also to evaluate behavioural additionality. Therefore, the distinction between the output and behavioural additionality is quite blurred.

1.4 Empirical findings on welfare

The evidence on the effect of government direct support for private firms' R&D investment is very scarce. Therefore, the findings of only 3 articles are presented in this section. See Table A.4 in the Appendix.

Clausen, T. H., 2007 examined the impact of Community Innovation Survey, CIS3 and of the R&D survey conducted in Norway in 2002 and found empirical support for the theoretical argument that subsidies stimulate the best private R&D expenditure where the gap between the social and the private rate of return to R&D is high. Takalo, T. et al., 2013 based on Finish project level data estimated the social rate of return on targeted subsidies of 30 to 50%. They found smaller spillover effects of subsidies compared to their effects on firm profits. Gómez M.S., and Sequeira, T., 2014, based on an endogenous growth model, calibrated to the US economy, found that subsidies to research are the most welfare-

[9] More on the classification of behavioural additionality see OECD 2006 study.

increasing among the budget-neutral policies. They conclude that the optimal structure of subsidies entails substantial increase of subsidy to R&D, maintaining a zero subsidy to production, and reducing the subsidy to education. A detailed sensitivity analysis shows the robustness of these results.

The evidence on the effect of government direct support for R&D on welfare is very scarce. The available evidence suggests a positive effect of subsidies on social rate of return and that subsidies to research are the most welfare-increasing policies. The scarcity of this evidence prevents us to come up with a more generalized conclusion regarding the effect of direct government support for R&D on welfare.

2 An overview of empirical evidence on the impact and effectiveness of government indirect support for R&D and innovation

This chapter presents the evidence of econometric work evaluating the effectiveness and the impact of tax incentives for R&D. Fiscal incentives, particularly tax credit, increasingly feature as an alternative policy measure for stimulating private firms to increase their R&D investment and are used as a complementary measure to direct support (subsidies, grants, loans) to stimulate firms' R&D investment and innovation activities. Tax incentives are often seen as a better instrument compared to subsidies, loans and grants since tax credits are typically directed to all firms. Tax credit is not altering the firm's choice of R&D projects and the support is not affected by the selection bias often linked to the R&D projects funded by public agency. Tax incentives are assumed to be more effective since they are based on firms' decisions, while grants and subsidies highly depend on the information available to the policy makers that manage the R&D programs and on the strategic priorities set by them. In addition firms might lobby successfully for subsidies that are in their interest, possibly diverting subsidies in ways not conductive to innovation.

The use of tax credits has significantly increased after 2000. Today tax incentives present the major source of allocation of public funds to SMEs in OECD countries (Cunningham, P., et al., 2013, OECD, 2014). [10] Currently, 25 Member States in the EU are using R&D tax incentives in an effort to boost firms' R&D investment, increase productivity and economic growth (EC DGRI, 2017). [11] It is estimated that for every euro invested in business R&D in the EU an average R&D tax subsidy of Member States is 12 cents (European Commission, 2016 in the European Commission DGRI, 2017, p. 4). In the EU countries the most common tax incentives are based on corporate income taxes. In recent years there is a shift from volume-based tax schemes (tax applies to total R&D expenditure) to incremental tax schemes (tax applies to an addition of firm's R&D funding with respect to a base level).

What follows is the presentation of empirical evidence of published and unpublished studies of the effect of tax incentives on input additionality, i.e. crowding in and crowding out effect of tax incentives on private firms financing of R&D activities, on output additionality, i.e. to what extent innovation outputs would not have been achieved without support, and on behavioural additionality, i.e., to what extent tax

[10] Over the period 2001 to 2011, R&D tax incentives were expended in a 19 out of 27 OECD countries. R&D tax incentive schemes are widely adopted in: US and Japan, Canada, Norway and EU MS of which only Germany and Estonia and Finland do not have a tax policy aimed directly at stimulating business R&D.

[11] Tax incentives for R&D are also used by other advanced and emerging economies such as Brazil, China, India and South Africa. (EC DGRI, 2017).

incentives affect firms behaviour and strategy with respect to firms' investment in R&D. The review also includes very few studies that looked at welfare effects of the tax incentives.

2.1 Empirical findings on input additionality

The evidence on tax incentives on input additionality mostly comes from the following source: CPB Netherlands Bureau for Economic Policy Analysis, 2014, "A study on R&D Tax Incentives. Final report". TAXUD/2013/DE/315.

The review includes also the evidence reported by authors not cited in this publication.

Empirical assessment of the impact of R&D tax incentives is most commonly quantified by using two approaches: 1) by estimating the elasticity of R&D expenditure with respect to the user cost of capital[12], regressing R&D expenditure directly on a variable that accounts for the presence or strength of the R&D tax credit (the estimated coefficient usually can be directly interpreted as the input additionality of the R&D tax incentive), and 2) measuring the input additionality directly using the treatment evaluation method (by estimating treatment effects by explicitly comparing the R&D expenditure of a 'treatment' group with that of a 'control' group) and/or estimating BFTB or "incrementality ratio"[13]

The user cost of capital is defined as the 'actual cost' of R&D faced by firms, where the R&D tax incentive is one of the determinants, next to the wage rate of researchers and the price of equipment (Hall, B. and Van Reenen, J., 2000). The coefficient is the elasticity of R&D expenditure with respect to the user cost of capital. Tax incentive is effective if the sing of elasticity coefficient is negative. BFTB or 'tax sensitivity' ratio' is a measure obtained by dividing the amount of R&D generated by the R&D tax incentives with the net tax revenue loss - tax expenditure (Mohnen, P., and Lokshin, B., 2009, p. 5). Input additionality indicates whether the firm spends more on R&D compared to what it saves on taxes on R&D, while BFTB measures input additionality as the firm's R&D expenditure that can be attributed to the policy intervention relative to the size of the tax incentives. Input additionality is 1 if the firm spends every euro it saves on taxes on R&D (Mohnen, P., and Lokshin, B., 2009).

Table B.1a in the Appendix presents the estimates of the response in a firm's R&D expenditure to tax incentives measured by the elasticity of R&D expenditure with respect to the user cost of R&D capital. Table B.1b in the Appendix presents the summary of studies estimating treatment effects of R&D tax incentives[14], or by using control group approach (estimating treatment effects).

The estimated elasticities of R&D expenditure with respect to the user cost of R&D capital suggest a positive impact of R&D tax incentive on firms R&D expenditure. The short-run elasticities range from -0.03 to -4.4 and the long-run ones between -0.12 and -2.60, indicating an increase in the level of R&D expenditure of firms due to tax incentives. The discrepancies between the estimated short-run and long-

[12] The advantage of this method is that it captures marginal cost of the investment taking into account tax rules, interest rates, depreciation rates and other type of subsidies and that response to policy changes corresponds to the elasticity of the investment demand to the marginal cost of capital. This method compared to others is better grounded in economic theory (Caiumi, A., 2011, p. 14).

[13] Also known as »cost effectiveness ratio«, or «incrementality ratio« introduced by Parsons, M. and Phillips, N. , 2007.

[14] Methodologically price R&D elasticity in some studies not included in Table B.1a are derived by estimating R&D demand equations either using a dummy variable for the tax credit or a proxy for tax credit.

run elasticities, the latter being larger, can be attributed to the adjustment costs firms may face if an increase in R&D investment leads to an inelastic supply of either capital or skilled labour or both in the short run.

Relatively large variations in the user cost of R&D capital elasticities in Table B.1a in the Appendix, either in the short-run or in the long-run can be explained by the differences in the method of evaluation used by various authors. The largest user cost elasticities are reported by studies using generalized method of movements while studies using fixed effect estimator report the smallest elasticities. Variations are also attributed to different periods covered in the estimation analysis by different authors (before and after the introduction of tax incentives), the sub-population of firms covered by the study, the design of the R&D tax incentives schemes (tax credits vs. allowances or depreciation for example, volume based or incremental tax schemes), the rates may vary according to the size of the firm or its amount of R&D. The effect of incremental schemes compared to volume based schemes on the magnitude of input additionality, Lester, J. and Warda, J., 2014 show that the cost-effectiveness of incremental schemes is similar to volume-based schemes. These results are contrary to the OECD conclusion that volume based schemes have an additionality of below one, while incremental based schemes above one (CPB, 2014).

While findings in Table B.1a in the Appendix indicate quite strong positive effects of tax incentives on input additionality, the reliability of results may be questionable. The difficulties of this evaluation approach (Mohnen, P., and Lokshin, B., 2009; European Commission, 2014) is the endogeneity of the tax credit. Namely, causality runs both ways. The size of the tax credit is dependent on the amount of R&D performed. This problem is not solved even if using a dummy variable indicating that tax credit was claimed, since some firms decide not to apply at all for R&D tax credit. This endogeneity problem leads to potential underestimation of the effectiveness of tax incentives. Uncertainty of results may also be affected when researchers did not control selection bias in their evaluation techniques. As reported in the study published by CPB, 2014 p. 29, the two studies that adopted econometric techniques to avoid these problems are Lokshin, B., and Mohnen, P., 2012 and Mulkay, B., and Mairesse, J., 2013, yielding robust results with small standard error. A more recent OECD study by Westmore, B., 2013, reports negative elasticity to be around unity: 6% increase in the generosity of R&D tax incentives is estimated to increase the level of R&D by about 6 % in the long run.

To summarize, reviewed estimated elasticities vary depending on the data, estimation method and model specification. The size of the effect of the negative elasticity (elasticity of R&D expenditure with respect to the user cost of capital) in the long run is found broadly to be below unity.

Other authors not included in Table B.1a in the Appendix supplement these results as summarized in Table 6 below.

Table 6: Summary of findings of authors not included in Table B.1a

Study	**Country**	**User-cost of R&D capital elasticity/R&D elasticity**
Belitz, H.,2016	9 OECD countries	Lower than unity
Castellacci, F., and Lie, C. M., 2015	Meta- regression	-0.23
McKenzie, K.I., and Sershun, N., 2010	9 OECD countries	SR: 0.15 to 0.22 LR: 0.46 to 077
Thomson, R., 2010	Australia	Not an important determinant of firms' R&D investment decisions
Parson, M., and Phillips, N., 2007	US, Canada and other OECD countries	-1.0912 set to the median value
Hall, P.A., 1993	USA	1.0 to 1.5
Hines, J.K., 1993	USA	1.2 to 1.6

Meta-regression analysis of the 34 articles, 16 of them estimating additionality ratio and 18 user-cost elasticity dated between 1993 and 2012 by Castellacci, F., and Lie, C. M., 2015 found the corrected elasticity of the user costs of R&D capital of -0.23. Negative long run elasticity around unity -1.0912 was found by Parson, M., and Phillips, N., 2007 who collected estimates from a broad range of studies undertaken between 1990-2006 in the US, Canada and other OECD countries. Elasticity around unity was found by Hall, P.F., 1993, Hines, J.R. Jr., 1993 for USA manufacturing publicly listed enterprises only, 1.0 to 1.5 and 1.2 to 1.6 respectively, while lower than unity was found by Belitz, H., 2016. McKenzie, K.I., and Sershun, N., 2010 report a short run R&D elasticity between 0.15 and 0.22 and between 0.46 to 0.77 in the long run, using dynamic panel models for manufacturing firms of 9 OECD countries. Returns on R&D are positive irrespective whether R&D is financed by public or private fund. Thomson, R., 2010, examined if tax policy was influencing Australian firms to increase investment in R&D. Based on empirical testing considering an unbalanced panel of financial data of approximately 500 large Australian firms between 1990 and 2005, he could not find the evidence that the user cost of R&D was an important determinant of firm R&D investment decisions.

Table B.1b in the Appendix gives an overview of the results on input additionality of studies estimating treatment effect of R&D tax incentives directly. Estimates are based on a variety of methods, ranging from explicitly comparing the R&D expenditure of a 'treated' group with those of the 'control' (matching) group, then finding differences in the level of R&D between the firms affected by tax incentive and a group of very similar firms but unaffected by the policy (difference-in-difference estimator), to evaluating 'tax sensitivity ratio' (BFTB). Due to this variety of methods, direct comparison of presented treatment effect is difficult. Therefore, the comparison of results will be limited only to the studies estimating input additionality as the firm's R&D expenditure that can be attributed to the policy intervention relative to the size of the tax incentives - "tax sensitivity ratio' (BFTB). The tax sensitivity ratio (BFTF) is found to be between 0.15 and 3.5.

Other authors not included in Table B.1b in the Appendix supplement these results as summarized in Table 7 below.

Table 7: Summary of findings of authors not included in Table B.1b in the Appendix

Study	Country	Additionality/coefficient
Castellacci, F., and Lie, M. C., 2015	Meta-regression	0.03; sectors matter
Kohler, C., et al., 2012	Survey of econometric work	3.0 to 0.3
Yang, C.H., et al., 2012	Taiwan	53.80 % higher R&D expenditure
Cappelen, A., et al., 2010	Norway	1.3

Castellacci, F., and Lie, M. C., 2015 who performed meta-regression analysis of the 34 articles, 16 of them estimating additionality ratio and 18 user-cost elasticity dated between 1993 and 2012 found additionality ratio of 0.03. They also found that studies which focused on sub-sample of high tech industries have on average obtained a smaller estimated additionality effect of tax credit, and that R&D tax credits were on average stronger for SMEs, firms in the service sectors, and firms in low-tech sectors within the countries with incremental scheme. Kohler, C., et al., 2012, based on an overview of econometric work on input additionality of R&D tax incentive found input additionality ranging from 3.0 to 0.3. Cappelen, A., et al., 2010, when evaluating the Norwegian R&D Tax Credit Scheme introduced in 2002 found that scheme is cost-effective and was used by a large number of firms. It increases firms' investment into R&D, estimated additionality was 1.3 in the period 2002 - 2005, and in particular the effect is positive for small firms with little R&D experience. Yang, C.H., et al., 2012, examined the effect of tax incentives on R&D activities in Taiwanese manufacturing firms. Propensity score matching (PSM) estimates showed that recipients of R&D tax credits appeared on average to have 53.80% higher R&D expenditures than that they do without receiving tax credits, while there is no significantly higher growth rate of R&D expenditure.

To summarize, there is rather large evidence about the size of the effect of elasticity of R&D expenditure with respect to the user cost of capital. It is around or below unity, indicating that a loss in tax revenue of one euro results in growth of firm's R&D expenditure of less than one euro. With respect to treatment effect of R&D tax incentive the evidence of these effects is diverse, with input additionality ranging from 3 to 0.3. In spite of these variations, most studies do show a positive effect: an increase in firms' R&D expenditures due to R&D tax incentives. The effect of tax incentives seems to depend on cross-industry differences i.e., on sector specific conditions that affect firms' innovation activities and their dynamics in different industries.

2.2 Empirical findings on output additionality

The evidence on output additionality is presented on two levels: empirical findings of R&D tax incentives on innovation at the firm level and separately on macroeconomic outcomes.

Table B.2 in the Appendix presents the findings on output additionality of 18 published articles and studies, one presenting critical review of methodologically sound policy evaluations. The period of publication is between 1993 and 2017. Compared to input additionality fewer studies looked at economic effects of R&D support beyond immediate impact on the R&D expenditures. Output additionality at the firm level is most commonly estimated by evaluating the impact of R&D tax incentive on patents, product and processes, and at the macroeconomic level by productivity. The total number of results is greater than the total number of studies.

The impact of tax incentives is difficult to measure. Appelt, S., et al, 2016 give the following reasons for this. First, available measures of innovation output are highly imperfect, innovations can result with a lag following the implementation of the policy instrument, the benefits of the measure may spillover to other firms that have not received support, which complicates the matching methodology and the impact may differ between the firms if some firms were simultaneously receiving additional support e.g., grants or subsidies.

2.2.1 Impact on innovation at the firm level

In Table 8 we present the summary of findings in this section.

Table 8 Summary of output additionality on a firm level

Study	Complementarity/ Positive effect	Substitutability/ Negative effect	Mixed results	Insignificant/ No effect	Total	Publication period
What* Works Centre for Local Economic Growth, 2015	1				1	2013
Individual studies	7		2		9	2007-2017
Total	8		2		10	

*Includes only a study which is not listed under the individual studies presented.

Positive impact of R&D tax incentives on firms' sales is found in the following studies. Cappelen, A., et al., 2012, found that R&D tax-incentives introduced in Norway in 2002 resulted in the development of new production processes and to some degree the development of new products for the firm but did notfind that the scheme would result in innovations in the form of new-to-the- market products or patenting. Falk, R., 2007, on a sample of 1.200 Austrian firms found that fiscal R&D incentives increased the probability of firms to introduce new-to-the market products, but no effect was found for probability to introduce new-to-the firm products. Similar result was found by Czarnitzki, D., et al., 2011. R&D tax incentives increased the sales of new products, increased probability to introduce a new-to-the market and new-to-the world product and the share of sales with new products. However, they found no effect on macroeconomic outcomes such as firm profitability, national and international market share and on competition. Berube, C., and Mohnen, P., 2009 studied the impact of tax incentives and grants offered at the same time on a sample of Canadian firms compared to the impact when firms were receiving only tax incentives. They found that firms receiving tax credits and grants are more innovative in respect of number of innovations, world-first innovations, and commercialization than those receiving only tax credit.

De Jong, J.P.J., Verhoeven, W.H.J., 2007, Ernst, C., Spengel, C., 2011, Westmore, B., 2013, and Aralica, Z., and Botric, V., 2013, they all found positive impact on patenting. What Works Centre for Local Economic Growth, 2015 found a positive impact of R&D tax incentives on firms' selfreported effect on innovative activity in the period 2002-2004 in GB. Ernst, C., and Spengel, C., 2011 in addition found a negative impact of statutory corporate income tax on patenting. What Works Centre for Local Economic Growth, 2015 found that impacts of R&D tax incentives on innovation outcome may depend on firm size, with small firms slightly more likely to experience positive benefits. Dechezleprêtre, A., et al., 2016 found statistically in economically significant impact of tax change on both R&D expenditure (price elasticities of about 2.6 higher than the values typical in recent literature of between 1 and 2) and patenting: R&D approximately doubled in the treated firms and patenting rose about 60%.

Freitas, I.B., et al., 2015 studied who benefits most from the R&D tax incentives using the panel data from the three waves of Innovation Surveys for Norway, Italy and France. Findings indicated that these are the firms in industries with high R&D orientation.

2.2.2 Impact on macroeconomic outcomes

In Table 9 we present a summary of findings in this section.

Table 9: Summary of output additionality on macroeconomic level

Study	Complementarity/ Positive effect	Substitutability/ Negative effect	Mixed results	Insignificant/ No effect	Total	Publication period
*What Works Centre for Local Economic Growth, 2015,	1				1	1993
Individual studies	4	1	1	1	7	2011-2017
Total	5	1	1	1	8	

*Includes only a study which is not listed under the individual studies presented.

Colombo et al., 2011 who estimated the effect of R&D tax incentive on productivity of new tech based firms from manufacturing and service sectors found insignificant effect on total factor productivity of recipient firms. Bravo-Biosca, A., et al., 2013, on the basis of cross-country analysis of OECD countries found that more generous R&D fiscal support is correlated with lower productivity and on aggregate level with lover employment growth. In case of high-growth firms, more generous R&D tax incentives were even strongly negatively corelated with employment, while positive effect on employment growth was found only in the case of incumbent firms. A statistically significant positive impact of tax credit on Taiwanese firms' productivity during 2001-2008 period was found by Huang, C-H, 2015, and Caiumi, A., 2011 showed that tax incentive programme leads to overall increase of the productivity of firms, the impact being stronger for firms with lower productivity. Hallepee, S., and Garcia, A.H., 2012 found 8.4% increase in employment for treated firms, and increase of survival rate of firms, and higher wages using French data. What Works Centre for Local Economic Growth, 2015, in one study that examined the effect of tax credit introduced in 1982 in US, using a panel of firms between 1975-1989, found that firms benefited from tax credit; the market value of equity rose by 1.99% between 1982 and 1989.

Minniti, A. and Venturini, F., 2017 assessed the long-run growth effects of public policies to business R&D using data for US manufacturing industries and taking Schumpeterian growth theory as guideline. Their analysis indicates that R&D policy in the form of R&D tax credits fosters the rate of productivity growth over the long-term horizon. This effect is quantitatively important: increasing R&D tax credits by 10% raises the growth rate of labour productivity by 0.4% per year. Their findings are robust due to controlling for several policy instruments, growth determinants and econometric issues. Moreover, the overall evidence is consistent with the predictions of second-generation fully-endogenous growth models.

Moretti, E. and Wilson, D.J., 2013, looked at the impact of R&D tax incentive on firms' innovation from sectoral dimension. They found that the effect on productivity of R&D tax incentives depends on a particular industry considered. They found mixed results for the impact of R&D tax credits on employment in US biotech related sectors.

To summarize, studies reporting the effect of R&D tax incentive on output additionality tend to find a positive impact on innovation outcomes at the firm level, specifically on patenting, an outcome that seems to be relatively robust due to similar results found in spite of various method and data sources used. The impact of R&D tax incentives on macroeconomic outcomes such as productivity, employment and firms' competitiveness is mixed. Some studies found on average positive effect on productivity, but the impact is stronger for firms with the lower productivity. Some other studies found negative impact: support is correlated with lower productivity and on aggregate level with lower employment growth. Reviewed studies also suggest that the magnitude of the impact of R&D tax incentives on firm innovation and macroeconomic outputs may depend on firm size, and tends to be stronger for SMEs and depends on industry concerned. Positive impact on firm-level (notably patenting) is more frequently found than for macroeconomic outcomes such as productivity or employment.

2.3 Empirical findings on behavioural additionality

There are even fewer studies estimating the impact of R&D fiscal incentive on behaviour additionality than in the case of output additionality and input additionality. The reason probably is that studies evaluating the impact on behaviour additionality are of more recent stream of research on the topic and because of the measurement problems already discussed in the previous section on government direct support for R&D.

Corchuelo, B., and Martines-Ros, E., 2010, have analysed the effectiveness of R&D fiscal incentives on firm innovation behaviour, using a panel sample of 2,000 Spanish manufacturing firms in the period 1990-1998 and found positive effects especially in SMEs and for financially constrained firms. Similar results were obtained by Caiumi, A., 2011. Based on the study of Italian firms she also found that this relationship holds most likely for SMEs and credit-constraint firms. Haegeland, T., and Moen, J., 2007 evaluating the impact of Norwegian SkatteFUNN found the strongest impact on behaviour for the firms without or with limited previous R&D activities. Positive impact on the changes in firms' behaviour with respect to innovation was found also by Ernst, C. and Sepengel, C., 2011, and Teirlinck, P., et. al., 2012. The former found that tax incentives induce changes in European firms behaviour, while Teirlick, P., et al., 2012, when analysing representative sample of young innovative companies (YICs) in Belgium, found the evidence that government support in terms of taxation-related financial slack influences the firm's internal management capabilities that empower resource-constrained YICs to strengthen creative innovation behaviour in terms of risk and acceleration of R&D projects during economic turbulence. See Table B.3 in the Appendix.

Due to the scarcity of empirical evidence and estimation problems (in most cases the same indicators are used as in the evaluation of output additionality on a firm level or such that are difficult to quantify), it is difficult to reach a decisive conclusion on the nature of the impact of government indirect support on the behaviour of the firms receiving government support.

2.4 Empirical findings on welfare

Few studies have tried to estimate private and social rates of return to R&D induced by tax incentives and also performed social cost-benefit analysis. However, the effectiveness of tax incentives from the policy perspective cannot be measured by input additionality or even by output additionality alone but rather by the degree this type of intervention is successful from the macroeconomic aspect. For this reason the evaluation of its welfare effect is important, either in terms of social return to R&D or its net welfare effect (social cost and benefit analysis). This is even more important as empirical studies reveal, that overall welfare effect may be positive even if there is a certain effect of crowding-out so that firms spent less money on R&D compared to the magnitude of government tax expenditure for the R&D (Mohnen, P., and Lokshin, B., 2009). However, estimating social return to R&D and the effects of government support for business R&D is not an easy task (Klette T.J., et al., 2000) due to problems associated with how to measure the effects without government support, due to pre-selection biases for the supported firms, biased answers in interviews, small sample sizes in case studies and so forth. The impact on welfare is thus affected by the choice of variable as a proxy for measuring welfare. Findings are presented in Table B.4 in the Appendix.

The review of the rather scarce literature by Hall, B.H. et al., 2009, finds that variables used to estimate social rate of return to R&D are imprecisely measured in many cases and that social rate of return tends to exceed estimates of the private rate of return. Parson, M. and Phillips, N., 2007 report significant spillover[15] rate to Canadian R&D of 56% calculated from the surveyed Canadian studies covering different periods in-between 1964 to 1997. More recently, Bloom, N. et al., 2013 confirms that the social rate of return exceeds the private rate as being at least twice as high as private returns, based on the study of firms in the US between 1981 and 2001. Their estimates show that private returns aggregated across all firms are between 22% and 39%, while social returns vary between 55% and 59% where both returns are defined as the return to a marginal US dollar spent on R&D. Their analysis whether these returns differ

[15] The sum of the 'private rate of return' to the innovating firm and the 'external rate of return' (spillover rate) benefiting other firms yields the 'social rate of return' to research.

between firms of different size found that size does matter: they found social returns higher for largest firms compared to smallest firms while private returns did not differ much (21:61 % for large and 21:27% for small firms.

The ultimate goal for policy decision whether to continue with tax incentives as innovation policy tool is to find out what is the overall net effect of this instrument, i.e. whether the net effect, after accounting for costs and benefits, is positive. This shows the overall welfare effect of tax incentives for R&D. Several empirical attempts were made to estimate this effect. Diao, X. et al., 1999 estimated welfare effect of almost 0.36 on a tax credit in Japan. Mohnen, P. and Lokshin, B., 2009 performing cost-benefit analysis for the Dutch programme estimate a welfare gain of 16%. Russo, B., 2004 and Ghosh, R., 2007 based on computable general equilibrium model (CGE) found welfare gain of 0.176 and 0.086%, while Parson, M. and Phillips, N., 2007, found a net gain of 0.11 in Canada, using macroeconomic model. In summary, based on reviewed empirical studies it seems that social rates of return (broadly above 50%) as well as net welfare gains of tax incentives for R&D (cost effectiveness ratio above unity) are positive. These findings are in line with prevailing positive effects of R&D tax incentives on input and output additionality.

Conclusion

This study is the review of empirical evidence on the impact and effectiveness of government support for R&D and innovation. We reviewed 98 articles and studies evaluating effectiveness and impact of government support for R&D on firms' R&D expenditure, innovation output, firms' behavioural changes and general welfare. In each of the levels of review also studies based on meta-regression analysis and studies providing systematic review of empirical evaluations on the topic concerned are included, so that the total number of estimates greatly exceeds the total number of individual articles and studies reviewed. The review covers findings for EU and OECD countries and a few for China and Taiwan. The period covered is 1960 till 2017; the literature published between 2003 and 2017 is reviewed directly, while the empirical evidence prior to this period mostly relies on the findings published in survey studies.

The review is structured to cover both government direct and indirect support for R&D and innovation. Direct support focus mostly on subsidizing specific projects with especially high social returns and indirect intend to increase the overall spending for private R&D. Chapter 1 covers the direct measures: grants, subsidies and in few cases also loans, however, subsidies are the most often used variable in the reviewed articles and studies. Chapter 2 covers the indirect measures: fiscal incentives, where tax credit is the most often used variable in the reviewed articles and studies. Each of these two types of government measures – direct and indirect - was further subdivided into the impact on input additionality, i.e. firms' R&D expenditure, innovation additionality, i.e. innovation activities, behavioural additionality, i.e. changes in firms' behaviour and on welfare. Output additionality was further subdivided on the impact at the firm level and on macroeconomic outcomes.

The review reveals great heterogeneity of empirical studies with respect to the periods analysed as well as the level of aggregation and data used – firm level, plant level or aggregate data on the level of industry or countries using time series, cross-section or panel data. Further, studies differ according to geographical scope, the measurement and definition of variables such as R&D expenditure and the use of different government support measures (use of grants, subsidies or loans or tax incentives measured by tax-credit based either on incremental or volume tax system and so forth). There is a relative abundance of studies evaluating the effect of government support on R&D expenditure compared to the number of studies evaluating output additionality or impact on welfare and those evaluating the impact on macroeconomic outcomes such as productivity, employment and growth. Most evaluations were performed for manufacturing and very rarely also for service or any other sector.

Methodologies used in the surveyed research include a wide range of empirical approaches. Linear regression models without techniques to control for endogeneity, selection bias and unobservable heterogeneity were used mostly in the studies prior 2000. Over time researchers started to use complex empirical analyses and statistical techniques to control for endogeneity, selection bias and unobserved heterogeneity and also started to use more comprehensive data (panel data, industry level data) on micro level to control for the effects of cross-section and temporal variations in technological opportunities. New econometric approaches were introduced such as difference-in-difference estimators, sample selection models, instrumental variables, and non-parametric matching methods, propensity score matching, to address endogeneity problem and potential bias associated with the "selections on un-observables". The choice of evaluation methodology has a significant impact on the empirical results obtained: the more sophisticated econometric techniques are used, the more prevailing becomes a positive impact of public support for R&D and innovation and results are more reliable. The overview of evaluations accumulated from 1960-2017 shows that a substantial part of the differences in obtained results between studies can be explained by study characteristics such as econometric method used, specification of the estimated equations, the output variable used as a dependent variable, and the definition of the R&D input variable, output variable, firm behaviour and welfare.

All of the above make direct comparison difficult. For this reason it is difficult to arrive at any firm conclusion regarding the sign and the magnitude of the relationship between public and private R&D expenditure and on the impact and effectiveness of government support for R&D and innovation. Some evidence, nevertheless, can be extracted from the overview of the present state of empirical knowledge in this field of research.

The results on government direct support, covered in Chapter 1, are as follows.

The surveyed econometric evidence on input additionality, i.e. whether the government support in the form of grants, subsidies and loans crowds out private investment is inconclusive, when taking into account the reviewed results over the period from mid-1960 till 2005. The impact seems to be stronger for SMEs than for large firms, stronger during the recent financial crisis disregarding the size of firms and that effect of government support decreases at a higher level of subsidies. The more recent empirical work, especially post 2005, very seldom reports crowding-out effect between public subsidies and private R&D expenditure. Therefore, the overall summary of studies on input additionality indicates a slightly dominant positive impact of public support to firms' R&D expenditure. However, the evidence whether public support crowds out private investment is still inconclusive. Mixed findings, positive and negative effects indicate that support may have a positive impact on firm's R&D expenditure but the effects are not always positive. Mixed results generally mean that impact varies with the firm size. For example, it is positive for SMEs but negative or insignificant for large firms, or a positive impact of subsidies is found up to a certain level, while negative one is found for more generous levels of subsidies, or when a firm receives subsidies continuously.

In summary, the evidence presented on output additionality at the firm level, accumulated over the period 2003-2017, suggests that direct government support such as grants, subsidies and loans may positively impact innovation outcomes: increased number of patents, sales of new product and introduction of new processes, but not always. The greater impact on firm innovation output is generally found for SMEs. The effect of public R&D targeted to a particular sector appears to be slightly worse in terms of increasing innovation compared to those that are sector neutral. This indicates the existence of a modest positive impact of direct government support for R&D on firm output additionality. It should be noted, that these results are even more imprecise compared to input additionality due to problems associated with the definition of innovation output. For example, are patents which are the most common definition of innovation output, an adequate measure of innovation output? Further, the impact of government support might take longer to materialize and therefore it is not captured by econometric evaluation. Finally, how to take into account that R&D investment is usually associated with high uncertainty. Due to several methodological issues related to definition of innovation output the results are even more imprecise than the results evaluating the effect on firm's R&D expenditures.

The reviewed empirical findings over the period 2000-2015 of the impact of government direct support on macroeconomic outcomes (employment, firm performance, productivity and growth) tend to show positive impact; the impact differs across different types of measures of innovation: productivity, employment, and firm performance (profit, sales or turnover). The positive impact is more likely on employment than on productivity or growth. However, it is difficult to come up with unambiguous conclusion due to the rather limited empirical evidence.

The reviewed empirical findings on whether government direct support influences the behaviour of firms suggest a consistently positive impact on firms' behaviour, meaning that government funding led to positive changes in management and organization structure in order to better support firms innovation activities and their reorientation of expenditure into more innovative investment. The measurement of behavioural additionality has two main problems. First, the measures are quite heterogeneous and are difficult to quantify. Second, in most cases indicators measuring the changes in the firm behaviour used are the same as in the evaluation of output additionality on a firm level. Therefore, the distinction between the output and behavioural additionality is quite blurred.

The evidence on the effect of government direct support for R&D on welfare is very scarce and heterogeneous. The available evidence suggests a positive effect of subsidies on social rate of return and that subsidies to research are the most welfare-increasing policies. The scarcity of this evidence prevents us to come up with a more generalized conclusion regarding the effect of direct government support for R&D on welfare.

The results on government indirect support, Chapter 2, are as follows.

There is rather large econometric evidence on input additionality of fiscal incentives on private R&D expenditure of firms receiving tax incentives. Evaluation of input additionality is most commonly quantified by estimating the elasticity of R&D expenditure with respect to the user cost of capital or by measuring the input additionality directly using the treatment evaluation method. The reviewed econometric evidence on tax incentives accumulated over the period from early 1990s till 2017 vary depending on the data, estimation method and model specification. Nevertheless, most of the surveyed studies show a positive response of firms to tax incentives – increases in R&D expenditure. However, the effect of negative elasticity in the long run is found to be moderate, broadly below unity, indicating that a loss in tax revenue of one euro results in growth of firm R&D expenditure of less than one euro. Also, additionality ratio indicates positive effect, ranging from 3 to 0.3 due to differences in the countries and the sub-populations of firms covered by studies, the design of R&D tax incentives schemes and the evaluation methodologies employed. In spite of these variations, most studies do show a positive effect: an increase of firms' R&D expenditure due to R&D tax incentives. Evidence also suggests that the additionality effect is the highest for SMEs, young firms and firms with high R&D orientation. The estimated effect of tax incentives seems to depend on cross-industry differences i.e., on sector specific conditions that affect firms' innovation activities and their dynamics in different industries.

The reviewed empirical studies of the impact of R&D tax incentives, accumulated over the period 1993-2017 tend to find a positive impact on innovation outcomes at the firm level, specifically on patenting, an outcome that seems to be relatively robust due to similar results obtained even when various methods and data sources are used. However, compared to input additionality, fewer studies looked at economic effects of R&D support through tax incentives beyond immediate impact on the R&D expenditure. Reasons may be found in highly imperfect measures of innovation output, the difficulty to capture the spillover benefits to other firms that have not received support and difficulty to isolate the effect of taxes if firms simultaneously receive additional support e.g. grants or subsidies.

Most of the studies evaluating the impact of R&D tax incentives on macroeconomic outcomes found mixed impact. The reviewed studies also indicate that the impact on productivity depends on the industry concerned, that the impact is stronger for firms with lower productivity, and that more generous R&D fiscal support is correlated with lower productivity and on the aggregate level with lower employment growth.

The reviewed econometric evidence of the impact of R&D tax incentives on behavioural additionality over the period 2007-2012 comes from only 5 studies that all show positive effect, especially in SMEs and financially constrained firms as well as in young innovative firms. Due to the scarcity of empirical evidence and estimation problems (in most cases the same indicators are used as in the evaluation of output additionality on a firm level), it is difficult to reach a decisive conclusion on the nature of the impact of government indirect support on the behaviour of the firms receiving government support.

The available econometric evidence, accumulated over the period from 1999 to 2013 on the effects of tax-incentives for R&D on welfare leads to the conclusion that both social rate of return, broadly above 50%, and net welfare gain, cost effectiveness ratio above unity, are positive. Although these findings are in line with prevailing positive effects of R&D tax incentives on input and output additionality it should be underlined that the variables used to estimate social rate of return to R&D are imprecisely measured and therefore the results obtained may not be fully reliable.

What can be said as an overall conclusion about the impact and effectiveness of government support for R&D? With some degree of simplification due to the problems related to the heterogeneity of studies and diversity of empirical models, the overall conclusion leans towards complementarily of private and public R&D expenditure, a positive but modest impact on innovation at the firm level and a positive impact on welfare. However, the degree and magnitude of the effect vary with firm size and nature of firms, generosity of support, size of the project supported, industry studied, the tax system etc. The effectiveness of government support is greater when targeted to R&D expenditure and it diminishes with respect to its impact on firm innovation activities and macroeconomic outcomes that are the end goal of policy intervention. Thus the impact on firm R&D expenditure is greater compared to the impact on firm innovation activities, macroeconomic outcomes and firm behaviour. This is due to the definition of concepts since R&D expenditure is the most clearly defined concept, as many countries follow the Frascati definition of R&D. This also explains the relative abundance of literature evaluating input additionality of government support compared to the rest of the impact studied. The empirical evidence on which kind of government support, i.e., direct or indirect, is more effective in increasing social welfare, is uncertain. Direct grants and subsidies seem to leverage more R&D than indirect tax incentives, but the former generate lower spillovers.

To come to a better understanding of the impact of government support for R&D and innovation to firms and thus to a more conclusive view of the nature and the magnitude of its impact and effectiveness, more studies evaluating the impact of government direct and indirect support on innovation output at the firm and macroeconomic levels as well as on welfare are needed. In addition, due to a host of methodological issues, the pure econometric estimations of the impact and effectiveness of government support needs to be complemented by long-term ex-post evaluation studies and qualitative in-depth case studies.

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Appendix A

Overview of empirical evidence on the impact and effectiveness of government direct support for R&D and innovation

Table A.1 Effects of government direct support on input additionality

Reference	Country	Period	Method	Data	Results
David, P. , et al., 2000		Econometric evidence accumulated over the past 35 years back from 2000	Meta-evaluation of 33 econometric studies that use micro, mezzo and macro data, most studies till 1990s refer to USA, also UK and Canada	Included: Pre cross-section studies on the micro level; panel data studies at the micro level within a given industry; aggregate or macroeconomic studies; and studies that attempt to control for the simultaneity between private and public R&D spending using instrumental variables	11 studies out of 33 reported substitution effect, which tend to be more present in studies that are on firm or line of business aggregation, US based studies tend to find more net substitution effect that non US-based studies. Sixteen report complementarity, three insignificant and 3 mixed results
Garcia-Quevedo, J., 2004	13 countries	Heterogeneous	Meta-regression of 74 studies	Industry, firm level, cross section; time series and panel data; 22 based on US data and 16 on others countries	38 indicated complementarity, 17 sustainability and results of 19 studies were insignificant. Crowding-out is more common in firm level studies compared to industry and country level studies
Correa, P. et al., 2013	US and other OECD countries	2004-2011	Meta-analysis a sample of 37 studies published during 2004-2011 assessing the impact of direct subsidies on business research and development.	A cross-section dataset, pooled data and/or longitudinal datasets	The effect of public investment on research and development is predominantly positive and significant. Public funds do not crowd out but incentivize firms to revert funds into research and development. The coefficient of additionality impacts on research and development ranges from 0.166 to 0.252, with reasonable confidence intervals at the 95 percent level
Cunningham, P., et al., 2013	EU and other OECD countries	Heterogeneous	Systematic review of empirical studies on input additionality. Statistical techniques used: matching, controlling the interindustry differences in technological opportunities, first difference GMM specification, DID estimator, parametric and semiparametric two-step selection model, Heckman selection model, Control-function regression, propensity score matching, treatment effect analysis, the pooled ordinary least squares model, the fixed effect model, the random model, combining DID with propensity score and matching methods	Cross section, time series and panel data, SMEs level, firm-level, industry level, country- level data, various EU CIS data, OECD database	Review of 24 studies estimating input additionality of public support to private firms' R&D expenditure. Out of 24 studies, 12 report complementarity effect of public support to firm R&D expenditure, 2 substitution effect, 3 insignificant results and 7 mixed results. There are a number of studies that calculated the project additionality around 70%, while there are counter examples, smaller firms, firms in relatively low technology sectors and firms from less advanced regions tend to exhibit more input additionality. The analysis of the literature shows that the results are usually exceedingly sensitive to methodology applied

Zuniga-Vicente, J. A., at al., 2014		**Heterogeneous**	**Critical review of 77 empirical studies; nearly half of studies performed during 2000s; the problem of endogeneity was treated with difference-in-difference estimations, sample selection models, instrumental variables, and non-parametric matching methods**	**US, EU data on firm or lower level, most studies used cross section data and less longitudinal data ; most focus on manufacturing industries**	**60 % of studies report crowding-in effect, 20% crowding-out, 20% obtained insignificant results**
Becker, B., 2015		**Econometric evidence accumulated before and after 2000**	**Systematic review of empirical studies; pree-2000 studies' results were affected by sample selection bias, post-2000 studies use more sophisticated empirical tools (matching, treatment effect analysis, conditional difference-in-differences estimator, parametric and semi-parametric two step selection models)**		**Empirical results before 2000 are inconclusive with respect to crowding-out and crowding-in hypothesis; More recent research more unanimously rejects substitution effect and tends to find additionality effect.**
What Works Centre for Local Economic Growth, 2015	**GB, other OECD**	**Heterogeneous**	**Critical review of 18 empirical studies**		**8 studies found positive effect on R&D spending while for the remaining 8 the evidence is mixed. 1 study reports substitutability and 1 insignificant result. The results obtained weakly support crowding-in hypothesis.**
Guellec, D., and van Pottelsberghe de la Potterie, B., 2003	**17 OECD countries**	**1983-1996**	**Econometric analysis of aggregate data from OECD MSTI and ANEBERD**		**Direct government funding of R&D performed by firms has a positive effect on business financed R&D; the stimulating effect of government funding varies with respect to its generosity: it increases up to certain threshold (about 10% of business R&D) and then increases beyond**
Kaiser, U., 2004	**Denmark**	**1999 and 2002**		**Firm-level, exporting and service firms**	**No crowding out effect between public subsidies and private R&D spending.**
Clausen, T.H., 2007	**Norway**	**1999-2002**		**Community Innovation Survey (CIS3) and R&D Survey conducted in Norway in 2002**	**Highly significant and positive input additionality of subsidies for research on firm R&D investment budget, but substitution effect was found in the case of subsidies for development (activities close to the market). Also found empirical support for the theoretical argument that subsidies stimulate the best private R&D expenditure where the gap between the social and the private rate of return to R&D is high**
Hewitt-Dundas, N., and Roper, S. J., 2009	**Ireland**	**1991-2011**			**Weak input additionality**

Carboni, O.A., 2011	**Italy**		**Non-parametric matching technic**	**Firm-level, manufacturing sector**	**Rejects crowding-out hypothesis; public subsidies on average increase private R&D. Grants encourage the use of internal sources to finance R&D**
Bloch, C., and Graversen, E.K, 2012	**Denmark**		**Dynamic panel data regression analysis**		**Obtained additionality effects of public funding**
Jaklic, A., et al., 2013	**Slovenia**		**Propensity score matching methodology; DID approach**		**Confirm complementary effect of subsidies on private R&D spending**
Czarnitzki, D. and Lopes-Bento, C., 2013	**Flanders**		**Microeconomic evidence on public R&D grants on R&D investment and employment, review of the effects of a specific government-sponsored commercial R&D programme from various angels**		**Results indicate that the treatments effects are stable over time, that different policies are not subject to full crowding out, receiving subsidies from other sources in addition to the program under evaluation, does not decrease the estimated treatment effect, and receiving grants repeatedly does not decrease the magnitude of the treatment effects either**
Arque-Castells, P., 2013	**Spain**	**1998-2009**		**Panel-level data, manufacturing firms**	**Subsidies generate permanent inducement effect for 9% of firms**
Czarnitzki, D. and Lopes-Bento, C., 2014	**Germany**		**Non-parametric matching estimator**		**Results suggest the co-existence of national and European policies on innovation input. They found that one policy does not crow out the effect of the other**
Aristei, D., et al., 2015	**France, Germany, Italy, Spain and UK**	**2007 - 2009**	**Propensity Score Matching (PSM) to address the problem of "selection on observables", the parametric regression analysis to address potential bias of selection on un-observables; the impact of R&D subsidies was evaluated by means of OLS in the absence of endogeneity**	**Firm-level data, European Firms in the Global Economy- EFIGE Survey**	**Results strongly reject the full crowding-out hypothesis of additionality. Firms did not cut investment plans in spite of the crises period of 2008 due to public support. In this sense public support was effective**
Czarnitzki, D. and Delanote, J., 2015	**Valuation of the current focus of EU policy on independent young SMEs in high Tech sectors**		**Treatment effect analysis**	**Firm-level, young SMEs (low-tech and high tech)**	**Full crowding out effect for all firm type is rejected. The treatment effect is the highest for high-tech firms**
Hud, M., and Hussinger, K., 2015	**Germany**	**2006-2010**	**Econometric analysis**	**Firm-level data, Mannheim Innovation Panel, SMEs**	**Crowding-out effect for the crisis year 2009 and positive effect for the whole period. The substitution effect was caused by reluctant innovation investment of subsidies**

Dai, X., and Liwei, C., 2015	**China**		**Application of the generalized propensity score, estimate of dose-response function**	**Manufacturing firms**	**Found E-shaped relationship and inverted-U correlation with the firm's total R&D and private investment with different levels of public subsidies, what indicates the existence of optimal interval of subsidy beyond which a further increase in public subsidies would partially or completely crowd out firm's private R&D investment**
Radicic, D., et al., 2016	**7 European regions**		**Evaluating output additionality of national and European Union (EU) R&D programmes both separately and in combination**	**SMEs**	**For innovation inputs, they found positive treatment effects from national and EU programmes separately as well as complementary effects for firms supported from both sources relative to firms supported only by national programmes**
Yu, F., et al, 2016	**China**		**Classical panel data model including the pooled ordinary least squares model, the fixed effect model and the random effect model**		**Government grants have a significant crowding-out effect on firms' R&D investment**
Carnitzki, D., and Delanote, J., 2016	**Belgium**		**Crépon-Duguet-Mairesse (CDM) model**		**Results largely confirm insights of the input additionality literature, i.e. public subsidies complement private R&D investment**
Marino, M., et. al., 2016	**France**	**1993-2009**	**Combining DID with propensity score and matching methods**	**Firm-level data**	**No evidence of additionality or substitution effect between public and private R&D expenditure. Crowding out effect appears to be more pronounced for medium high levels of public subsidies and generally under the R&D tax credit regime**

Table A.2: Effects of government direct support on output additionality - firm and macroeconomic level

Reference	Country	Period	Method	Data	Results
Cunningham, P. et al., 2013	EU and other OECD countries	Heterogeneous	Systematic survey of empirical studies (published articles) on output additionality	Econometric analysis of various CIS and various EU countries, econometric analysis of survey of innovation from different countries, government supported innovation programme, analysis of business strategy survey, econometric analysis of young high-tech firms. Mostly focused on manufacturing few on services	24 articles and studies reviewed examining output additionality of public support on firm level or macroeconomic level. Firm level: out of 17 studies 7 report complementarity, 2 insignificant results, 4 substitutability, and 4 mixed results. Macroeconomics level: out of 7 studies 6 report complementarity and 1 mixed effect.
What Works Centre for Local Economic Growth. 2015	GB, other OECD	Heterogeneous	Critical review of 36 empirical studies for output additionality	Firm level: 16 evaluations of patents or self-reported product or process innovation, and the remaining 3 the effect on quality of academic publications, on the innovation process, and on collaboration. Macroeconomic level: 17 evaluations on productivity, employment or firm performance and 2 on exports	The results indicate mixed findings - positive and negative effect of grants, loans, subsidies may positively impact innovation and productivity but not always. The effects differ across types of innovation and are weaker for patents than for self-reported measures of process or product innovation.
Donselaar, P., and Koopmans, P., 2016		Heterogeneous	Meta-analysis of the effect of R&D on productivity at the micro, meso and macro level of 38 studies	1214 output elasticities of R&D from 38 studies; R&D capital is the accumulated R&D expenditure, adjusted for depreciation due to obsolescence of knowledge	Two results: 1) a substantial part of the differences in results between studies can be explained by study characteristics such as econometric method used the specification of the estimated equations, the output variable used as dependent variable, the definition of the R&D input variable etc. 2) Assuming "optimal" study characteristics, the meta regressions are used to compute "best guess" estimates of the output elasticities of business R&D capital and public R&D capital in non-G7 countries. For domestic business R&D capital the best guess output elasticity is 0.06, for domestic public R&D capital 0.03 was derived but is subject to much uncertainty because of diverging results in a small number of studies For non-G7 countries the output elasticity of foreign private R&D capital is estimated to be substantially higher than the elasticity of domestic private R&D capital.

Almus, M., and Czarnitzki, D., 2003	**East Germany**		**Empirical analysis of average causal effects of all public R&D schemes in Eastern Germany using a nonparametric matching approach.**	**Firm level**	**Compared to the case in which no public financial means are provided, the results show that firms increase their innovation activities by about 4 percentage points**
Zemplinerova, E., and Hromadkova, A., 2012	**Czech Republic**	**2004-2007**	**Innovative activities of firms are modelled as a four stage model (CDM) which allows studying several interrelated questions while controlling for simultaneity and for causality problem**	**Large firm dataset**	**Analysis proved that innovation input significantly increases innovation output, with increasing firm´s size, however, ceteris paribus, the innovation output is decreasing. This means that bigger firms are less efficient in transforming the innovation input into output. More importantly, our analysis shows that access to subsidies has significant, yet negative influence on innovation output. This result may throw a shadow on the efficiency of supported firms and have some implications for competition policy**
Herrera, L. and Sanchez-Gonzalez, G., 2013	**Spain**		**Estimated the additionality effects of R&D subsidies on innovation activity: allocation of in-house R&D expenditures and economic returns as a function of a firm size.**		**Regardless of the size of the firm public funding stimulates firm's investment into applied research and technological development but not also into basic research. In small firms they increased the expansion of the sale of products new to the firm, in large subsidized firms they improved the sales of products new to the market.**
Czarnitzki, D. and Lopes-Bento, C., 2013	**Flanders**		**Microeconomic evidence of grants for R&D on employment, review of the effects of a specific government-sponsored commercial R&D programme from various angels**		**The policies are not subject to full crowding out; the treatment effects on employment are stable over time; receiving other subsidies than from programme does not have a substitution effect**
Czarnitzki, D., and Lopes-Bento, C., 2014	**Germany, analysis of the effect of EU and national funding on firm's innovation**				**Results suggest the co-existence of national and European policies on innovation input. In terms of output, results suggest that subsidy recipients are more active with respect to patenting. A citation analysis of patents reveals that the subsidy recipients file patents that are more valuable (in terms of forward citations) than those filed in the counterfactual situation of receiving no public support. These results suggest that public funding triggers socially beneficial research projects and that the co-existence of national and European policies does not lead to crowding-out effects when compared to a hypothetical world of a closed economy with no supplemental European policies**

Bronzini, R., and Piselli, P. 2014	**Region of Northern Italy innovation programme**	**early 2000s**	**Regression discontinuity design strategy to compare the number of patent applications, and the probability of submitting one, of subsidized firms with those of unsubsidized firms close to the cut-off**	**Firm-level**	**Programme had a significant impact on the number of patent applications, particularly in the case of smaller firms; it also increased their likelihood of applying for a patent.**
Czarnitzki, D., and Delanote, J., 2015	**Evaluation of the current focus of EU policy on independent young SMEs in high Tech sectors**		**The indirect effect of subsidies on output is evaluated with a patent production framework**	**Firm-level, young SMEs, high tech sectors (low-high tech and high-tech.)**	**Independent young high-tech firms have no lower output as other firms; this suggests that current policy focus is not ineffective.**
Radicic, D., and Pugh, G., 2015	**European SMEs**		**Analysis of treatment effects on a wide range of innovation outputs.**	**Firm-level, SMEs**	**The estimated effects of innovation support programmes are positive, typically increasing the probability of innovation and of its commercial success by around 15%**
Becker, L., 2015	**15 EU member states**	**2008**	**Cross-section analysis, propensity score matching, structural probit estimation , OLS regression estimating the effect on turnover, employment and labour productivity**	**CIS 2008, a sample of 29,451 firms**	**Found positive influence of public innovation support on labour productivity although insignificant, a negative for employment and turnover. Private R&D investment on the contrary increases firms' competitiveness measured by the same innovation indicators**
Brautzsch, H.U., et al, 2015	**Germany**	**2008-2009**	**Standard input-output model to study the macroeconomic effects of R&D subsidies on employment and production in the business cycle**	**The German Central Innovation Programme for SMEs**	**R&D subsidies have stimulated a substantial leverage effect on employment, value added and production in the business cycle that amounts to a least twice the initial financing and counteracted the decline of GDP by 0.5% in the year 2009**
Karhunen, H., and Huovari, J., 2015	**Finland**	**2000-2012**	**Combining matching and DID method to control for selection bias**	**SMEs**	**No significant positive effect on labour productivity over the five-year period after a subsidy is granted but positive employment effect**
Hong, J., et al. , 2015	**China**	**2001-2011**	**Stochastic frontier model and a unique panel data set of 17 high tech industries**	**High tech industries**	**Government funds exert a negative influence on innovation efficiency of high tech industries. On the contrary the effect of private R&D funding is significant and positive. Grouping of industries showed different effects on the innovation in each high-tech sub-group**
Montmartin, B. and Herrera, M., 2015	**25 OECD countries**	**1990-2009**	**Special dynamic panel models**	**High tech industries**	**A substitution effect between the R&D subsidies and fiscal incentives implemented within a country. Positive spatial spillovers among private R&D investments**

Radicic, D., et al., 2016	**7 European regions**		**Several matching estimators**	**SMEs, firm-level**	**Positive treatment effects are found for the propensity for patent application but not on innovative sales.**
Carnitzki, D., and Delanote, J., 2016	**Belgium**		**Crépon-Duguet-Mairesse (CDM) model**		**Results point to positive output effects of both purely privately funded and subsidy-induced R&D**
Guo et. al, 2016	**China**	**1988-2007**	**Examining the effect of government R&D programme Innovation Fund for SMEs**	**Panel dataset of Chinese manufacturing firms**	**Results indicated that Innofund-backed firms generate significantly higher technological and commercialized innovation outputs measured by (patents, sales from new products, and exports) compared with their non-Innofund-backed counterparts and the same firms before winning the grant. The effect intensified after 2005 when centralized governance was replaced by decentralized**
Szczygielski, K., et al., 2017	**Poland and Turkey**	**2010**	**Assessing the efficiency of innovation policies by looking at data from 2010 Innovation surveys**	**Firm-level**	**Government aid for R&D activities contributed to better innovation performance by firms in both countries. However, EU-funded grants for physical and human capital upgrading in Poland were inefficient in fostering innovation but have actually impeded it**
Huergo, E., and Moreno, L., 2017	**Spain**	**2002-2005**	**A multivariate probit to analyze the determinants of firms' participation in public R&D programmes and then the impact of this participation on firms' R&D activities**	**4407 firms**	**Results suggest: 1) direct aid clearly increases the probability of conducting R&D activities, 2) the greatest effect corresponds to EU grants, here the impact is more than 3 times larger than the one of loans.3) the full crowding out of private R&D is rejected for all types of support - low interest loans and national and EU subsidies, 4) impacts of subsidies and loans reinforce each other when jointly awarded to SMEs, but in case of large firms, the existence of crowding-out effect between subsidies and loans cannot be ruled out**
Radicic,D., and Pugh, G., 2016	**28 EU countries**		**Evaluating output additionality of national and European Union (EU) R&D programmes both separately and in combination.**	**SMEs**	**No evidence of innovation output additionality from national programmes and crowding out from EU programmes cannot be rejected. However, crowding out from EU support is eliminated by combination with national support. These findings have policy implications for the governance of R&D policy and suggest that the European paradox—success in promoting R&D inputs but not commercialization—is not yet mitigated**

Table A.3: Effects of government direct support on behavioural additionality

Reference	Country	Period	Method	Data	Results
Cunningham, P., et al., 2013	EU and other OECD countries	Heterogeneous	Systematic survey of empirical studies and articles)on output additionality		Effect is inconclusive due to imprecise definition of behavioral additionality -they focus too much on the questions of how much and by whom and fail to explain the dynamics of these effects.
Clarysse, B. et al., 2009	Flanders	2001-2004	Survey of 192 recipients of R&D grants provided by the IWT in Flanders matched to a 84 firms that never had a grant bid accepted		The results confirm congenital learning and interorganizational learning leading to increased behavioural additionality, but decreases with the number of subsidized project that are undertaken by the company
Afcha, C.S., 2011	Spain	1998-2005	Matching estimators to address endogeneity problems	Firm-level, manufacturing	Regional subsidies are especially effective in fostering cooperation with universities and technology centers in those firms not currently engaged in R&D cooperation. On the other hand subsidies on the national level have a higher impact by stimulating cooperation with universities and technology centers of those firms already engaged in R&D cooperation
Wanzenboeck, I. et. al, 2013	Austria	2006	Analysis of survey data of 155 Austrian firms to study how distinct firm characteristics influence the realization of behavioural additionality	Firm-level; R&D funding scheme in the field of intelligent transport systems in 2006	R&D related firm characteristics significantly affect the realization of behavioural additionality. Small, young and technologically specialized firms are more likely to realize behavioural additionality
Afcha, C.S., and Lopez, G.I., 2014	Spain	1991-2008	Survey on Business Strategies (ESEE) of Spain to assess whether R&D subsidies influences the composition of R&D expenditure		Results confirm a positive impact on internal R&D and especially in the decision to conduct R&D internally and externally simultaneously
Radas, S., et al., 2015				SMEs	Subsidies and tax incentives strengthen the R&D orientation of SMEs, to some degree on innovation and output. Compared to tax incentives subsidies are more effective
Yu, F., et al., 2016	China		Panel data analysis including the pooled ordinary least squares model, the fixed effect model and the random effect model	Renewable energy	Government subsidies have a significant crowding out effect on firms' R&D investment behaviour

Table A.4: Effects of government direct support on welfare

Reference	Country	Period	Method	Data	Results
Clausen, T.H., 2007	Norway	1999-2002		Community Innovation Survey (CIS3) and R&D Survey conducted in Norway in 2002	Found empirical support for the theoretical argument that subsidies stimulate the best private R&D expenditure where the gap between the social and the private rate of return to R&D is high
Takalo, T., et. al. 2013	Finland		Model	Project level data	The social rate of return on targeted subsidies is 30% to 50% , but the spillover effects of subsidies are smaller than effects on firm profits
Gómez, M.S., and Sequeira, T., 2014	US		Endogenous growth model with R&D, physical capital, and human capital with several externalities to evaluate the effect on growth and welfare of implementing different budget-neutral policies		Subsidies to research are the most welfare-increasing amongst the budget-neutral policies. A detailed sensitivity analysis showed the robustness of these results.

Appendix B

Overview of empirical evidence on the impact and effectiveness of government indirect support for R&D and innovation

Table B.1a: Estimates of the user cost of R&D capital elasticity (negative estimate implies positive effect)

Study	Published	Country	Period	Scheme	Obs. level	Method	Dependent variable	short-run	Mean result long-run
Baghana and Mohnen (2009)	yes	Quebec	1997-2003	incremental, volume	firm	OLS	log R&D level	-0.08	-0.12
Bloom et al. (2002)	yes	OECD	1979-1999	incremental, volume	industry	IV	log R&D level	-0.25	-0.97
Caiumi (2011)	no	Italy	1998-2005	Volume	firm	matching; GMM	log R&D level	-0.30	-0.60
Corchuelo, Martinez-Ros (2009)	no	Spain	1990-1998	incremental, volume	firm	selection model; IV	log R&D level	-1.09a	
Corchuelo, Martinez-Ros (2009)	no	Spain	2002	incremental, volume	firm	selection model; IV	log R&D level	-0.47a	
Dagenais et al. (1997)	no	Canada	1975-1992	Volume	firm	IV	log R&D level	-0.07a	
Harris et al. (2009)	yes	North. Ireland	1998-2003	Volume	firm	GMM	log R&D level	-0.53	-1.37
HMRC (2010)	no	United Kingdom	2003-2007	enhanced allowance,	firm	GMM	log R&D level	Total:	Total:
				volume				-0.91b	-2.60b
								SME scheme:	SME scheme:
								-2.32	-2.16
								Large:	Large:
								-2.41	-3.65
Koga (2003)	yes	Japan	1989-1999	incremental	firm	IV	log R&D level	-0.61a	
Lokshin and Mohnen (2012)	yes	Netherlands	1996-2004	volume	firm	IV	log R&D level	-0.38	-0.63
Mulkay and Mairesse (2003)	no	France	1982-1996	incremental	firm	fixed effects	log R&D level	-0.14	-0.05
Mulkay and Mairesse (2008)	no	France	1983-2002	incremental	firm	fixed effects	R&D intensity	-0.14	-0.28
Mulkay and Mairesse (2013)	yes	France	2000-2007	incremental, volume	firm	fixed effects; GMM	log R&D level		-0.16
Parisi and Sembenelli (2001)	no	Italy	1992-1997	volume	firm	Tobit, rand. eff.	log R&D level	-4.36a	
Poot et al. (2003)	no	Netherlands	1997-1998	volume	firm	OLS	log R&D level	-0.11	-1.12
Rao (2013)	no	United States	1981-1991	incremental	firm	IV	R&D intensity	-1.64	
Westmore (2013)	no	OECD	1983-2008	incremental, volume	country	OLS	log R&D level	-0.03	-0.88
Wilson (2009)	yes	United States	1981-2004	incremental	firm	OLS	log R&D level	-1.21	-2.18

a Short-run or long-run not specified; b Estimates that assumed endogenous user-cost elasticity; c Study has been published in peer-reviewed journal

Source: CPB, 2014, "A Study on R&D Tax Incentive". Final Report. TAXUD/2013/DE/315, p.30.

Table B.1b: Direct estimates of treatment effects of R&D tax incentives

Study	Published[b]	Country	Period	Scheme	Obs. level	Method	Dep. variable	Measure	Mean result
Aralica et al. (2013)	Yes	Croatia	2007-2009	volume	firm	matching		Treatment effect	0.14
Aralica et al. (2011)	No	Croatia	2007-2009	volume	firm	survey/tax record analysis	R&D level	BFTB	1.19
Corchuelo and Martinez-Ros (2009)	No	Spain	2002	mixed	firm	matching	log R&D level	Treatment effect	0.66
Cornet and Vroomen (2005)	No	Netherlands	1994-2004	volume	firm	diff-in-diff, first diff.	log R&D wages	BFTB	0.15 startups: 0.65
De Jong et al. (2007)	No	Netherlands	2001-2005	volume	firm	fixed effects	log R&D wages	BFTB	1.72
Duguet (2012)	Yes	France	1993-2003	incremental	firm	binary; matching	R&D growth	BFTB	1
Dumont (2013)	Yes	Belgium	2001-2009	volume	firm	panel, selection model	log R&D level	BFTB	research coop.: 2.22
									young innov.: 0.79
									PhD: 3.50
									master: 0.82
Hægeland and Moen (2007a)	No	Norway	1993-2005	volume	firm	diff-in-diff	log R&D level	Treatment effect	1.34
Hallépée and Garcia (2012)[a]	No	France	2002-2005	volume	firm	matching	employment	Treatment effect	>1
Ho (2006)	No	United States	1963-1999	incremental	firm	matching; diff-in-diff	log R&D level	Treatment effect	0.07
Kasahara et al. (2013)	Yes	Japan	2000-2003	volume	firm	selection model; GMM	log R&D level	Elasticity pooled	1.58
Klassen et al. (2004)	Yes	United States, Canada	1991-1997	incremental, volume	firm	fixed effects	log R&D level	Elasticity pooled	1.81
Lee (2011)	Yes	Japan, Canada, Korea, Taiwan, China, India	1997	incremental, volume	firm	GMM, IV	R&D intensity	Elasticity pooled	0.18
Lhuillery et al. (2013)	No	France	1993-2009	volume	firm	matching	R&D level	Treatment effect	small firms: -1.10 medium firms: -0.71 large firms: 0.50
Verhoeven et al. (2012)	No	Netherlands	2006-2010	volume	firm	GMM	log R&D wages	BFTB	1.77
Yohei (2011)	No	Japan	2006-2009	mixed	firm	matching	R&D intensity	Treatment effect	1.25

[a] standard errors and econometric specifications are not published; [b] Study has been published in peer-reviewed journal

Source: CPB, 2014, "A Study on R&D Tax Incentive". Final Report. TAXUD/2013/DE/315, p. 33.

Table B.2: Effects of fiscal incentives on output additionality - firm and macroeconomic levels

Reference	Country	Period	Industry	Method	Data	Result
What Works Centre for Local Economic Growth, 2015	GB-at the firm level US-at the macroeconomic level	2002-2004 1975-1989		Critical review of a methodologically sound study		1 study reports a positive effect on firms' self reported innovative activity between 2002-2004. Tax credit appears to be particularly effective for SME. On macroeconomic level, 1 study examined the effect of tax credit introduced in 1982 in US, using a panel of firms between 1975-1989 and found that firms benefited from tax credit - the market value of equity rose by 1.99% between 1982 and 1989.
De Jong, J.P.J., and Verhoeven, W.H.J., 2007	The Netherlands	2001-2005				Found a positive effect on patenting
Falk, R., 2007	Austria	2005-2007	Manufacturing and services	Probit	1.200 firms	Fiscal R&D incentive increases probability to introduce new-to-the-market products. No effect on probability to introduce new-to -the -firm products.
Berube, C., and Mohnen, P., 2009	Canada	2005		Econometric analysis	Survey of Innovation from Statistics Canada	Firms receiving tax credits and grants are more innovative (number of innovations, world-first innovations, and commercialization) from those receiving only tax credit
Czarnitzki, D., et al., 2011	Canada	1999	Manufacturing and services	Non-parametric matching technique		Use of fiscal R&D incentives increases the number of newly introduced products, the probability to introduce a new -to-the world and a new-to the market product and share of sales with new products. No effect on increased frim profitability, national and international market share and increased competitiveness.
Colombo, M.G., et al., 2011	Italy	1994-2003	New tech based firms from manufacturing and services	Estimation o+F13f the total factor productivity (Generalised Method of Movements)		No significant effects for variable indicating the use of fiscal R&D incentives on total factor productivity of recipient firms. On the contrary selective R&D subsidies lead to a positive impact.
Caiumi, A. 2011	Italy				Firm-level	Tax incentive program did overall raise the productivity of firms. The impact was stronger for firms with lower productivity, more likely to stimulate R&D behaviour.
Ernst, C., and Spengel, C., 2011	European - corporations	Between 1998 and 2007			Firm-level patent data combined with financial data	found positive effect of R&D tax credit and negative impact of statutory corporate income tax on patenting.
Cappelen, A. et al., 2012	Norway		Manufacturing and services	Logistic regressions (regular and conditional upon innovation success in previous period)	Reach database for Norwegian firms	Tax-based incentives resulted in the development of new production processes and to some extent the development of new products to the firm. However the scheme did not result in innovations in the form of new-to-the-market products or patenting.

Hallepee, S., and Garcia, A.H., 2012	**France**			**Matching**		**8.4% point increase in employment for treated firms, an increase of survival rate of firms, higher wages,**
Westmore, B., 2013	**19 OECD countries**				**Country level**	**Found a positive effect on patenting**
Aralica, Z., and Botric, V., 2013	**Croatia**					**Found a positive effect on patenting**
Bravo-Biosca, A., et al., 2013	**OECD countries**			**OECD study**		**More generous R&D fiscal support is correlated with lower productivity and on aggregate lower employment growth. More generous R&D tax incentives were strongly negatively related with high-growth firms. Employment growth is positively correlated with more generous R&D tax incentives only in case of incumbent firms.**
Moretti, E., and Wilson, D. J., 2013	**US**					**They found mixed results for the impact of R&D tax credits on employment in US biotech related sectors and that the effect on productivity of R&D tax incentives depends on a particular industry considered.**
Huang, C.H., 2015	**Taiwan**	**2001-2008**	**Manufacturing**	**Panel instrumental variable approaches to control for tax credit endogeneity and firm heterogeneity**	**Firm-level**	**Firms' tax credit produced a positive and statistically significant effect on productivity**
Freitas, I.B., et al., 2015	**Norway, Italy and France**	**2004, 2006 and 2008**		**Micro-econometric analysis**	**Panel data from the three waves of Innovation Surveys**	**Findings indicate that firms in industries with high R&D orientation benefited most from the R&D tax incentives.**
Dechezlepretre, A., et al., 2016	**GB**	**2006-2011**		**A regression discontinuity design**	**Tax data on population of GB SMEs**	**Found statistically and economically significant effects of tax change, on both R&D expenditure and patenting. R&D tax price elasticities are larger at about 2.6, probably because the treated group is from a sub-population of smaller firms and subject to financial constraints. Over the study period aggregate business R&D would be around 10% lower in the absence of the tax relief scheme. Results show also that the R&D generated by tax policy creates spillovers on the innovation of technologically related firms.**
Minniti, A., and Venturini, F. (2017)	**US**		**US manufacturing industries**	**Schumpeterian growth theory as guideline**		**R&D tax credits foster the rate of productivity growth over the long-term horizon. This effect is quantitatively important: increasing R&D tax credits by 10% raises the growth rate of labour productivity by 0.4% per year.**

Table B.3: Effects of fiscal incentives on behavioural additionality

Reference	Country	Period	Industry	Method	Result
Haegeland, T., and Moen, J., 2007	Norway			Evaluation of Norwegian SkatteFUNN	Positive effects, the strongest impact on behaviour was for firms without or with limited previous R&D activity
Corchuelo, B., and Martinez-Ros, E., 2010	Spain	1990-1998	Manufacturing	Panel sample of 2,000 firms	Positive effects, especially in SMEs and for financially constrained firms
Caiumi, A. 2011	Italy				Medium sized firms and start-ups and credit constrained firms were more likely to invest in R&D in the presence of tax credit.
Ernst, C. and Spengel, C., 2011	Europe				Tax-incentives induced changes in European frims behaviour
Teirlinck, P., et. al., 2012	Belgium	2011	Young innovative companies, representative sample	Analysis of the questionnaire sent in 2011 to all R&D active firms - quantitative and qualitative questions	The evidence was found that that government support in terms of taxation-related financial slack influences the firm's internal management capabilities that empower resource-constrained YICs to strengthen creative innovation behaviour in terms of risk and acceleration of R&D projects during economic turbulence

Source: CPB, 2014, "A Study on R&D Tax Incentive". Final Report. TAXUD/2013/DE/315, pp. 35-36.

Table B.4: Effects of fiscal incentives on welfare

Reference	Country	Period	Industry	Method	Result
Diao, X., at al., 1999	Japan			Cost-benefit analysis	Welfare effect of almost 0.35 on a tax credit in Japan
Russo B., 2004				Computable general model- cost benefit analysis	Found increases in research effort and welfare gain of 0.176 %
Ghosh, R., 2007	Canada			Computable general model - cost benefit analysis	Found welfare gain of 0.086 %
Parson, M. and Phillips, N., 2007	Canada			Cost-benefit analysis of Canadian tax credit system -evaluating welfare impact of federal SR&ED Tax incentives	Tax incentives have a positive welfare effect of eleven cents for every dollar speeding in terms of lost tax revenue (net welfare gain per dollar of tax subsidy on the SR&ED is 0.11) Spillover rate to Canadian R&D is set to the median value of 56% calculated from the surveyed Canadian studies covering different periods in-between 1964 to 1997.
Hall, B.H., et al., 2009			Largely apply to manufacturing	Review of the literature, "imprecisely measured in many cases"	Social rate of return to R&D tend to exceed estimates of the private rate of return to R&D
Lokshin, B., and Mohnen, P., 2012	The Netherlands			Cost-benefit analysis of Dutch WBSO programme, macroeconomic model	Even if BFTB falls below 1, the general welfare effect can still be positive due to spillover effects. They estimated that the Dutch WBSO programme resulted in a 16% net welfare gain
Bloom, N., et al., 2013	USA	1981 and 2001			Social rate of return to R&D are at least twice as high as private returns. Private returns aggregated across all firms are between 21% and 39% while social returns vary between 55% and 59%. Both are defined as the return to a marginal US dollar spent on R&D. Private returns of largest firms are around 21% and social around 67 %; for smallest the relationship is: 21%:27%. Reason: large firms are active in technological fields, small concentrate on "niche" markets and generate less knowledge spillovers