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Assessing the Effect of Public Subsidies on Firm R&D Investment: A Survey*

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ABSTRACT

This survey examines the empirical literature on the relationship between public R&D subsidies and private R&D investment over the past five decades. The survey reveals a considerable heterogeneity of empirical results that cannot be explained fully by methodological issues. We aim to provide further explanations of the possible causes of that heterogeneity. In particular, we emphasise a set of issues that, in our view, are critical to understanding the potential effect of public R&D subsidies on private R&D spending. Special attention is paid to the dynamic aspects and composition of firm R&D, the constraints faced by the firm (such as financial constraints), and the amount and source of public subsidies. None of these issues have been investigated in depth. We formulate a set of research assumptions to guide future empirical research in this field.

***Keywords**:* Public subsidies, R&D investment, Innovation.

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INTRODUCTION

The use of public funding to foster private research and development (R&D) activities is a common practice in many countries. According to Eurostat (2009), the public share in R&D activities from the mid-1990s to the mid-2000s was about 35% in the EU27, 30% in the United States, and 18.5% in Japan. Furthermore, a sizeable amount of these public funds is actually used to subsidise R&D activities undertaken by private firms.

The major argument raised by economists to justify the public support of R&D (through public subsidies, among other means) is that market failures would otherwise hamper firms from reaching the socially optimal level of R&D (Arrow, 1962; Stiglitz, 1988). Such market failures have to do with the incomplete appropriability of R&D returns and the problems of information and incomplete markets. The 'public good' characteristics of R&D would prevent firms from completely appropriating the potential benefits from the innovations generated from their R&D activities as other firms would have the opportunity to free ride. Even if innovations could be fully appropriated, the existence of capital market imperfections may also lead private firms to disregard socially valuable R&D projects (Griliches, 1986; Hall, 2002). Due to the risk associated with R&D activities and information asymmetries between borrowers and lenders, the financial opportunities to engage in R&D activities are limited. Policymakers could then contribute to reducing the cost of riskier but socially valuable R&D projects, increasing the firms' expected return to such R&D projects.

Certainly, public policies should be aimed at supporting only those private R&D projects that are socially desirable and would not otherwise be undertaken. Nevertheless, given the aforementioned information problems associated with R&D projects, identifying the target projects to which public effort should be devoted is not a simple task. Typically, public policies to support private R&D have consisted of tax allowances and, above all, public subsidies to partially fund private R&D projects.[1] The conditions for both eligibility and granting decisions are very broad and differ over time and among countries or regions and sectors of activity. To ascertain the effectiveness of public expenditures in this context, a large body of empirical research has assessed the relationship between public R&D subsidies and company-financed R&D. The major research question has been whether public R&D subsidies are either complementary and, thus, 'additional' to company-financed R&D or whether they substitute for and, thus, 'crowd out' private R&D (David *et al.* 2000). After almost five decades of research, the empirical evidence is mixed, and the question is far from having a conclusive answer. The disparity in results can be attributed to differences in the populations under study (time periods, countries of interest, business sectors), the variables used, and the empirical approach (see, among others, Aerts and Schmidt, 2008; Capron and Van Pottelsberghe, 1997; David *et al.*, 2000; García-Quevedo, 2004; González and Pazó, 2008).

The main goals of this survey are to provide a critical and systematic review of the empirical literature on the relation between public R&D subsidies and private R&D investment and to identify issues that may require further exploration.[2] Namely, we are concerned with firm R&D dynamics and composition, firm financial structure, and the history and funding sources of subsidies (i.e., federal/national, regional or local). We seek to connect these issues with situations under which the alternative hypotheses of additionality (i.e., the crowding-in effect) and substitution (i.e., the crowding-out effect) are more likely to occur. This knowledge could help researchers to obtain new insights and, hence, gain a better understanding of the real nature of the link between public R&D subsidies and private R&D spending.

To the best of our knowledge, and as will be observed in the literature review, the evidence about the roles of the aforementioned issues in the impact of public subsidies on company-financed R&D is limited. Despite its importance, research has mostly focused on solving several methodological problems, like the choice of the most valid evaluation method, and on extending previous studies to other contexts (e.g., a different time period, country, or sector of activity).

The study is organised as follows. The second section provides a systematic review of the empirical literature about the link between public R&D subsidies and company-financed R&D. We use this baseline to deepen our examination of each of the critical issues at stake and posit our research assumptions in the next section. The paper ends with our concluding remarks and suggestions for future research.

LITERATURE REVIEW

Blank and Stigler (1957) were among the first researchers to perform an empirical analysis of the relationship between publicly funded and private R&D investment. Their results were mixed, with evidence supporting both additionality and substitution effects. Such findings are highly representative of the evidence reported since then in this field of study. In Table 1 we provide a representative list of the most relevant empirical studies carried out since the middle of the 1960s, which amount to 77 quantitative empirical studies. The table indicates the authorship, the country in which the study was performed, the sample period, the unit of analysis, the definition and measurement of the relevant variables, the empirical approach, and the main findings. We also report for each paper whether the following essential standardised issues were accounted for: a) the sources of public subsidies; b) the composition of firm R&D; c) the firm's past and current subsidies; d) the specific time lag structure, namely short- and/or long-term effects; e) the functional form of the effect (linear or nonlinear); and f) the potential financial constraints. Additionally, in the last column of the table, we report for each study an indicator of its age-weighted citations to provide a measure of its relative impact in the subsequent development of this research topic.

Insert Table 1 about here

We can summarise the results from Table 1 as follows. First, most of the relevant empirical studies listed in Table 1 were performed during the 2000s (43 out of 77). Together with the increasing availability of appropriate datasets, this is a clear sign of the growing concern about the role that public subsidies play in private R&D decisions. Second, examination of the main findings corroborates the existence of a great diversity of results. The results from many studies support the so-called ‘additionality’ or ‘crowding-in’ hypothesis, according to which public R&D subsidies tend to stimulate additional company-financed R&D. Other studies, on the contrary, find evidence for the so-called ‘crowding-out’ hypothesis, according to which public R&D subsidies offset private R&D. Last, some studies find insignificant or mixed effects.

From a theoretical point of view, the net effect of public subsidies on the level of company-financed R&D is ambiguous. There exist counteracting effects, and the net effect depends on different factors. Needless to say, testing the additionality hypothesis is a policy-relevant issue for evaluating the use of public funds to subsidise private R&D activities. The existence of conflicting results among different empirical studies is usually ascribed to methodological differences related to the unit of analysis (country, industry, firm, establishment or plant), the geographical scope, the measurement and definition of the variables or the quantitative methods used. As mentioned earlier, such methodological differences hamper comparisons of results between different empirical studies.

Table 1 shows that about three fourths (56 out of 77) of the reviewed studies were conducted at the microeconomic level, for which the unit of analysis is the firm or even the plant and/or line of business, whereas the remaining studies used aggregate data by industry or by country. In line with Mansfield and Switzer (1984), and others (e.g., Ali-Yrkkö, 2005;

David *et al.*, 2000; Levy and Terleckyj, 1983), we advocate for the obvious advantages of firm-level studies. Studies at a high level of aggregation cannot account for heterogeneities between firms. Precisely, this literature is aimed at evaluating the effect of public subsidies, which are granted at the firm level, so the relevant unit of analysis is the firm itself.

Table 2 summarises, for the whole list of studies, the distribution of the overall findings by a simple vote-counting approach. The sample of studies in Table 1 has been grouped according to the disaggregation level and the geographical scope of the analysis. Approximately 60 percent of the studies find that public subsidies are complementary and thus 'add' to private R&D investment. Nonetheless, it is worth noting that this result is prevalent regardless of the level of aggregation considered.[3]

Insert Table 2 about here

In light of Table 1, the following issues with respect to data structure are worth mentioning. First, studies differ widely in the time period under analysis. Second, studies using cross-sectional data prevail over those using longitudinal data. Third, the dominant geographical scope for testing the effectiveness of R&D subsidies has changed substantially over time. Until the 1990s, most of the empirical studies were performed with US data, and occasionally data from Canada or the UK. Since the 1990s, most studies have used data from the EU and other developed countries (Austria, Belgium, China, Denmark, Finland, France, Germany, Ireland, Israel, Japan, the Netherlands, Norway, Spain and Sweden). However, the conflicting results obtained in different studies are independent of the group of countries considered (see Table 2). Studies of developing countries, in addition to Özçelik and Taymaz (2008) for Turkey, are very scant. Fourth, studies also differ in the industries considered. Most studies are focused on manufacturing industries. However, there are many differences in the degree of innovation across different manufacturing industries. Whereas many studies consider firms belonging to industries with different innovation levels, others are concentrated on firms operating in high-technology industries (Aerts and Thorwarth, 2008; Ali-Yrkkö, 2005; Duguet, 2004; Howe and McFetridge, 1976; Klette and Møen, 1998; Koga, 2005; Leyden and Link, 1991; Leyden *et al.*, 1989; Mansfield and Switzer, 1984; Shrieves, 1978; and Wallsten, 2000).

Other potential sources of ambiguity in the results include the alternative definitions and measures of the main variables of interest. With regard to the dependent variable, private R&D, there are several alternative measures, as shown by Table 1. The most common measure is R&D intensity, i.e., firm R&D expenditure relative to sales. Two alternative measures of R&D expenditure are used: total R&D expenditures and private R&D expenditures (i.e., total R&D expenditures minus the amount of total public R&D subsidies). With regard to the subsidy variable, studies differ in considering public grants, contracts, or total government funding of firm R&D activity. Quite often, measurement and definition differences are due to limitations related to the availability of data. Therefore, researchers should be conscious of this important fact when interpreting their empirical results.

David *et al*. (2000) criticised the econometric methods of nearly all research performed until the end of the 1990s for largely ignoring endogeneity problems.[4] Table 1 shows how the traditional approach relied on least squares (OLS) estimation of linear regression models. However, the potential sources of endogeneity might lead to inconsistent estimates of the causal effect of subsidies on private R&D decisions. To address endogeneity problems in such a way as to obtain appropriate estimates of this causal effect, several approaches have been used, which can be summarised as follows: 1) difference-in-differences estimators; 2) sample selection models; 3) instrumental variables; and 4) non-parametric matching methods.[5] The approaches depend on different sets of assumptions, so they differ in their advantages and disadvantages. This fact has led several researchers (e.g., Aerts and Thowarth, 2008; Görg and Strobl, 2007; Özçelik and Taymaz, 2008) to suggest combining some of them (see Table 1) to improve the accuracy of the evaluation study. Recently, some researchers have taken a step forward by proposing new econometric approaches, such as the conditional difference-in-differences estimator (e.g., Aerts and Schmidt, 2008).[6]

SOME KEY ISSUES IN THE RELATIONSHIP BETWEEN PUBLIC R&D SUBSIDIES AND PRIVATE R&D SPENDING

As discussed earlier, the empirical literature reports mixed results about the causal effect of public subsidies on private R&D investment. To disentangle the reasons behind this conflicting evidence, it is worthwhile to put forward some ways to improve the empirical analysis about this causal relationship that have been scarcely explored until now. Among the most representative issues, we focus on firms' subsidy history, the time lag, the existence of financial constraints, the components of R&D, and the amount and sources of public subsidies of private firms' R&D.

Subsidy History

Among the main contributions that describe the history of subsidies to firms, it is worth mentioning Aschhoff (2009), Duguet (2004), Bloch and Graversen (2008), Hussinger (2008), and González and Pazó (2008). There is pervasive evidence in the existing literature to indicate that the subsidies granted to a firm are relatively persistent over time, so that a firm whose R&D activity was subsidised in the past is more likely to be subsidised again. However, from the theoretical point of view, it is uncertain how a firm's subsidy history affects its level of R&D investment as there can be opposing crowding-in and crowding-out effects. Aschhoff (2009, pp.6-7) describes the existence of several forces at play in this relationship.

Firms that were successful in the past in achieving public subsidies for their R&D projects might benefit from their experience, learning and information advantages in subsequent calls for subsidy applications. Such advantages entail lower application costs and better application opportunities for previously funded firms. Hence, their relative probabilities of applying more often increase. Additionally, their applications are expected to be better tailored to the subsidy criterion, which increases their probabilities of receiving a grant. We would thus expect the projects of previously funded firms to be selected more often, irrespective of the firms' actual need for financial support.

The government's behaviour can also favour projects of firms that apply for subsidies more often for two reasons. On the one hand, governments tend to maximise the success rate of subsidised R&D projects, thus following a picking-the-winners strategy. On the other hand, government might comply with attempts of specific interest groups to prioritise certain firms. In both cases, authorities give preference to the projects of those firms that show strong R&D capabilities in the light of the requirements of the call for applications.[7] However, projects with high expected returns would otherwise be fully financed by the firms or by private external investors.

Thus, firms that are granted public subsidies for their R&D are more likely to benefit from grants that reduce their own risk and cost of financing R&D projects. Consequently, the odds of a crowding-out effect for frequent recipients of R&D subsidies are increased (Aschhoff, 2009; Lööf and Hesmati, 2005; Wallsten, 2000).

All prior supplementary arguments lead us to put forward the following assumption:

Research assumption 1a: *The crowding-out effect of public subsidies on private R&D investment might be stronger in firms that are frequent recipients of public subsidies than in first-time recipients.*

Aschhoff (2009) argues that a firm may become a frequent applicant for public R&D subsidies because of a governmental policy that prioritises riskier but promising projects that firms would not have conducted without public funding. Furthermore, the time schedule of the subsidies can be shorter than the duration of the R&D project, so firms that have already received a subsidy for a particular R&D project might subsequently apply for new subsidies to keep financing the same project.[8] Such a subsidy scheme would be rather stable in terms of recipient firms, and we would not expect a substitution effect. Aschhoff (2009), Duguet (2004), and Hussinger (2008) provide support for these arguments, by which public R&D subsidies might have a stimulating (crowding-in) effect on the R&D investments of these firms. We then state the following assumption:

> **Research assumption 1b:** *The crowding-in effect of public subsidies on private R&D investment might be stronger in firms that are frequent recipients of public subsidies than in first-time recipients.*

Time Lag

Most empirical studies have been concerned mainly with evaluating a contemporaneous or short-term effect of public R&D subsidies on private R&D investment. However, as R&D investment takes time to implement, the full effect of a subsidy may be distributed over a longer period of time. To our knowledge, few empirical studies feature the specific time lag structure of subsidies on private R&D investment. Levy and Terleckyj (1983) find an average three-year lag in the complementary relationship between public R&D subsidies and private R&D.[9] Mansfield and Switzer (1984) and Lichtenberg (1984) also find a complementary relation that takes effect after two years.[10] Klette and Møen (1998) find that temporary R&D subsidies seem to stimulate firms to increase their R&D expenditures after the subsidies have expired —in most cases, during the first two years. Bentzen and Smith (1999) also reveal a positive and significant influence of public R&D on private R&D in the long term. Nevertheless, they do not identify the specific time lag. Guellec and Van Pottelsberghe (2000) find a one- or two-year lag. Callejón and García-Quevedo (2002) and Lach (2002) find that the effect of public subsidies primarily takes place with a time lag of one year and becomes non-significant after the second year.

In line with Levy and Terleckyj (1983, p.554) and other researchers (e.g., Klette and Møen, 1998; Lach, 2002; or Cerulli, 2010), we argue that the effect of subsidies on private R&D activities might last longer than the subsidy itself. Receiving public funding via subsidies in one year can boost additional private R&D activities in subsequent years. David *et al.* (2000, pp.508-509) and others (e.g., Koga, 2005, pp.60-61) suggest that public funding of R&D can have two positive dynamic or 'long-term' effects on private R&D investment. First, firms can benefit from the spillovers of the new science and engineering knowledge resulting from public R&D funding, thus enhancing firms' technological opportunities and, ultimately, innovative ability. Second, the availability of qualified research personnel that firms can hire is increased thanks to public funding of R&D activities.

Another important reason why the effect of subsidies need not be instantaneous and can be distributed over several years is the existence of firm adjustment costs (Lucas, 1967) associated with R&D activities. These activities are complex to implement and involve handling new resources or reallocating existing firm resources, such as qualified personnel, which would otherwise be devoted to production. If the firm optimal level of R&D investment is so high that it requires a substantial reorganisation within the firm, the costs to the firm can be much higher that if the firm distributes the necessary changes over a longer length of time. In addition to technological reasons, adjustment costs can be increased by the existence of market imperfections. The major consequence of adjustment costs is that, in general, it will take several years for the firm to achieve its target R&D investment. In particular, the response of firm R&D investment to public subsidies will not be instantaneous, but rather distributed over several years.

All of these arguments lead us to posit the following assumption:

Research assumption 2: *The effect of public subsidies on private R&D investment might not be instantaneous, but rather distributed over several years.*

Financial Constraints

Financial constraints due to capital market imperfections have been raised as a major reason for government intervention in private R&D investment (Arrow, 1962; Hall, 1992, 2002; Ughetto, 2008; Takalo and Tanayama, 2010). Among the authors who have explored this specific issue empirically, Ali-Yrkkö (2005), Hyytinen and Toivanen (2005), and Czarnitzki *et al.* (2011) are notable.

Many empirical studies show that private R&D projects are mostly financed by internal funds (e.g., Brown *et al.*, 2008; Hall, 1992; Hao and Jaffe, 1993; Himmelberg and Petersen, 1994; Ughetto, 2008). There are several reasons for the relative scarcity of external funding of R&D projects, all of which have to do with the extreme uncertainty about their success and their potential benefits (e.g., Czarnitzki *et al.*, 2011; Carpenter and Petersen, 2002; Ughetto, 2008) and the strategic nature of R&D, which might restrain managers from revealing the features of their R&D projects to prevent their disclosure to competitors (Bhattacharya and Ritter, 1983; Czarnitzki *et al.*, 2011; Scellato, 2007; Ughetto, 2008). Such reasons lead to asymmetry of information problems, like adverse selection and moral hazard (Jensen and Meckling, 1976; Stiglitz and Weiss, 1981), that might discourage external investors, whose assessment of the expected returns is less reliable than the internal assessment (Czarnitzki and Hottenrott, 2010; Czarnitzki *et al.*, 2011; Takalo and Tanayama, 2010; Ughetto, 2008). Moreover, the intangible nature of R&D hinders the use of collateral by innovative firms to secure their borrowing (Berger and Udell, 1990; Bester, 1985; Hubbard, 1998; Močnik, 2001; Ughetto, 2008).

The aforementioned circumstances can lead to a higher cost of external finance due to requirements of a risk premium on external finance, or even to the possibility of finance rationing. Thus, firms will be prompted to put more weight on internal funds to conduct their R&D projects, making their R&D decisions sensitive to their availability of internal liquidity. In this respect, a shortage of internal liquidity might circumscribe firms' ability to conduct R&D projects that would otherwise be undertaken (Czarnitzki *et al.*, 2011, p.528).[11]

The empirical evidence is, in general, consistent with the view that financial constraints may deter successful R&D projects (Czarnitzki *et al.*, 2011) and that public R&D subsidies appear as a public policy instrument aimed at offsetting the negative effect of financial constraints on private R&D activities (Wren, 1994; Blanes and Busom, 2004; Hyytinen and Toivanen, 2005).[12] Ali-Yrkkö (2005) shows that financially constrained companies are more likely to use public subsidies to finance riskier but promising R&D projects that would otherwise be dismissed or postponed. In particular, he finds a positive effect of public funding on R&D of small firms, which are more likely to face financial constraints.[13] Furthermore, we think the role of public subsidies can be especially relevant for small and young firms, for which liquidity constraints can be more severe.[14] All of these arguments lead us to propose the following:

Research assumption 3: *The crowding-in effect of public subsidies on private R&D investment will be stronger in financially constrained firms. In this context, we also expect the crowding-in effect to be stronger in small and young firms.*

Components of R&D

Most empirical studies, as shown by Table 1, have treated private R&D expenditure as a single or homogeneous activity. However, Mansfield (1980) and others (Aerts and Thorwarth, 2008; Clausen, 2007; Diamond, 1999; Link, 1982; Nelson, 1959; Robson, 1993) have highlighted that R&D activity spans a wide range of different complex tasks. At a minimum, the traditional breakdown of R&D expenditure into its two major components, *Research* and *Development*, deserves to be considered.[15]

Several studies have explored the effect of public subsidies and public R&D activities on the two major components of R&D. For instance, the empirical studies by Higgins and Link (1981) and Aerts and Thorwarth (2008) note that public R&D activities tend to reduce the research expenditure by private firms. The latter authors find a positive effect of public R&D subsidies on private expenditures on development. In the same line, Link (1982) finds a positive effect of increased public R&D subsidies on private R&D expenditure, which is mostly aimed at development.[16] On the contrary, Robson (1993) and Diamond (1999) find positive effects of public subsidies on private R&D, which mostly affect (basic) research expenditures. Czarnitzki *et al.* (2011) find that public subsidies have a significant and positive effect on private research expenditures, whereas the effect on private development expenditures is also positive but non-significant. Interestingly, Clausen (2007) distinguishes between public subsidies for research and for development. He finds that whereas subsidies to research have a positive effect on private R&D (particularly, research) expenditures, subsidies to development tend to substitute for private R&D expenditures, mostly reducing private development spending.

It is widely agreed that research activities and development activities are very different in their features and their prospects. In particular, uncertainty and intangibility characterise research to a greater extent than development. Cohen and Levinthal (1989) and Cockburn and Henderson (1998), among others, emphasise that a firm's research activity stimulates its 'absorptive capacity', a major intangible that improves the firm's competitive advantage. Nelson (1959) suggests that firms devoted to exploratory research, which are more focused on research than on development, enjoy better long-term prospects. Czarnitzki *et al.* (2009), in line with Griliches (1986), also show that research expenditures yield higher probabilities of patenting than development expenditures.

By the same token, the uncertain and intangible outcomes of research projects prevent their full appropriation by firms. Nelson (1959) and Arrow (1962) suggest that firm underinvestment is likely to be more stringent in research than in development activities as the returns associated with the former are harder to appropriate. In this respect, public subsidies can reduce the gap between social and private benefits, fostering research projects of private firms (Clausen, 2007; Czarnitzki et *al.*, 2011). On the contrary, development projects usually face less uncertainty and have much higher tangibility than research projects. These projects are 'close to the market' and, therefore, "similar to practical and firm specific problem-solving activities" (Clausen, 2007, p.5). Moreover, such projects usually have specific commercial (and therefore tangible) objectives, so firm have the proper incentives to perform their development projects to the extent that their returns can usually be appropriated (Aerts and Thorwarth, 2008). Consequently, the traditional market failure argument (Arrow, 1962; Stiglitz, 1988) to justify public subsidies is much weaker in the case of development projects as opposed to research projects.

All of these arguments lead us to put forward the following assumption:

> **Research assumption 4:** *The response of firms to public subsidies might be dependent on the composition of R&D investment. We would expect public subsidies to have a stronger crowding-in effect, the larger the weight of research activities and the smaller the weight of development activities in firm R&D investment.*

Subsidy Amount

In the empirical assessment of the effect of public subsidies on firms' R&D investment, most studies have disregarded the amount of the subsidy granted to the firm. However, the amount of subsidies received differs very much between firms. Four notable studies focus on the quantitative effect of the subsidy amount granted to the firms. Guellec and Pottelsberghe (2000) find a nonlinear relationship between public subsidies and privately financed R&D, namely, an inverted U-shaped curve. Thus, the subsidy effect is positive but marginally decreasing up to a certain threshold, beyond which the effect becomes negative. This result suggests a crowding-in effect of moderate subsidy amounts and a crowding-out effect for subsidies beyond a certain level. Zhu *et al.* (2006) and Görg and Strobl (2007) find similar results. Aschhoff (2009) demonstrates that a minimum grant size is necessary to increase the scope of firm-financed R&D activities and remarks that, for a certain subsidy amount, the sign of its effect might depend on the size of the project. Larger projects might be more dependent on the provision of public money, whereas firms might be more willing to bear the risk of a smaller project alone. Hence, for a given subsidy amount, the larger the project, the higher the probability of a crowding-in effect becomes. Nevertheless, we should expect R&D activities to be inelastic beyond a certain degree. The firm's resources circumscribe the scale of its business, which also includes R&D activities, because their capabilities are limited. If the firm receives more subsidies to conduct a larger project, so that it must use its resources to its maximum capacity, the firm might reallocate R&D funds from other projects to the largest one, thus postponing or discontinuing other projects. Therefore, other things being equal, the probability of a crowding-out effect can be expected to increase with the subsidy size. Thus, we assume that:

Research assumption 5: *The effect of public subsidies on private R&D investment might be characterised by an inverted U-shaped curve. Such an effect is positive up to a certain threshold (i.e., the crowding-in effect would prevail) and negative beyond (with the crowding-out effect dominating).*

Sources of Funding

In most countries, a variety of public agencies provide public subsidies for private R&D. In particular, supranational, national and regional subsidy programmes exist in EU countries,[17] and federal and state subsidy programmes operate in the US. Most empirical studies have addressed the effect of public subsidies on private R&D investment irrespective of the public agency granting the subsidies, so the ‘average’ effect of subsidies is considered. This statement is acknowledged in Table 1, which shows that most existing research has evaluated the effect of single subsidy programmes allocated by agencies at the level of federal or national governments. Nonetheless, several researchers have explored the average effect of R&D programmes allocated by different public agencies at the international, national or regional levels.[18] Although the evidence is mixed, most studies provide support for additionality when the ‘average’ effect of subsidies awarded by different agencies is considered. Blanes and Busom (2004)[19] find that differences between firms, industries and public agencies affect firms’ participation in different public subsidy programmes (mainly at the national and regional levels). To our knowledge, Clausen (2007) is the only study that addresses whether public programmes conducted by different public agencies entail different effects on private R&D investment.

We argue that the way in which private R&D investment is affected by the features of the source of public funding, namely, the public agency involved, deserves further study. In particular, it would be worthwhile to study the grant criteria established by the different public agencies and construct taxonomies to assess how different requirements and awarding criteria can stimulate or substitute private R&D spending (see David *et al.*, 2000; Klette *et al.*, 2000, among others). Clausen (2007) finds that the source of a subsidy influences whether it is used to stimulate firm R&D activities (mainly research activities) or to substitute some of them (mainly development activities).[20]

Even in the unlikely case that requirements and awarding criteria do not differ among public agencies, assuming also small application costs, we would expect that a firm applying to one agency for a subsidy might also apply to other agencies for subsidies to fund the same R&D project (Blanes and Busom, 2004). Eventually, a firm might obtain subsidies from multiple agencies to fund the same R&D project. In this case, public subsidies are more likely to substitute private R&D spending. A firm in this situation might enjoy excess resources to finance a certain project, especially if the project is small, which can be diverted towards non-subsidised projects. More realistically, a firm with several projects, each subsidised by different public agencies, may end up reallocating funds between the projects, thus creating a substitution effect. On the contrary, a firm might have a large and riskier project that would require funding from multiple public agencies. In this case, we might find that a complementary effect exists between the sum of the subsidies received from different agencies and firm R&D investment. All of these arguments lead us to put forward the following two assumptions:

Research assumption 6a: *The crowding-out effect of public subsidies on private R&D investments might be more likely in firms conducting small R&D projects when these projects are financed by different agencies.*

Research assumption 6b: *The crowding-in effect of public subsidies on private R&D investments might be more likely in firms conducting large R&D projects when these projects are financed by different agencies.*

CONCLUSIONS

A large number of empirical studies in the last five decades have investigated the effectiveness of public subsidies of private R&D spending. In general, scholars and policymakers agree about the desirability of subsidising private R&D activities. The market failure argument resting on the ‘public good’ nature of innovations, which deters full appropriation and leads the level of private innovation below the socially optimal level, drives this agreement. Furthermore, capital market imperfections leading to financial constraints on risky projects, such as R&D activities, also contribute to reducing the private R&D investment below the socially optimal level (Arrow, 1962; Hall, 1992, 2002). Public R&D activities and public subsidies of private R&D are used as policy instruments to fill the gap between the private and the socially optimal levels of R&D investment. Accordingly, many empirical studies have aimed at assessing the causal effect of public subsidies on private R&D investment.

Our review of the empirical literature on the impact of public subsidies on private R&D investments yields the following conclusions. First, together with the increasing availability of appropriate data, there is rising concern about the effectiveness of public subsidies, which reflects societal demands for efficient use of public funds. Second, most studies have concentrated on developed countries, mainly the US and the EU countries, and there is little evidence for other countries, particularly developing and emerging countries. Third, most available data come from studies performed at the firm level, as the firm is the real recipient of public subsidies. We agree there are outstanding empirical contributions based on aggregate data on the effect of subsidies on private R&D decisions, and that studies with aggregate and micro data complement each other. However, we believe that longitudinal micro data at firm, establishment or plant level allow addressing questions at the very same level at which decisions are taken. Such data allow accounting not only for dynamic considerations —as with aggregate time-series data— but also for heterogeneity among those agents (firms, establishment or plants) that are the potential receivers of public subsidies. More aggregated data are less adequate because they hide firm heterogeneity, which is extremely relevant for distinguishing firms’ R&D strategies. To our knowledge, many current firm-level datasets lack information that would be critical for understanding the role of public subsidies in private R&D. We have, implicitly or explicitly, suggested the information that would be worthy of investigation as it applies to the issues that have been examined in this research. Fourth, empirical work has mostly focused on the manufacturing sector. However, the services sector has an increasing and prominent weight in most developed countries. It is therefore important to analyse R&D investment in this sector, to understand how public subsidies affect it, and to compare the results with those for manufacturing. Fifth, most studies have explored the effect of public subsidies on private R&D investments in the short term, but dynamic considerations must be acknowledged. Empirical evidence suggests that the effect of public subsidies on private R&D need not be instantaneous and can be distributed over a longer span of time, so short-term and long-term effects might differ. Cross-sectional data cannot be used for this purpose, and firm-level longitudinal data are needed.

The empirical evidence on the effectiveness of public subsidies is mixed and therefore inconclusive. Although results supporting the additionality hypothesis prevail, there are valuable contributions in favour of the substitution hypothesis and others that demonstrate a negligible effect. We believe that, in addition to methodological differences, the theoretical framework of analysis, the population under study (e.g., the country and sample period, the type of firms) and the sources and characteristics of the subsidy programmes might determine whether the additionality or the substitution effect is observed.

Although the most recent studies are more similar to one another in their methodological approaches, we argue that the empirical literature has tended to focus on a subset of the issues at stake while disregarding others. The existing empirical literature on the effectiveness of public R&D subsidies has been constrained by a lack of information and analysis on the following main issues: 1) the firm's history of past and current subsidies (i.e., the frequency with which a firm receives subsidies); 2) the time lag structure (i.e., how the potential effect of subsidies is distributed over time); 3) the firm's internal liquidity and potential financial constraints; 4) the composition of firm R&D; 5) the amount of subsidy granted to the firm; and 6) the different sources of public subsidies. Our survey shows that most of these issues have been addressed separately in different studies, primarily since the end of the 1990s. We believe that considering all of these issues explicitly would improve our understanding of public subsidies and their impact on firm R&D strategy. Specifically, we aimed at contributing to scholarly knowledge with the research assumptions propounded in this study. We posit that, under different situations, public subsidies are expected to exert additionality or substitution effects on private R&D investment.

We must acknowledge, nonetheless, that there are further interesting issues that we have not raised in this study that would also be worth exploring.[21] These include the wage effects of subsidies (see Goolsbee, 1998), the interaction of public subsidies with other mechanisms —such as tax incentives— to boost private R&D (see Guellec and Pottelsberghe, 2003; Bérubé and Mohnen, 2009), or the potential impacts of uncertainty and instability on subsidy policies (see Guellec and Pottelsberghe, 2003).[22] This latter issue may also be of special interest in countries that are facing the negative consequences of the economic crisis that arose in the late 2000s.

In conclusion, a great number of researchers have made much progress in the study of the potential effect of public subsidies on private R&D investment. The issues explicitly considered in our study can inspire further advancement in the near future. Our survey suggests that although significant progress has already been made in this field of study, many interesting research issues remain to be tackled.

REFERENCES

Aerts, K. and Czarnitzki, D. (2004) Using innovation survey data to evaluate R&D policy: the case of Belgium. *ZEW Discussion Paper No. 04-55*, Mannheim.

Aerts, K. and Czarnitzki, D. (2006) The impact of public R&D funding in Flanders. *IWT-Studies No. 54*, Brussel.

Aerts, K. and Schmidt, T. (2008) Two for the price of one? Additionality effects of R&D subsidies: a comparison between Flanders and Germany. *Research Policy* 37(5): 806-822.

Aerts, K. and Thorwarth, S. (2008) Additionality effects of public R&D funding: 'R' versus 'D'. *FBE Research Report MSI No 0811*. Katholieke Universiteit Leuven. Belgium.

Ali-Yrkkö, J. (2005) Impact of public R&D financing on private R&D. Does financial constraint matter? *Working Paper* No. 30. ENEPRI, Brussels.

Almus, M. and Czanitzki, D. (2003) The effects of public R&D subsidies on firm's innovation activities. The case of Eastern Germany. *Journal of Business & Economic Statistics* 21(2): 226-236.

Antonelli, C. (1989) A failure-inducement model of research and development expenditure. *Journal of Economic Behavior and Organization* 12(2): 159-180.

Arrow, K.J. (1962) Economic welfare and the allocation of resources to invention. In Nelson, R.R. (ed.), *The Rate and Direction of Inventive Activity: Economic and Social Factors* (pp. 609-625). Princeton University Press.

Aschhoff, B. (2009) The effect of subsidies on R&D investment and success. Do subsidy history and size matter? *ZEW Discussion Paper* No. 032, Mannheim.

Bentzen, J. and Smith, V. (1999) An empirical analysis of R&D expenditure in the Nordic countries. *Paper presented at the IAES Meeting*, Montreal, october.

Berger, A.N. and Udell, G.F. (1990) Collateral, loan quality and bank risk. *Journal of Monetary Economics* 25(1): 21-42.

Bérubé, C. and Mohnen, P. (2009) Are firms that receive R&D subsidies more innovative? *Canadian Journal of Economics* 42(1): 206-225.

Bester, H. (1985) Screening versus rationing in credit markets with imperfect information. *American Economic Review* 75(4): 850-855.

Bhattacharya, S. and Ritter, J. (1983) Innovation and communications: signalling with partial disclosure. *Review of Economic Studies* 50(2): 331-46.

Blanes, J.V. and Busom, I. (2004) Who participates in R&D subsidy programs? The case of Spanish manufacturing firms. *Research Policy* 33(10): 1459-1476.

Blank, D.M. and Stigler, G.J. (1957) *The Demand and Supply of Scientific Personnel*. New York: National Bureau of Economic Research.

Bloch, C., and Graversen, E.K. (2008). Additionality of public R&D funding in business R&D. *Working Paper No 5*. The Danish Center for Studies in Research and Research Policy, University of Aarhus, Denmark.

Branstetter, L. and Sakakibara, M. (1998) Japanese research consortia: a microeconometric analysis of industrial policy. *Journal of Industrial Economics* 46(2): 207-233.

Brouwer, E. and Kleinknecht, A. (1999) Keynes-plus? Effective demand and changes in firm-level R&D: an empirical note. *Cambridge Journal of Economics* 23(3): 385-391.

Brown, J.R. Fazzari, S.M., and Petersen, B.C. (2008) Financing innovation and growth: cash flow, external equity and the 1990s R&D boom. *Journal of Finance* 64(1): 151-185.

Busom, I. (2000) An empirical evaluation of R&D subsidies. *Economics of Innovation and New Technology* 9(2): 111-148.

Buxton, A. (1975) The process of technical change in UK manufacturing. *Applied Economics* 7(1): 53-71.

Callejón, M. and García-Quevedo, J.G. (2002) Las ayudas públicas a la I+D empresarial. Un análisis sectorial. *Document de Treball No. 6*. Institut d'Economia de Barcelona. Barcelona.

Capron, H. and van Pottelsberghe, B. (1997) Public support to business R&D: a survey and some new quantitative evidence. In OECD, *Policy Evaluation in Innovation and Technology. Towards Best* Practices (pp. 171-187). Paris.

Carmichael, J. (1981) The effects of mission-oriented public R&D spending on private industry. *Journal of Finance* 36(3): 617-627.

Carpenter, R. and Petersen, B. (2002) Capital market imperfections, high-tech investment and new equity financing. *Economic Journal* 112(447): 54-72.

Cerulli, G. (2010) Modelling and measuring the effect of public subsidies on business R&D: a critical review of the econometric literature. *The Economic Record* 86(274): 421-449.

Clausen, T.H. (2007) Do subsidies have positive impacts on R&D and innovation activities at the firm level? *Working Paper 2007/0615*, Centre for Technology, Innovation and Culture, University of Oslo, Oslo.

Cockburn, I.M. and Henderson, R.M. (1998) Absorptive capacity, coauthoring behavior and the organization of research in drug discovery. *The Journal of Industrial Economics,* 46(2): 157-182.

Cohen, W.M. and Levinthal, D.A. (1989) Innovation and learning: the two faces of R&D. Implications for the analysis of R&D investment. *Economic Journal* 99(397): 569-596.

Czarnitzki, D., Ebersberger, B. and Fier, A. (2007) The relationship between R&D collaboration, subsidies and R&D performance: empirical evidence from Finland and Germany, *Journal of Applied Econometrics* 22(7): 1347-1366.

Czarnitzki, D. and Fier, A. (2002) Do innovation subsidies crowd out private investment? Evidence from the German service sector. *Applied Economics Quarterly* 48(1): 1-25.

Czarnitzki, D. and Hottenrott, H. (2010) Financing constraints for industrial innovation: what do we know? *Working Paper OR 1004*, Katholieke Universiteit LEUVEN, Belgium.

Czarnitzki, D., Hottenrott, H. and Thorwarth, S. (2011) Industrial research versus development investment: the implications of financial constraints. *Cambridge Journal of Economics*, 35(3): 527-544.

Czarnitzki, D. and Hussinger, K. (2004) The link between R&D subsidies, R&D spending and technological performance. *ZEW Discussion Paper No. 056*, Mannheim.

Czarnitzki, D., Kraft, K. and Thorwarth, S. (2009) The knowledge production of 'R' and 'D'. *Economic Letters* 105(1): 141-143.

Czarnitzki, D. and Licht, G. (2006) Additionality of public R&D grants in a transition economy. The case of Eastern Germany. *Economics of Transition* 14(1): 101-131.

Czarnitzki, D. and Toole, A.A. (2007) Business R&D and the interplay of R&D subsidies and product market uncertainty. *Review of Industrial Organization* 31(3): 169-181.

David, P.A., Hall, B.H. and Toole, A.A. (2000) Is public R&D a complement or substitute for private R&D? A review of econometric evidence. *Research Policy* 29(4-5): 497-529

Diamond, A.M. (1999) Does federal funding "crowd in" private funding of science. *Contemporary Economic Policy* 17(4): 423-431.

Duguet, E. (2004) Are R&D subsidies a substitute or a complement to privately funded R&D? Evidence from France using propensity score methods for non-experimental data. *Revue d'Economie Politique* 114(2): 263-292.

Ebersberger, B (2005) *The Impact of Public R&D Funding*. Vuorimiehentie : VTT Publications.

Egeln, J., Licht, G. and Steil, F. (1997) Firm foundations and the role of financial constraints. *Small Business Economics* 9(2): 137-150.

Eurostat (2009) *Research and Development Expenditure, by Sectors of Performance* (http://epp.eurostat.ec.europa.eu). European Commission.

Falk, R. (2004) Behavioural additionality effects of R&D subsidies: empirical evidence from Austria. *TIP Working Paper*, Vienna.

Gannicott, K. (1984) The determinants of industrial R&D in Australia. *The Economic Record* 60(3): 231-235

García-Quevedo, J. (2004) Do public subsidies complement business R&D? A meta-analysis of the econometric evidence. *KYKLOS* 57(1): 87-102.

Globerman, S. (1973) Market structure and R&D in Canadian manufacturing industries. *Quarterly Review of Economics and Business* 13(1): 59-68.

Golberg, L. (1979) The influence of federal R&D funding on the demand for and returns to industrial R&D. *Working Paper CRC-388*. The Public Research Institute.

González, X., Jaumandreu, J. and Pazó, C. (2005) Barriers to innovation and subsidy effectiveness. *RAND Journal of Economics* 36(4): 930-950.

González, X. and Pazó, C. (2008) Do public subsidies stimulate private R&D spending? *Research Policy* 37(3): 371-389.

Goolsbee, A. (1998) Does government R&D policy mainly benefit scientists and engineers? *American Economic Review* 88(2): 298-302.

Görg, H. and Strobl, E (2007) The effect of R&D subsidies on private R&D. *Economica* 74(294): 215-234.

Griliches, Z. (1986) Productivity, R&D, and the basic research at the firm level in the 1970's. *American Economic Review* 76(1): 141-54,

Guellec, D. and van Pottelsberghe, B. (2000) The impact of public expenditure on business R&D. *STI Working Papers 2000/4*, OECD, Paris.

Guellec, D. and van Pottelsberghe, B. (2003) The impact of public R&D expenditure on business R&D. *Economics of Innovation and New Technologies* 12(3): 225-244.

Hall, B.H. (1992) Investment and research and development at the firm level: does the source of financing matter? *NBER Working Paper No. 4096*, Cambridge.

Hall, B. H. (2002) The financing of research and development. *Oxford Review of Economic Policy* 18(1): 35-51.

Hall, B.H. and van Reenen, J. (2000) How effective are fiscal incentives for R&D? A review of the evidence. *Research Policy* 29(4-5): 449-470.

Hamberg, D. (1966): *Essays on the Economics of Research and Development*. New York: Random House.

Hao, K.Y. and Jaffe, A.B. (1993) Effect of liquidity on firm's R&D spending. *Economics of Innovation and New Technology* 2(4): 275-82.

Herrera, L. and Heijs, J. (2006) Difusión y adicionalidad de las ayudas públicas a la innovación. *Revista de Economía Aplicada* 14(41): 45-65.

Herrera, L. and Martínez, A. (2009) La I+D pública complementa o sustituye la I+D privada? Un análisis de la insdustria manufacturera española. Paper presented to the *XIX National Conference of ACEDE*.

Higgins, R.S. and Link, A.N. (1981) Federal support of technological growth in industry: some evidence of crowding out. *IEEE Transactions on Engineering Management* 28: 86-88.

Himmelberg, C.P. and Petersen, B.C. (1994) R&D and internal finance: a panel study of small firms in high-tech industries. *Review of Economics and Statistics* 76(1): 38-51.

Holden, D.R. and Swales, J.K. (1996) Subsidies, additionality and financial constraints: a comment on Wren. *Journal of Regional Science* 36(2): 303-310.

Holemans, B. and Sleuwaegen, L. (1988) Innovation expenditures and the role of government in Belgium. *Research Policy* 17(6): 375-379.

Howe, J.D. and McFetridge, D.G. (1976) The determinants of R&D expenditures. *Canadian Journal of Economics* 9(1): 57-71.

Hubbard, G. (1998) Capital market imperfections and investment. *Journal of Economic Literature* 36(1): 193-225.

Hussinger, K. (2008) R&D and subsidies at the firm level: an application of parametric and semiparametric two-step selection models. *Journal of Applied Econometrics* 23(6): 729-747.

Hyytinen, A. and Toivanen, O. (2005) Do financial constraints hold back innovation and growth? Evidence on the role of public policy. *Research Policy* 34(9): 1385-1403.

Irwin, D.A. and Klenow, P.J. (1996) High-tech R&D subsidies: estimating the effects of Sematech. *Journal of International Economics* 40(3-4): 323-344.

Janz, N., Lööf, H. and Peters, B. (2003) Firm level innovation and productivity– Is there a common story across countries? *ZEW Discussion Paper No. 03-26*, Mannheim.

Jensen, M. and Meckling, W. (1976) Theory of the firm, managerial behavior, agency costs and ownership structure. *Journal of Financial Economics* 5(4): 305-60.

Kaiser, U. (2004) Private R&D and public R&D subsidies: microeconometric evidence from Denmark, *CEBR Discussion Paper 2004-19*, Denmark.

Klette, T.J. and Møen, J. (1998) *R&D Investment Responses to R&D Subsidies: A Theoretical Analysis and a Microeconomic Study*. Preliminary draft presented at the NBER Summer Institute, july.

Klette, T.J. and Møen, J. (1999) From growth theory to technology policy coordination problems in theory and practice. *Nordic Journal of Political Economy* 25(1): 53-74.

Klette, T.J., Møen, J. and Griliches, Z. (2000) Do subsidies to commercial R&D reduce market failures? Microeconomic evaluation studies. *Research Policy* 29(4-5): 471-495.

Koga, T. (2005) R&D subsidy and self-financed R&D: the case of Japanese high-technology start-ups. *Small Business Economics* 24(1): 53-62.

Lach, S. (2002) Do R&D subsidies stimulate or displace private R&D? Evidence from Israel. *Journal of Industrial Economics* 50(4): 369-390.

Lerner, J. (1999) The government as venture capitalist: the long-run impact of the SBIR program. *Journal of Business* 72(3): 285-318.

Levin, R.C. and Reiss, P.C. (1984) Tests of a Schumpeterian model of R&D and market structure, in Griliches Z. (ed.) *R&D, Patents, and Productivity* (pp. 175-208). Chicago: University of Chicago Press.

Levy, D.M. (1990) Estimating the impact of government R&D. *Economic Letters* 32(2): 169-173.

Levy, D.M. and Terleckyj, N.E. (1983) Effects of government R&D on private R&D investment and productivity: a macroeconomic analysis. *Bell Journal of Economics* 14(2): 551-561.

Leyden, D.P. and Link, A.L. (1991) Why are governmental R&D and private R&D complements? *Applied Economics* 23(10): 1673-1681.

Leyden, D.P., Link, A.L. and Bozeman (1989) The effects of governmental financing on firm's R&D activities: a theorical and empirical investigation. *Technovation* 9(7): 561-575.

Lichtenberg, F.R. (1984) The relationship between federal contract R&D and company R&D. *American Economic Review* 74(2): 73-78.

Lichtenberg, F.R. (1987) The effect of government funding on private industrial research and development: a re-assessment. *Journal of Industrial Economics* 36(1): 97-104.

Lichtenberg, F.R. (1988) The private R&D investment response to federal design and technical competitions. *American Economic Review* 78(1): 550-559.

Link, A.N. (1982) An analysis of the composition of R&D spending. *Southern Economic Journal* 49(2): 342-349.

Long, W.F. and Ravenscraft, D.J. (1993) LBOs, debt and R&D intensity. *Strategic Management Journal* 14(1): 119-135.

Lööf, H. and Heshmati, A. (2005) The impact of public funding on private R&D investment: new evidence from a firm level innovation study. *CESIS Electronic Working Paper Series, Paper No. 06*, Stockholm.

Lucas, R.E. (1967) Adjustment costs and the theory of supply. *Journal of Political Economy* 75(4): 321–334.

Mamuneas, T.P. and Nadiri, M.I. (1996) Public R&D policies and cost behavior of the US manufacturing industries. *Journal of Public Economics* 63(1) 57-81.

Mansfield, E. (1980) Basic research and productivity increase in manufacturing. *American Economic Review* 70(5): 863-873.

Mansfield, E. and Switzer, L. (1984) Effects of federal support on company-financed R and D: the case of energy. *Management Science* 30(5): 562-571.

Meeusen, W. and Janssens, W. (2001) Substitution versus additionality: econometric evaluation by means of micro-economic data of the efficacy and efficiency of R&D subsidies to firms in the Flemish region. *CESIT Discussion paper No 2001/01*, University of Antwerp.

Močnik, D. (2001) Asset specificity and a firm's borrowing ability: an empirical analysis of manufacturing firms. *Journal of Economic Behaviour and Organization* 45(1): 69-81.

National Science Board (2008) *Science and Engineering Indicators 2008*, vol. 1, Chapter 4. National Science Foundation.

Nelson, R.R. (1959) The simple economics of basic scientific research. *Journal of Political Economy* 67: 297-306.

Özçelik, E. and Taymaz, E. (2008) R&D support programs in developing countries: the Turkish experience. *Research Policy* 37(2): 258-275.

Petersen, M. and Rajan, R. (1994) The benefits of lending relationships: evidence from small business data. *Journal of Finance* 49(1): 3-37.

Petersen, M. and Rajan, R. (1995) The effect of credit market competition on lending relationships: evidence from small business data. *Quarterly Journal of Economics* 110(2): 407-443.

Robson, M. (1993) Federal funding and the level of private expenditure on basic research. *Southern Economic Journal* 60(1): 63-71.

Rosenberg, J.B. (1976) Research and market share: a reappraisal of the Schumpeter hypothesis. *Journal of Industrial Economics* 25(2): 101-112.

Savignac, F. (2008) Impact of financial constraints on innovation: what can be learned from a direct measure? *Economics of Innovation and New Technology* 17(6): 553-569.

Scellato, G. (2007) Patents, firm size and financial constraints: an empirical analysis for a panel of Italian manufacturing firms. *Cambridge Journal of Economics* 31(1): 55-76.

Scott, J. (1984) Firm versus industry variability in R&D intensity. In Griliches, Z. (Ed.): *R&D, Patents and Productivity*. Chicago: University of Chicago Press.

Shrieves, R.E. (1978) Market structure and innovation: a new perspective. *Journal of Industrial Economics* 26(4): 329-347.

Sørensen, A., Kongsted, H.C. and Marcusson, M. (2003) R&D, public innovation policy, and productivity: the case of Danish manufacturing. *Economics of Innovation and New Technology* 12(2): 163-178.

Stiglitz, J. (1988) *Economics of the Public Sector*. W.W. Norton and Company: New York.

Stiglitz, J. and Weiss, A. (1981) Credit rationing in markets with imperfect information, *American Economic Review* 71(3): 393-410.

Streicher, G., Schibany, A. and Gretzmacher, N. (2004) Input additionality effects of R&D subsidies in Austria, *TIP Working Paper 04-03*, Vienna.

Suetens, S. (2002) R&D subsidies and production effects of R&D personnel: evidence from the Flemish region. *CESIT Discussion Paper 2002/03*, University of Antwerp.

Takalo, T. and Tanayama, T. (2010) Adverse selection and financing of innovation: is there a need for R&D subsidies? *Journal of Technology Transfer* 35(1): 16-41.

Terleckyj, N.E. (1985) Measuring economic effects of federal research and development expenditures, recent history with special emphasis on federal R&D performed in industry. Paper presented to the *Workshop on the Federal Role in Research and Development*. National Academies of Science and Enginieering. Washington, DC.

Toivanen, O. and Niininen, P. (1998) Investment, R&D, subsidies and credit constraints. *Working Paper No W-264*, Helsinki School of Economics, Helsinski.

Ughetto, E. (2008) Does financial finance matter for R&D? New evidence from a panel of Italian firms. *Cambridge Journal of Economics* 32(6): 907-925.

Von Tunzelmann, N. and Martin, B. (1998) Public vs. private funding of R&D and rates of growth: 1963-1995. *Working Paper*, Science Policy Research Unit (SPRU), University of Sussex.

Wallsten, S.J. (2000) The effects of government-industry R&D programs on private R&D: the case of the small business innovation research program. *RAND Journal of Economics* 31(1): 82-100.

Wolff, G.B. and Reinthaler, V. (2008) The effectiveness of subsidies revisited: Accounting for wage and employment effects in business R&D. *Research Policy* 37(8): 1403-1412.

Wren, C. (1994) The build-up and duration of subsidy-induced employment: evidence from U.K. *Journal of Regional Science* 34(3): 387-410.

Wu, Y. (2005) The effects of state R&D tax credits in stimulating private R&D expenditure: a cross-state empirical analysis. *Journal of Policy Analysis and Management* 24(4): 785-802.

Zhu, P., Xu W. and Lundin, N. (2006) The impact of government's fundings and tax incentives on industrial R&D investments. Empirical evidences from industrial sectors in Shanghai. *China Economic Review* 17(1): 51-69.

Table 1. Empirical studies analyzing the effect of public R&D subsidies on a firm's R&D spending

Author(s)	Country	Period	Unit of analysis	Dependent Variable	Independent Variable	Method	Source of Funding[1]	R&D [2]	Subsidy History[3]	Time lag[4]	Shape of the effect[5]	Financ. Constr. [6]	Main Findings	Citations[7]
Hamberg (1966)	USA	1960	Firm: 405 (8 ind.) [manuf.]	Private R&D Employ./Total Employ.	Gov. Contracts/ Assets	Regress. (Weigh. OLS)	F.G.	A	No	S-t	L	No	Mixed: Additionality and N.S.	[0.98; 2.28]
Globerman (1973)	Canada	1965-69	Industry: 15 [manuf.]	Private R&D Employ./Total Employ.	Gov. R&D/Sales	Regress. (OLS)	F.G.	A	No	S-t	L	No	Additionality	[0,46; 1.26]
Buxton (1975)	UK	1965	Industry: 11 [manuf.]	Private R&D/Gross output	Gov. R&D/ Gross output	Regress. (OLS)	F.G.	A	No	S-t	L	No	Additionality	[0.11; 0.51]
Howe & McFetridge (1976)	Canada	1967-71	Firm: 81; 256 firm-year obs. [manuf.]	Private R&D expend.	Gov. R&D grants	Regress. (Weigh. OLS)	F.G.	A	No	S-t	L	No	Mixed: Additionality and N.S.	[0.86; 2.64]
Rosenberg (1976)	USA	1963-64	Firm: 100 [manuf.]	%Total Employ. alloc. to Profes. R&D Person.	Gov. R&D subsidies	Regress. (OLS)	F.G.	A	No	S-t	L	No	Additionality	[0.42; 1.58]
Shrieves (1978)	USA	1965	Firm: 411 [manuf.]	(log) Private R&D Employ.	% R&D finan. by the Gov.	Regress. (OLS)	F.G.	A	No	S-t	L	No	Substitution	[0.85; 3.09]
Golberg (1979)	USA	1958-75	Industry: 14 [manuf.]	(log) Private R&D/output	Gov. R&D/Sales	Regress. (FE OLS)	F.G.	A	No	S-t /L-t (1-year lag)	L	No	Substitution and Additionality in the case of 1-year lag. Additionality when the sum of coefficients is considered	[0.03; 0.67]
Carmichael (1981)	USA	1976-77	Firm: 46; 92 firm-year obs. [transp. ind.]	Private R&D expend.	Gov. R&D contracts	Regress. (Weigh. OLS)	F.G.	A	No	S-t	L	No	Substitution	[0.45; 1.58]
Higgins & Link (1981)	USA	1977	Firm: 174 [manuf.]	% of Research in private R&D	Gov. R&D expend.	Regress. (OLS)	F.G.	S [R]	No	S-t	L	No	Substitution [estimated elasticity: -0.13]	[0.16; 1.00]

Link (1982)	USA	1977	Firm: 275 [manuf.]	Private R&D/Net Sales	Gov. R&D expend./ Net Sales	Regress. (OLS)	F.G.	A S [BR; AR; D]	No	S-t	L	No	Additionality for aggregate R&D; Additionality for 'Development'; N.S. for 'Applied Research'; Substitution for 'Basic Research'	[1.00; 3.33]
Levy & Terleckyj (1983)	USA	1949-81	Country	Private Industry R&D expend.	Total Gov. R&D exp.; Gov. contr. R&D and all other Gov. R&D	Regress. (GLS)	F.G.	A	No	S-t/L-t (3-year lag)	L	No	Additionality for Total Gov. Expend. and Gov. contract R&D (3-year lag) [$1 of Gov contract performed in industry induced about 0.27$ of private expenditure]	[1.41; 4.55]
Gannicott (1984)	Australia	1976-77 and 1978-79	Industry: 13 [manuf.]	Private R&D expend.	Gov. grants	Regress. (2SLS)	F.G.	A	No	S-t	L	No	N.S.	[0.14; 0.54]
Levin & Reiss (1984)	USA	1963, 67 and 72	Industry: 20 [manuf.]	Private R&D/production costs	Gov. R&D/ shipments	Regress. (2SLS)	F.G.	A	No	S-t	L	No	Additionality [On the average, $1 increase in Gov. R&D spending is associated with a 7-cent increase in company-financed R&D expend.]	[2.75; 9.71]
Lichtenberg (1984)	USA	1) 1963-79 2) 1967, 72, 77	1) Industry: 12 [manuf.] 2) Firm: 991 [manuf.]	1) Change in firm-funded R&D (expend. or empl.) 2) R&D expend./ Sales and Change in Comp. R&D expend./Sales	1) Change in Fed. R&D expend. 2) Gov. contract R&D/Sales and Change in Gov. cont. R&D/Sales	Regress. (FE OLS)	F.G.	A	No	S-t/L-t (1 and 2-year lags)	L	No	1) Mixed for R&D expenditure: N.S. in the S-t, Additionality for 1-year lag, Substitution for 2-year lag. Substitution for R&D employ. in the S-t, Additionality for 2 year-lag 2) Additionality, Substitution	[1.75; 5.82]
Mansfield and Switzer (1984)	USA	1979	Firm: 25 (4 ind.) [manuf.]	Change in comp-financed energy R&D expend.	Change in the firms' Gov.-financed energy R&D expend.	Aggregate and Regress. (Logit)	F.G.	A	No	S-t/L-t (1 to 3-year lags)	L	No	Additionality 1-3 year-lags [For each $1 increase in federal support these 4 ind. would have increased their own support of energy R&D by 6 cents in each of the first 2 years after the increase in federal funds]	[0.64; 1.68]
Scott (1984)	USA	1974	Firm: 437 and 3,388 Line of Bus. [manuf.]	Comp-financed R&D/Sales and (log) Comp-financed R&D	Gov.-financed R&D/Sales; and (log) Gov.-financed R&D	Regress. (FE)	F.G.	A	No	S-t	L	No	Additionality [The relation is far less significant when the intensity variables are removed from the analysis]	[0.07; 8.64]
Terleckyj (1985)	USA	1964-84	Country	Private Industry R&D expend.	Gov. contract R&D	Regress. (GLS)	F.G.	A	No	S-t	L	No	Additionality	[0.11; 0.22]

Lichtenberg (1987)	USA	1) 1956-83 2) 1979-84	1) Country 2) Firm: 187 [manuf.]	1) Company funds for R&D 2) Company funds for R&D	1) Fed. funds for R&D 2) Fed. funds for R&D	Regress. 1) OLS 2) Pooled OLS	F.G.	A	No	1) S-t /L-t (1-year lag) 2) S-t	L	No	1) Additionality in the Restric. Model [Add. for 1-year lag] and N.S. in the Unrestr. 2) Additionality in the Restrict. and N.S. in the Unrestric. Model	[1.28; 5.52]
Lichtenberg (1988)	USA	1979-84	Firm: 169 [manuf.]	Company-funded R&D expend.	Gov. R&D contr. (compet., non-competit.)	Regress. (Weigh. OLS, IV)	F.G.	A	No	S-t	L	No	Mixed: Additionality in the case of Weighted OLS and Substitution in the case of IV	[2.08; 7.33]
Holemans & Sleuwaegen (1988)	Belgium	1980-84	Firm: 236 firm-year obs. (4 ind.) [man.]	(log) Private R&D expend.	(log) Gov. R&D grants	Regress. (FE OLS)	F.G.	A	No	S-t	L	No	Additionality [estimated elasticity: 0.25-0.48]	[0.63; 2.04]
Antonelli (1989)	Italy	1983	Firm: 86 [manuf.]	Priv. R&D expend.; (log) priv. R&D expend.	% Gov. –finan. R&D; and (log) Gov. R&D/total R&D	Regress. (OLS)	F.G.	A	No	S-t	L	No	Additionality [estimated elasticity: 0.31-0.37]	[1.35; 4.30]
Leyden *et al*. (1989)	USA	1987	Laboratory: 120, 120 firm [manuf.]	1) Laboratory's R&D budget	Laboratory's Gov.-financed R&D budget	Regress. (3SLS, 2SLS, OLS)	F.G.	A	No	S-t	L	No	1) N.S. with 3SLS [but Additionality with OLS]	[0.26; 0.70]
Levy (1990)	9 OECD countries	1963-84	Country	Private R&D expend.	Gov. contract R&D	Regress. (FGLS and Box-Cox pr.)	F.G.	A	No	S-t	L	No	Mixed: Additionality (the United States, Japan, Germany, Sweden, France) Substitution (the UK and the Netherlands) and N.S. (Italy, Swiztzerland)	[0.41; 2.55]
Leyden & Link (1991)	USA	1987	Laboratory: 137 [manuf.]	1) Total Private R&D budget	Gov. R&D approp., contr., grants, value scient., techn. equip. and facilit.	Regress. (3SLS, 2SLS, OLS)	F.G.	A	No	S-t	L	No	1) Additionality [a $10 million exogenous increase in Gover. R&D would result in $22.9 million increase in private R&D]	[0.86; 2.57]
Robson (1993)	USA	1955-88	Country	Change in Priv. expend. on Basic Research	Change in Federal Spend. on Basic Res. and Fed. funds for Appl. R&D	Regress. (OLS)	F.G.	S [BR]	No	S-t	L	No	Additionality for 'Basic Research'	[0.47; 2.47]
Mamuneas & Nadiri (1996)	USA	1956-88	Industry: 15 [manuf.]	(log) Company-financed R&D	(log) Total Publ. R&D; [(log) Inside publ. R&D; (log) Outside publ. R&D]	Regress. (OLS)	F.G.	A	No	S-t	L	No	Substitution for total publicly funded R&D; Additionality for inside publicly funded R&D; and Substitution for outside publicly funded R&D	[1.81; 9.25]

Capron & van Pottelsberghe (1997)	7 indust. countries	1973-90	Industry: 22 [manuf.]	(log) Private R&D	(log) Gov. R&D subsidies	Regress. (OLS FE IV 2SLS)	F.G.	A	No	S-t /L-t (1-year lag)	L	No	Mixed: Additionality (the UK), Substitution (Canada, France, Italy) and N.S. (the US, Japan, Germany)	[0.33; 2.87]
Goolsbee (1998)	USA	1968-94	Scientists and engineers: 17,700 observations	(log) Real Income (log) Wages (log) Hours	(log)Total R&D spending/GDP (log) Federally funded R&D/ GDP	Regress. (not specified) and Simple Correlation	F.G	A	No	S-t/Lt	L	No	Gov. spending crowds out private spending by raising wages. The simple correlation between federally funded R&D to GDP and non-fed. funded R&D to GDP is -0.4. [The elasticity of the R&D worker wage with respect to government spending is about 0.09 in the L-t]	[3.53; 15.57]
Klette & Møen (1998)	Norway	1982-95	Business Units: 192 (697 obs.) [manuf.]	Total R&D investments	Total Gov. R&D subsidies	Regress (FE, First Diff. OLS)	1) F.G. 2)Councils Ind. funds, Ministr.)	A	No	S-t /L-t (2-year lag)	L	No	1) In the S-t, there is no crowding out and additionality; Additionality for 2-year lag 2) There are no clear cut differ. between the effects of sub. award. by each agency	[0.64; 3.93]
Toivanen & Niininen (1998)	Finland	1989, 1991, 1993	Firm: 133 [manuf.]	Private R&D expenditure	Gov.-financed R&D (loans and subsidies)	Regress. (First Diff. IV)	F.G.	A	No	S- t /L-t (1-year lag)	L	No	Substitution in the case of subsidies to large firms; N.S. in the case of small firms	[0.21; 4.00]
Von Tunzelman & Martin (1998)	22 OECD countries	1969-95	Country	Change in Private R&D	Change in Public R&D	Regress. (FE)	F.G	A	No	S-t	L	No	Mixed: Additionality in 5 countries; Substitution in 2 countries and N.S. in the remaining countries	[0.00; 1.64]
Bentzen & Smith (1999)	5 Nordic countries	1975-95	Country: 105 obs.	Bus. Enterp. Exp. on R&D; (log) BERD	Public R&D Exp. (PERD) and (log) PERD	ML-Proc. EG/OLS, Cointegrat.	F.G.	A	No	S-t /L-t	L	No	Mixed: Additionality in S-t and L-t in Denmark, Finland, Iceland; N.S. in S-t and L-t in Norway, Sweden	[0.00; 0.00]
Brouwer & Kleinknecht (1999)	The Netherl.	1988, 1992	Firm: 441 [manuf. serv.]	Change of the (log of) absol. numb. of R&D person years	Firm's partic. in EC R&D prog. in 1991-1992 (dummy var.)	Regress. (OLS)	European Union	A	No	S-t	L	No	Additionality [the model gives only a rough indication that participation in EC R&D programmes is favourable to R&D efforts; nothing can be said about the effects of subsidies since information about the amount of subsidies is lacking]	[0.92; 6.08]
Diamond (1999)	USA	1953-95	Country	(log) Level of Private Basic Research spending	(log) Level of Federal Basic Research spending	Regress. (First Diff. OLS)	F.G.	S [BR]	No	S-t	L	No	Additionality [A $1 million increase in Fed. 'Basic Research' spending results in about a $700,000 increase in total private 'Basic Research' spending]	[0.62; 4.31]

Busom (2000)	Spain	1988	Firm: 147 [manuf.]	Total R&D Expend. per Empl., R&D Personn./Empl.	Partic. in subs. loan prog. CDTI, Particip. in Eur. level R&D progr. (dum. var.)	Regress. (Prob. OLS) Selection (ML proc.)	N.G. (Spain: CDTI) EU	A	No	S-t	L	No	Mixed: Additionality and Substitution [Public funding induces an additional 20% private expenditure but for about 30% of participants complete crowding out cannot be ruled out]	[4.42; 4.92]
Wallsten (2000)	USA	1990-92	Firm: 81 obs. [manuf. serv.]	Private R&D spending in 1992	Number of SBIR awards and Total $ value of SBIR awards	Regress. (3SLS, IV)	F.G. (SBIR program)	A	No	S-t	L	No	Substitution. The SBIR grants crowd out private R&D spending dollar for dollar	[8.08; 37.17]
Meeusen & Janssens (2001)	Belgium (Fland.)	1992-97	Firm: 345; 685 firm-year obs.	Total am. 'intra muros' R&D expend./Turn.	Subsidy granted by IWT/Turnover	Regress. (AR1 NLS)	R.G. (IWT) EU	A	No	S-t/L-t (1-year lag)	L	No	Additionality for all firms [estimated elasticity; 0.32-0.66] and for sub-samples of small- and medium-sized firms	[0.00; 1.27]
Callejón & García-Quev. (2002)	Spain	1989-98	Industry: 24, 168-240 obs. [manuf.]	(log) Private R&D expend.	(log) Public R&D spending	Regress. (First Diff., GMM)	N.G.	A	No	S-t/L-t (1-2-year lags)	L	No	Additionality in the S-t and for 1-year lag	[0.10; 0.60]
Czarnitzki & Fier (2002)	German.	1996, 1998	Firm: 1,084 obs. [serv.]	Innovation expend./Sales	Probab. of receiv. public grants for innov. (dum. var.)	Matching (PS –Probit, NNM)	F.G.	A	No	S-t	L	No	Additionality [An innovation intensity of 5.7%-points is due to the participation in different public innovation programmes]	[1.30; 11.40]
Lach (2002)	Israel	1990-95	Firm: 136 firms, 325 firm-year obs. [manuf.]	Level of company-financed R&D expend.	Level of R&D subsidy (grants)	Regress. (Pooled DID)	F.G. (OCS Minist. of Industry and Trade)	A	No	S-t/L-t (1-2-year lags)	L	No	Mixed: Additionality in small firms [1 NIS increases their R&D by about 11 NIS] (Subst. in the S-t and Addit. 1 year after receiving the subsidy), N.S. in large firms	[5.10; 29.10]
Suetens (2002)	Belgium (Fland.)	1992-99	Firm: 262, 1,032 firm-year obs. (13 ind. [manuf.]	(log) Total R&D personnel	(log) Gov. Support for R&D (Amount of R&D workers spons. by IWT)	Regress. (FE OLS, 2SLS, IV, SUR, 3SLS)	R.G. (IWT in Flanders)	A	No	S-t/L-t (1-year lag)	L	No	Substitution in the S-t and L-t. [When ignoring fixed firm effects, about 60% of the public. finan. R&D would serve as a substitute for priv. R&D. Taking into account firm effects, almost comp.substit. prevails]	[0.20; 1.50]

Almus & Czarnitzki (2003)	German. (Eastern Germ.)	1995, 97, 99	Firm: 925 firm-year obs. (12 ind.) [manuf.]	(Private R&D expend./Sales) *100	Participation in Public R&D schemes (dummy var.)	Matching (PS –Prob. NNM)	Diff. Sour. F.G. R.G. EU	A	No	S-t	L	No	Additionality [The causal effect of subsidies is about 4 percentage points on average]	[5.44; 28.11]
Guellec & van Pottelsberghe (2003)	17 OECD countries	1981-96	Country	Business-funded and -performed R&D	Gov. fund. R&D implemented in Business (procurement and grants)	Regress. (3SLS)	F.G.	A	No	S-t/L-t (1 to 4-year lags)	C	No	Additionality in the S-t and L-t (1-2 and 4 year lags) but Substitution for 3-year lag. Inverted-U shape, increasing up to an average subsid. rate of about 10%, and decreasing beyond. Over a level of 20%, addit. publ. money substit. for priv. fund.	[4.78; 37.00]
Hyytinen & Toivanen (2005)	Finland	2002	Firm: 724 SMEs [manuf. serv.]	Private R&D expend.	Interaction term: Fraction of Total Debt and Equity attrib. to diff. Gov. Agenc.* Dep. exter. fin.	Regress. (Tobit ML, OLS, CLAD)	Different sources (All the agencies prov. public SME support)	A	No	S-t	L	Yes (Dep. of external finance) [Moderat or Variable]	Additionality. Gover. funding disproport. helps firms in industries that are dependent on external finance. The innovat. of small firms is constrained by access to extern. finance. Gov. funding is able to alleviate such constraints	[2.86; 16.14]
Janz *et al.* (2003)	German Sweden	1998-2000	Firm: 575 (Germ.) and 474 (Swed.) firm-year obs. [manuf.]	(log) Private innovation expend. per employee	Receipt of public finan. support for innov. Activ. (dummy var.)	Regress. (Tobit ML)	F.G.	A	No	S-t	L	No	N.S. (both countries)	[0.33; 13.89]
Sørensen *et al.* (2003)	Denmark	1974-95	Industry: 6 [manuf.]	Real private R&D expend.	Real Public Costs of Innov. Support (subs.)	Regress. (MG, PMG)	N.G. (Danish Agency for Trade and Industry)	A	No	L-t (long-run equilib. relat.)	L	No	Additionality [estimated elasticity: 0.062]	[0.22; 1.33]
Aerts & Czarnitzki (2004)	Belgium (Fland.)	1998-2000	Firm: 776 observ. [manuf. serv.]	(log) Priv. R&D expend. (log) Priv. R&D exp,./Turn.*100	Prob. of receiv. R&D subsidies (dummy var.)	Matching (PS –Prob. Kernel)	F.G. R.G. EU	A	No	S-t	L	No	Additionality [treatment effects: 2.2-2.8% for R&D intensity. Full and partial crowding-out effects are rejected]	[0.75; 7.38]

Czarnitzki & Hussinger (2004)	German.	1992-2000	Firm: 3,779 firm-year obs. [manuf.]	1) Total Private R&D exp. (Tot. R&D/Sal.*100) 2) Net am. of R&D subs. (Net am. of R&D/ Sales*100)	Prob. of receiv. subsidies (dummy var.)	Matching (PS, Probit, NN)	F.G.	A	No	S-t	L	No	Additionality [treatment effects: 1) 1.15 (1.89); 2) 0.90 (0.97)]	[4.00; 8.00]
Duguet (2004)	France	1985-97	Firm: 1,032-1,672 [manuf. serv.]	Maint. or incr. the priv. R&D to sales (dum. var.); Growth rate R&D to sal.	Probab. of receiv. a subsidy (grants) (dummy var.)	Matching (PS –Logit, Kernel)	F.G. (Ministries: Defense, Industry and Research)	A	Yes	S-t (yearly estimat.)	L	No	Additionality [On average, public funds add to private funds, so that there would be no significant crowding-out effect. Substitution effect in 1987]	[1.88; 16.88]
Falk (2004)	Austria	1995-2002	Firm: 1,064 [manuf. serv.]	(log) The average annual growth rate of R&D-personnel	(log) R&D-subs. ratio (i.e. FFF-subsid. share in total R&D-exp.)	Regress. (FE, Partial Adjust.)	F.G. (Austrian Fed. R&D-sup. schem-FFF)	A	No	S-t/L-t (1-year lag)	L	No	Additionality in the S-t and L-t (1-year lag) [estimated elasticity: 0.02 in the S-t and 0.06 in the L-t]	[0.00; 1.75]
Kaiser (2004)	Denmark	2001	Firms: 1,101 [manuf. serv.]	Private R&D expend./Sales	Prob. of receiv. public R&D sup. (dummy var.)	Regr. (Prob. OLS IV) Matching (PS –Prob. NNM Kern. Stratif.)	F.G. (Ministry of Econ. and Business Affairs)	A	No	S-t	L	No	N.S.	[1.13; 4.88]
Streicher *et al.* (2004)	Austria	1997-2002	Firm: 495; 2,194 firm-year observ.	Total Private R&D expend.	Public subsidies (FFF funding)	Regress. (FE GLS)	F.G. (Austrian Industrial Res. Prom. Fund -FFF)	A	No	S-t	L	No	Additionality [the funding coefficient is about 1.26-1.54]	[0.38; 2.25]
Ali-Yrkkö (2005)	Finland	1996-02	Firm: 441; 1,640 firm-year obs. (Techn. Ind.)	Private funded R&D	Public R&D subsid. granted (amount of public funding)	Regress. (OLS IV)	F.G. (Finnish Tech. Agency TEKES)	A	No	S-t/L-t (1-year lag)	L	Yes (L-t debt) [Mod. Var.]	Additionality in the S-t and L-t. Public R&D funding increases firms' total R&D expend. even in non-financially constrained firms	[0.00; 4.57]
Ebersberger (2005)	Finland	1994-96 1998-2000	Firm: 2,462 firm-year observ. [manuf. serv.]	1) Total priv. innov. exp./Sal. 2) Total priv. innov. expend.	Prob. of receiv. public funding (dummy var.)	1) Matching (PS –Prob. Kernel NNM) 2) Selection	F.G. (National Technology Agency-TEKES)	A	No	S-t	L	No	Additionality. Total (complete) or partial crowding-out effects are excluded [The impact varies between 6% and 25% of the total innovation expend.]	[0.43; 2.29]

González *et al*. (2005)	Spain	1990-99	Firm: 2,214 [manuf.]	(log) Total R&D expend./Sales	Total amount of public subsidies (grants)/Total R&D expend.	Regress. (Tobit ML)	N.G. (CDTI) R.G. EU	A	No	S-t	L	No	Additionality [The actual subsidies play a part, even if a modest one. This impact grows with the size of the subs.,but the increase in priv. effort for subs. running from 20% to 60% is by about 2% to 7%]	[4.14; 20.00]
Koga (2005)	Japan	1995-98	Firm: 223, 642 firm-year obs. (6 ind.) [manuf.]	(log) Corporate R&D expend.	Prob. of receiv. R&D subsidies (SRDCT) (dummy var.)	Regress. (FE OLS IV)	F.G.	A	No	S-t/L-t (1-year lag)	L	No	Additionality in the S-t and L-t (1-year lag), particularly in mature firms	[0.57; 2.86]
Lööf & Heshmati (2005)	Sweden	1998-2000	Firm: 770 [manuf. serv.]	R&D expend. per employee	Prob. of receiv. public R&D subs. (grants) (dummy var.)	Matching (PS –Prob. NNM Kernel)	F.G.	A	No	S-t	L	No	Additionality among small sized firms. N.S. for medium and large sized firms	[0.14; 4.00]
Wu (2005)	USA	1979-95	State: 13	Total per capita Comp. expend. for ind. R&D (in a state)	Per capita Federal R&D subsid. to indust. by state	Regress. (FE OLS)	F.G.	A	No	S-t	L	No	N.S.	[0.71; 3.71]
Aerts & Czarnitzki (2006)	Belgium (Fland.)	1998-2000	Firm: 776 observ. [manuf. serv.]	(log) Private R&D expend. Private R&D expend./Turn. *100	1) Prob. receiv. R&D subsidies (dummy var.) 2) Amount of publ. R&D fund.	Matching (PS –Prob. NNM) Regress. (IV)	R.G. (IWT in Flanders)	A	No	S-t	L	No	1) Additionality [Subsidized firms spend between 50% and 100% more on R&D] 2) Additionality. Full and partial crowding-out effects are rejected [treatment effect: 0.85-1.34%]	[0.67; 2.83]
Czarnitzki & Licht (2006)	German.	1994, 96, 98, 2000	Firm: 6,462 obs. [manuf.]	(log) Tot. priv. R&D exp.; (log) Inn. expend. Tot. R&D exp./ Sal*100; Inn. Exp./ Sal*100	Prob. of receiv. public R&D subsidies (dummy var.)	Matching (PS –Prob. NNM)	F.G. R.G. EU	A	No	S-t	L	No	Additionality: Both R&D intens. and innov. intens. are considered higher if firms receive public R&D grants. [The treatment effects are more pronounced in the East than in the West]	[3.83; 16.67]
Herrera & Heijs (2006)	Spain	1998-2000	Firm: 681 [manuf.]	Private R&D exp../Sales*100	Prob. of receiv. public R&D sub. (grants)	Matching (PS –Log. NNM)	N.G. R.G. EU	A	No	S-t	L	No	Additionality [treatment effect: 1.85%]	[0.17; 5.17]

Zhu *et al.* (2006)	China (Shang)	1993-2002	Industry: 32 [manuf.]	Private industr. R&D expend.	Gov. direct fundings (grants)	Regress. (First diff. GMM)	F.G.	A [AR and D]	No	S-t/L-t (1-year lag)	C	No	Additionality in the S-t and L-t: inverted U-shaped relationship between Gov. funding and R&D investment	[0.83; 2.00]
Clausen (2007)	Norway	1999-2001	Firm: 1,074	(log) Am. priv. intern R&D exp. (log) Res. exp. Dev. exp.	(log) 'Far from', 'Close to' the market subsidies	Regress. (2SLS IV)	Diff. Sourc. (SND, NRC, Ministries, FUNN, EU)	A S [AR; D]	No	S-t	L	No	Additionality: 'Far from the market' and Priv. R&D exp. and 'Research expend.' [estimated elasticities: 0.36 and 1.34] Substitution: 'Close to the market' and Priv. R&D exp. and 'Develop. expend.' [estimated elasticities: -0.66 and -0.67]	[0.40; 4.20]
Czarnitzki *et al.* (2007)	German. Finland	1996, 2000	Firm: 1,043 (Ger.) 1,459 (Fin.) [manuf. serv.]	Priv. R&D expend./Sales*100	Public funding (dummy var.)	Matching (PS –Prob. NNM)	F.G. Projektträg (Ger.) Tekes (Fin.)	A	No	S-t	L	No	N.S. in German firms Additionality in Finnish firms	[3.00; 14.60]
Czarnitzki & Toole (2007)	German.	1998-2000 P.C.S.	Firm: 702, 925 obs. [manuf.]	(log) Priv. R&D expend. (log) Priv. R&D expend./Sales	Public R&D subsidy awards	Regress. (Tob.)	Diff. Sourc. (F.G. R.G. EU)	A	No	S-t	L	No	Additionality [the marginal increase in R&D from receiving a subsidy is 39%]	[0.60; 4.80]
Görg & Strobl (2007)	Rep. of Ireland	1998-2002	Plant: 828-4,192 obs. Dom. Foreign [manuf.]	(log) Priv. R&D expend. (log) Priv. exp. per employ.	(log) value of Public R&D subs. (grants): Small-Med-Lar.	Matching (PS –Prob.) Regr. (DID)	F.G. (IDA Ireland, Forbairt)	A	No	S-t	C	No	Mixed: Additionality for domestic and small grants, Substitution for domestic and too large grants, N.S. for foreign. Inverted U-shaped relat. for domestic	[2.80; 13.00]
Aerts & Schmidt (2008)	German. Belgium (Fland.)	1998-2000, 2002-04	Firm: 3,902 (Ger) 1,471 (Flem); 4,565 obs. (Ger.) 1,665 (Flem) [manuf. serv.]	(log) R&D exp. (log) R&D exp./ Sales*100	Prob. of receiv. public R&D subs. (grants)	Matching (PS –Prob. NNM) Regress. (CDiDRCS)	F.G. R.G. EU	A	No	S-t	L	No	Additionality [R&D intensity of Ger. (Flem.) funded firms is 76% to 100% (64% to 91%) higher than R&D intensity of non-funded firms]	[1.50; 14.50]

Aerts & Thorwarth (2008)	Belgium (Fland.)	2002-04 2004-06	Firm: 521 obs.	Private R&D exp. Research. exp. Developm. exp.	Prob. of receiv. public R&D subs. (grants); Amount public subsid. receiv.	Selection (Prob.) Regress. (IV)	F.G. R.G. EU (IWT)	A S [R; D]	No	S-t	L	No	Additionality for R&D effort [A subsidy of 1 Mill. EUR increases the average R&D expenditure with 1.644 million EUR] Additionality for Develop. expend. and Substitution for Research expend.	[0.00; 0.25]
Bloch & Graversen (2008)	Denmark	1998-2005	Firm: 1,369 obs. [manuf. serv.]	Private R&D exp.	Prob. of receiv. public R&D Amount public subsd. receiv.	Selection (Heckman) Regress. (OLS, Boot, IV)	F.G. (Diff. Sources) E.U.	A	Yes	S-t	L	No	Additionality [A 1% increase in public funding yields 0.08-0.11% increase in private R&D]	[0.00; 0.50]
González & Pazó (2008)	Spain	1990-99	Firm: 2,214, 9,455 obs. [manuf.]	(Lagged) Priv. R&D exp./Sales Total R&D exp./Sales	Prob. of receiv. public financing (dummy var.)	Matching (PS –Prob. Bias-cor. NNM)	Diff. Sources. (N.G. R.G. EU)	A	No	S-t	L	No	Additionality [0.72 for total effort. Slighly higher effect in small and medium-sized and in high-tech firms] [0.35 for Private effort. Signif. effect in small and low-tech firms]	[5.50; 22.00]
Hussinger (2008)	German.	1992-2000	Firm: 3,744 observ. [manuf.]	Private R&D expend. per employee	Prob. of receiv. public R&D funding (dum. var.) (log) Am. of past publ. R&D fund.	Selection (Probit PS Heckman Cosslett Newey Robinson)	F.G. (BMBF)	A	Yes	S-t	C	No	Additionality. U-shaped relationship. The effect of past subsidies is negative up to some threshold level, above which it has a positive effect	[1.50; 22.75]
Özçelik & Taymaz (2008)	Turkey	1993-2001	Establish: 20,036, 98,366 obs. [manuf.]	Total R&D expend./Output Private R&D expend./Output	R&D Loan-recipient, R&D Grant recipient (dum. var.) R&D subs./Outp.	Regress. (Tob. FE RE IV GMM DID) Matching (PS –Log. NNM DID)	F.G. (TTGV TIDEB)	A	No	S-t	L	No	Additionality in Regress. and Matching [Matching Method: All observations –supported firms increase their R&D intensity by 2.56% points and own R&D intensity by 1.95%. Only R&D performers –support-recipients increase their R&D intensity by 1.14% points and own R&D intensity by 0.78 points]	[1.75; 5.00]
Wolff & Reinthaler (2008)	15 OECD countries	1981-2002	Country: 216-255 obs.	(log) Number of researchers (log) Total R&D expend.	(log) Subsidy rate=Gov. Subs./Own finan. (grants, procur.)	Regress. (IV LSDV LSDVC)	F.G.	A	No	S-t/L-t (1-year lag)	L	No	Additionality in the S-t and L-t [The elasticity is roughly 20% larger for expenditure than for employment. The short-term impact is much weaker than the long-run effect of subsidies]	[0.00; 5.50]

Aschhoff (2009)	German.	1994-2005	Firm: 3,583, 8,528 firm-year obs. [manuf. serv.]	(log) Total R&D exp. (/Sal.*100) (log) Priv. R&D exp. (/Sal.*100)	Prob. of receiv. public R&D subsid. (grants)	Matching (PS –Prob. Multinom. Prob. NNM)	F.G. (DPF Scheme)	A	Yes	S-t	L	No	Additionality [Frequently given grants as well as medium and large-sized grants are suitable to increase private R&D expend.]	[0.33; 3.00]
Bérubé & Mohnen (2009)	Canada	2005	Establish: 2,785 obs. [manuf.]	1) Nature of innovations 2) Number of new or significant. Improved products 3) Economic success of the newly introduced products	Prob. of receiv. public funding (grants) (dummy var.)	Matching (PS –Prob. NNM)	F.G.	A	No	S-t	L	No	Additionality [Firms that receive grants and tax credits instead of only tax credit are more innovative]	[0.00; 10.67]
Herrera & Martínez (2009)	Spain	1995-99	Industry: 12 [manuf.]	Priv. R&D exp. Priv. R&D expend./Sales	Public R&D funding	Regress. (not specified)	Diff. Sourc. (not specif.)	A	No	S-t	L	No	Additionality for priv. R&D expend. [1 add. € of funding induces firms to contribute an add. 44 cents of their own money] N.S. for R&D intensity	[0.00; 0.00]
Czarnitzki *et al.* (2011)	Belgium (Fland.)	1999-2007	Firm: 952 firms, 3,686 year obs. [manuf. serv.]	Priv. R&D exp. per tang. ass. Research exp. Developm. exp.	Gov. Funding (dum. var.)	Regress. (Tobit; RE, Wooldridge)	F.G.	S [R; D]	No	S-t/L-t (1-year lag)	L	Yes (Working Cap.) [Mod. Var.]	Additionality for 'Research' and N.S. for 'Development'. Public subsidies directed at 'Research' indeed alleviate financial constraints	[0.00; 12.67]

(1) This column shows information on the major public agencies providing support for private R&D: F.G. (Federal Government), N.G. (National Government), R.G. (Regional Government). **(2)** This column shows how the effect of private R&D spending is explored, i.e., aggregately (A) or separately (S). In this latter case, we also distinguish between Research (R), Basic Research (BR) or Applied Research (AR) and Development (D). **(3)** This column indicates whether the study provides information on a firm's subsidy history. **(4)** This column shows whether the study considers short-term (S-t) and/or long-term (L-t) effects. **(5)** This column shows whether the shape of the subsidy effect is assumed to be Linear (L) or Curvilinear (C). **(6)** This column shows whether the study explores the effect of financial constraints (Yes or No), as well as the specific moderator variable involved in the empirical analysis. (7) This column displays the number of citations of each study weighted by the number of years since publication. The first figure in the bracket uses the ISI Web of Knowledge, while the second one uses Google Scholar.

Table 2. Summary distribution of econometric studies of the effect of R&D subsidies on private R&D spending according to the aggregation level and data source

Aggregation level	**'crowding-in hypothesis'**	**'crowding-out hypothesis'**	**Non-significant effects**	**Total number of studies**
Firm or lower(*)	*48* *(63.15%)*	*15* *(19.74%)*	*13* *(17.11%)*	*76*(**) *(64.41%)*
Based only on US data	10	8	4	22
Based only on EU	33	6	7	46
Based on R. of the W. data	5	1	2	8
Industry	*10* *(50%)*	*5* *(25%)*	*5* *(25%)*	*20* *(16.95%)*
Based only on US data	4	3	2	9
Based only on EU data	4	1	1	6
Based on R. of the W. data	2	1	2	5
Country	*13* *(59.09%)*	*3* *(13.63%)*	*6* *(27.28%)*	*22* *(18.64%)*
Based only on US data	6	0	2	8
Based only on EU data	2	1	2	5
Based on R. of the W. data	5	2	2	9
Total number of studies	71 *(60.17%)*	23 *(19.49%)*	24 *(20.34%)*	118(**)

(*) Lower refers to studies performed at business unit- and plant-level or below.

(**) The total number of studies finding crowding-in, crowding-out or non-significant effects is 118. This number is greater than the number of reviewed studies (77) because there are several studies that find divergent results depending on the different assumptions and/or methods considered. Moreover, in most studies performed at country-level it is possible to confirm the crowding-in hypothesis in the case of some countries, but also the crowding-out hypothesis in the case of other countries, or even non-significant effects in some countries.

[1] There are several public policy instruments to boost R&D. The most important ones are direct subsidies (i.e., grants, loans or procurements), fiscal incentives (i.e., tax credits), public research performed in public institutions, and R&D consortia (David *et al*., 2000; Hall and van Reenen, 2000; Guellec and van Pottelsberghe, 2003). Nevertheless, our main concern in this study is public R&D subsidies.

[2] Qualitative and quantitative research studies are used in analysing the relationship between public and private R&D investment. We will focus our review on quantitative studies to facilitate the comparability of findings across different studies.

[3] This finding is in line with David *et al.* (2000), who reviewed 33 empirical studies, finding 11 studies reporting 'net' substitution.

[4] A detailed discussion of this critical issue can be found in David *et al*. (2000, pp.509-510), Klette *et al.* (2000, pp.479-481) or, most recently, Cerulli (2010).

[5] For a review of these econometric approaches, see, for example, Özçelik and Taymaz (2008) or Cerulli (2010).

[6] This approach combines the advantages of matching and difference-in-differences estimators and eliminates some of their respective disadvantages.

[7] In some way, this idea is reflected in several governmental programmes, such as the SEMATECH and SBIR programmes performed in the US (see, for example, Irwin and Klenow, 1996; Lerner, 1999; and Wallsten, 2000), the Japanese research consortia (see, for example, Branstetter and Sakakibara, 1998), or the IT programme supported in Norwegian high-tech firms (see, for example, Klette and Møen, 1999).

[8] More specifically, this author finds a stimulating (i.e., additional) and significant effect of subsidies on private R&D only for the firms that are frequent recipients of subsidies from the so-called Direct R&D Project Funding - a scheme used by the German Federal Government to fund R&D in firms.

[9] Specifically, they find "an effect of 19 cents induced in private industry R&D expenditures per dollar of federal outlay for R&D carried out outside industry after a three year lag" (1986, p.554).

[10] Drawing on a sample of 25 firms belonging to four leading American industries, the authors find that "For each dollar increase in federal support, these four industries, taken as a whole, would have increased their own support of energy R&D by 6 cents in each of the first two years after the increase in federal funds" (1984, p.564).

[11] The limited internal liquidity of firms may also be affected by the firms' debt payment obligations. The higher the firms' obligations in relation to the availability of internal funds, the less liquidity remains for activities that must be internally funded, like R&D. Consequently, high leverage (debt) levels may put pressure on the firm to use its internal funds to pay the debt interests at the expense of investing in R&D (Czarnitzki *et al.*, 2011; Hall, 1992; Long and Ravenscraft, 1993).

[12] However, Holden and Swales (1996), considering a more flexible formulation of financial constraints than Wren (1994), suggest that financial constraints may restrict leverage and thereby limit the effectiveness of public subsidies.

[13] Yet, it is also interesting to recognise that this author concludes that the additionality effect of public funding is even larger in large firms (that are classified as non-financially constrained) than in small firms.

[14] Savignac (2008) corroborates that the likelihood of financial constraints decreases with firm size and depends to a large extent on the firms' ex-ante capital structure. Egeln *et al.* (1997) and Petersen and Rajan (1994, 1995) provide empirical evidence for financial constraints in start-up firms.

[15] Whereas *Research* is primarily related to technical or scientific advancement, *Development* has to do with the translation of such advancements into particular products and/or process innovations. Therefore, Research activities will usually precede Development activities. Some national organisations foster an even finer breakdown: *Basic Research*, *Applied Research* and *Development*. *Basic Research* represents original investigation for the advancement of scientific knowledge that "does not have a specific immediate commercial objective although it may be performed in fields of present or potential commercial interest". *Applied Research* represents investigation to discover new scientific knowledge that "has a specific commercial objective with respect to products, processes or services". *Development* is the technical use of the scientific knowledge gained from Research "directed to the production of useful materials, devices, systems, or methods, including the design and development of prototypes and processes" (see, for example, National Science Board, 2008, Chapter 4, p.9). On the other hand, the existing literature also uses the concepts 'projects far from the market' for referring to Research projects and 'projects close to the market' for referring to Development projects (e.g., Clausen, 2007). Thus, such concepts may be used interchangeably.

[16] He warns that these findings should be interpreted cautiously because his study is based on survey responses for only one year and, thus, is likely to be biased by the subjective views of the respondents. Furthermore, neither Higgins and Link (1981) nor Link (1982) control for potential endogeneity problems between public and private R&D spending.

[17] There may be, nonetheless, some outstanding differences between the R&D programmes at the EU level and R&D programmes at the national and regional levels. Whereas EU programmes usually require firms to cooperate with other firms and/or institutions from several EU countries, national and regional programmes do not, although it might be encouraged.

[18] See, in Table 1, the studies by Almus and Czarnitzki, 2003; Aerts and Czarnitzki, 2004; Aerts and Schmidt, 2008; Aerts and Thorwarth, 2008; Busom, 2000; Czarnitzki and Licht, 2006; Czarnitzki and Toole, 2007; González *et al.*, 2005; González and Pazó, 2008; Herrera and Heijs, 2006; Herrera and Martínez, 2009; Hyytinen and Toivanen, 2005; Klette and Møen, 1998; or Meeusen and Janssens, 2001.

[19] This latter study is, in fact, more focused on the participation stage than on the effects that can be obtained from different programmes.

[20] Clausen (2007) merges policy support from the NRC, EU and SkatteFUNN's programmes into one type of subsidy called 'far from the market'. On the other hand, he merges the SND and Ministries' R&D programmes into another type of subsidy called 'close to the market'.

[21] We are grateful to one of the referees for this list of issues.

[22] Goolsbee (1998) argues that the conventional literature ignores the fact that most private R&D spending corresponds to salary payments for R&D personnel. Consequently, he finds that firms use an important fraction of public subsidies of private R&D to increase wages of existing R&D personnel rather than increasing R&D activity. This finding leads him to suggest that the conventional literature may be overstating the effects of government R&D spending by as much as 30-50 percent. He also finds that government R&D spending may directly crowd out private inventive activities because the correlation between the ratio of federally funded R&D to GDP and the ratio of non-federally funded R&D to GDP is -0.4. On the other hand, Guellec and Pottelsberghe (2003) find that direct government funding (via subsidies, for instance) and R&D tax incentives are substitutes. This means that increased intensity of one reduces the effect of the other on private R&D investment. However, Bérubé and Mohnen (2009) find an opposite result by which Canadian firms that received both R&D grants and R&D tax credits are significantly more innovative than those that received only R&D tax incentives. Finally, Guellec and Pottelsberghe (2003) also find that direct funding (and tax incentives) is more effective when it is stable over time. This implies that firms will not invest in additional R&D if they are not certain that the policy will be kept in the future.