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ASSESSING THE EFFECT OF PUBLIC SUBSIDIES ON FIRM R&D INVESTMENT : A SURVEY

José Ángel Zúñiga-Vicente
Universidad Rey Juan Carlos

César Alonso-Borrego
Universidad Carlos III de Madrid

Francisco J. Forcadell
Universidad Rey Juan Carlos

José I. Galán
Universidad de Salamanca

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. Innovation; Public subsidies; R&D investment

I. 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, Capron and Van Pottelsberghe, 1997; David *et al.*, 2000; García-Quevedo, 2004; Aerts and Schmidt, 2008; 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.

2. 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. In addition, 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.

We can summarise the results from Table 1 as follows. First, most of the relevant empirical studies 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 countervailing 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. Levy and Terleckyj, 1983; David *et al.*, 2000; Ali-Yrk o, 2005), 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 % 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

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

Table 1. Empirical Studies Analysing 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 ^a	R&D ^b	Subsidy history ^c	Time lag ^d	Shape of the effect ^e	Finance: Main findings	Citations ^g	
Hamburg (1966)	USA	1960	Firm: 405 (8 ind.) [manuf.]	Private R&D	Gov. Contracts/ Assets	Regress. (Weigh. OLS)	FG.	A	No	S-1	L	No	Mixed: Additivity and N.S.	[0.98; 2.28]
Gidderman (1973)	Canada	1965-69	Industry: 15 [manuf.]	Private R&D	Gov. R&D/Sales	Regress. (OLS)	FG.	A	No	S-1	L	No	Additivity	[0.46; 1.26]
Buxton (1975)	UK	1965	Industry: 11 [manuf.]	Private R&D	Gov. R&D/Gross output	Regress. (OLS)	FG.	A	No	S-1	L	No	Additivity	[0.11; 0.51]
Howe and McFarbridge (1976)	Canada	1967-71	Firm: 81; 236 firm-year obs. [manuf.]	Private R&D	Gov. R&D grants	Regress. (Weigh. OLS)	FG.	A	No	S-1	L	No	Mixed: Additivity and N.S.	[0.86; 2.64]
Rosenberg (1976)	USA	1963-64	Firm: 100 [manuf.]	%Total R&D	Gov. R&D subsidies	Regress. (OLS)	FG.	A	No	S-1	L	No	Additivity	[0.42; 1.58]
Shirees (1978)	USA	1965	Firm: 411 [manuf.]	(log) Private R&D	% R&D financ. by the Gov.	Regress. (OLS)	FG.	A	No	S-1	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)	FG.	A	No	S-1/L-1 (one-year lag)	L	No	Substitution and additivity in the case of one-year lag. Additivity 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)	FG.	A	No	S-1	L	No	Substitution	[0.45; 1.58]
Higgins and Link (1981)	USA	1977	Firm: 174 [manuf.]	% of Research in private R&D	Gov. R&D expend.	Regress. (OLS)	FG.	S [R]	No	S-1	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)	FG.	A S [BRC AR; D]	No	S-1	L	No	Additivity for aggregate R&D. 'Development'; N.S. for Applied Research'; Substitution for 'Basic Research'	[1.00; 3.33]

Table 1. Continued.

Author(s)	Country	Period	Unit of analysis	Dependent variable	Independent variable	Method	Source of funding ^a	R&D ^b	Subsidy history ^c	Time lag ^d	Shape of the effect ^e	Finance constraint ^f	Main findings	Citations ^g
Levy and 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)	FG.	A	No	S-t/L-t (three-year lag)	L	No	Additionality for Total Gov. Expend. and Gov. contract R&D (three-year lag) [51 of Gov. contract performed in industry induced about 0.275 of private expenditure]	[14]; 4,55]
Gannicott (1984)	Australia	1976-77 and 1978-79	Industry: 13 [manuf.]	Private R&D expend.	Gov. grants	Regress. (2SLS)	FG.	A	No	S-t	L	No	N.S.	[0.14; 0.54]
Levin and Reiss (1984)	USA	1963, 67 and 72	Industry: 20 [manuf.]	Private R&D/production costs	Gov. R&D/shipments	Regress. (2SLS)	FG.	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) Firm: 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)	FG.	A	No	S-t/L-t (one and two-year lags)	L	No	(1) Mixed for R&D expenditure; N.S. in the S-t. Additionality for one-year lag. Substitution for two-year lag. Substitution for R&D employ. in the S-t. Additionality for two year-lag (2) Additionality Substitution	[1.75; 5.82]
Mansfield and Switzer (1984)	USA	1979	Firms: 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)	FG.	A	No	S-t/L-t (one-three year-lags)	L	No	Additionality one-three 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 two years after the increase in federal funds]	[0.64; 1.68]

Table 1. *Continued.*

Author(s)	Country	Period	Unit of analysis	Dependent variable	Independent variable	Method	Source of funding ^a	R&D ^b	Subsidy history ^c	Time lag ^d	Shape of the effect ^e	Finance const ^f	Main findings	Cautions ^g
Scott (1984)	USA	1974	Firm: 437 and 3388 Line of Bus.	Comp-financed R&D Sales and (log) Gov.-financed R&D	Gov.-financed R&D Sales; and (log) Gov.-financed R&D	Regress. (FE)	F.G.	A	No	S-1	L	No	Additionality [The relation is far less significant when the intensity variables are removed from the analysis]	[0.07; 8.64]
Terleckij (1985)	USA	1964-84	Country [manuf.]	Private Industry R&D expend.	Gov. contract R&D	Regress. (OLS)	F.G.	A	No	S-1	L	No	Additionality	[0.11; 0.22]
Leitnerberg (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-1/L-1 (one-year lag) 2) S-1	L	No	(1) Additionality in the Restric. Model [Add. for one-year lag] and N.S. in the Unrest. 9 (2) Additionality in the Restric. and N.S. in the	[1.28; 5.52]
Leitnerberg (1988)	USA	1979-84	Firm: 169 [manuf.]	Company-funded R&D expend.	Gov. R&D contr. (compet. non-compet.)	Regress. (Weigh. OLS, IV)	F.G.	A	No	S-1	L	No	Unrestric. Model Mixed: Additionality in the case of Weighted OLS and Substitution in the case of IV	[2.08; 7.33]
Holmans and Steuwer-gen (1988)	Belgium	1980-84	Firm: 236 firm-year obs. (4 ind.)	(log) Private R&D expend.	(log) Gov. R&D grants	Regress. (FE OLS)	F.G.	A	No	S-1	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.-fin. R&D; and (log) Gov. R&D/total R&D	Regress. (OLS)	F.G.	A	No	S-1	L	No	Additionality [estimated elasticity: 0.31-0.37]	[1.35; 4.30]
Legden <i>et al.</i> (1989)	USA	1987	Laboratory: 120, 120 firm [manuf.]	Laboratory's R&D Budget	Laboratory's Gov.-financed R&D budget	Regress. (3SLS, 2SLS, OLS)	F.G.	A	No	S-1	L	No	N.S. with 3SLS but Additionality with OLS	[0.26; 0.70]

Author(s)	Country	Period	Unit of analysis	Dependent variable	Independent variable	Method	Source of funding ^a	R&D ^b	Subsidy history ^c	Time lag ^d	Shape of the effect ^e	Finance const. ^f	Main findings	Citations ^g
Levy (1990)	9 OECD countries	1963-84	Country	Private R&D expend	Gov. contract R&D	Regress (FGLS and Box-Cox P)	F.G.	A	No	S-1	L	No	Mixed: Additionality (the United States, Japan, Germany, Sweden, France) Substitution (the UK and the Netherlands) and N.S. (Italy, Switzerland)	[0.41; 2.55]
Leyden and Link (1991)	USA	1987	Laboratory: 137 [manuf]	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-1	L	No	Additionality [a \$10 million exogenous increase in Govt. 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-1	L	No	Additionality for 'Basic Research'	[0.47; 2.47]
Mannurens and Nadiri (1996)	USA	1966-88	Industry: 15 [manuf]	(log) Company-financed R&D	(log) Total Publi. R&D; [(log) Inside publ. R&D; (log) Outside publ. R&D]	Regress (OLS)	F.G.	A	No	S-1	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]
Capoen and van Peltshoeghe (1997)	7 industrial 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-1/L-1 (one-year lag)	L	No	Mixed: Additionality (the UK), Substitution (Canada, France, Italy) and N.S. (the US, Japan, Germany)	[0.33; 2.87]

Author(s)	Country	Period	Unit of analysis	Dependent variable	Independent variable	Method	Source of funding ^a	R&D ^b history ^c	Subsidy history ^e	Time lag ^d	Shape of the effect ^e	Finance constr. ^f	Main findings	Citations ^g
Goodspeed (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	FG	A	No	S-4/L1	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-1]	[3.53; 15.57]
Klette and Moen (1998)	Norway	1982-95	Business Units: 192 (697 obs.) [manuf.]	Total R&D investments	Total Gov. R&D subsidies	Regress (FE, First DIF, OLS)	(1) F.G. (2) Councils Ind. funds, Ministr.	A	No	S-4/L-1 (two-year lag)	L	No	(1) In the S-4, there is no crowding out and additionally: Additionally for two-year lag (2) There are no clear cut differ. between the effects of sub award, by each agency	[0.64; 3.93]
Toivanen and Niiranen (1998)	Finland	1989, 1991, 1993	Firm: 133 [manuf.]	Private R&D expenditure	Gov.-financed R&D (loans and subsidies)	Regress. (First DIF, IV)	FG	A	No	S-1/L-1 (one-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 Turzeman and Martin (1998)	22 OECD countries	1969-95	Country	Change in Private R&D	Change in Public R&D	Regress. (FE)	FG	A	No	S-4 (lag)	L	No	Mixed: Additionality in 5 countries; Substitution in 2 countries and N.S. in the remaining countries.	[0.00; 1.64]
Benzen and 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.	FG	A	No	S-4/L-1	L	No	Mixed: Additionality in S-4 and L-1 in Denmark, Finland, Iceland, N.S. in S-4 and L-1 in Norway, Sweden	[0.00; 0.00]

Table 1. Continued

Author(s)	Country	Period	Unit of analysis	Dependent variable	Independent variable	Method	Source of funding ^a	R&D ^b	Subsidy history ^c	Time lag ^d	Shape of the effect ^e	Frame ^f	Main findings	Citations ^g
Brouwer and Kleinknecht (1999)	The Netherl.	1988, 1992	Firm: 144 [manuf. serv.]	Change of the (log of) absol. numb. of R&D person-years	Firm's partic. in EC R&D progr. in 1991-1992 (dummy var.)	Regress. (OLS)	European Union	A	No	S4	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 DIF. OLS)	E.G.	S [BR]	No	S4	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]
Diamond (1999)	USA	1953-95	Country	(log) Level of Private Basic Research spending	(log) Level of Federal Basic Research spending	Regress. (First DIF. OLS)	E.G.	S [BR]	No	S4	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]
Buson (2000)	Spain	1988	Firm: 147 [manuf.]	Total R&D Expend. per Emp ¹ , R&D Person/Emp ¹	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	S4	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. (SLS, IV)	F.G. (SBIR program)	A	No	S4	L	No	Substitution. The SBIR grants crowd out private R&D spending dollar for dollar	[8;08; 3;117]

Table 1. *Continued.*

Author(s)	Country	Period	Unit of analysis	Dependent variable	Independent variable	Method	Source of funding ^a	R&D ^b	Subsidy history ^c	Time lag ^d	Shape of the effect ^e	Finance const. ^f	Main findings	Citations ^g
Messens and Janssens (2001)	Belgium (Fland.)	1992-97	Firm: 345; 685 firm-year obs.	Total am. intra-muros ^h R&D expend./Turn.	Subsidy granted by IWT/Turnover	Regress. (ARI NLS)	R.G. (IWT) EU	A	No	S-1/-1 (one-year lag)	L	No	Additionally for all firms (estimated elasticity: 0.32-0.66) and for sub-samples of small- and medium-sized firms	[0.00; 1.27]
Calliejon and Garcia-Quevedo (2002)	Spain	1989-98	Industry: 24, 168-240 obs. [manuf.]	(log) Private R&D expend. [manuf.]	(log) Public R&D spending	Regress. (First Diff., GMM)	N.G.	A	No	S-1/-1 (one-year two-year lags)	L	No	Additionally: in the S-1 and for one-year lag	[0.10; 0.60]
Czarnitzki and Fier (2002)	German.	1996, 1998	Firm: 1084 obs. [serv.]	Innovation expend./Sales	Probab. of receive public grants for innov. (dum. var.)	Matching (PS - Probit, NMM)	F.G.	A	No	S-1 (lags)	L	No	Additionally [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-1/-1 (one- two-year lags)	L	No	Mixed: Additionally in small firms [1 NIS increases their R&D by about 11 NIS] (Subst. in the S-1 and Addit. one year after receiving the subsidy), N.S. in large firms	[5.10; 29.10]
Suens (2002)	Belgium (Fland.)	1992-99	Firm: 262, 1032 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-1/-1 (one-year lag)	L	No	Substitution in the S-1 and L-1 [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. prevail] Additionally [The causal effect of subsidies is about 4 percentage points on average]	[0.20; 1.50]
Albus and Czarnitzki (2003)	German. (Eastern Germ.)	1995-97, 99	Firm: 925 firm-year obs. (12 ind.) [manuf.]	(Private R&D ex-pend./Sales) × 100	Participation in Public R&D schemes (dummy var.)	Matching (PS - Probit, NMM)	Diff. Sour. F.G. R.G. EU	A	No	S-1	L	No	Additionaly [The causal effect of subsidies is about 4 percentage points on average]	[5.44; 28.11]

Table 1. Continued.

Author(s)	Country	Period	Unit of analysis	Dependent variable	Independent variable	Method	Source of funding ^a	R&D ^b	Subsidy history ^c	Time lag ^d	Shape of the effect ^e	Finance constr. ^f	Main findings	Citations ^g
Guillec and van Pet- telsberghe (2003)	17 OECD countries	1981-96	Country	Business-funded R&D and -performed R&D	Gov. fund R&D implemented in Business (procurement and grants)	Regress. (3SLS)	E.G.	A	No	S-L-L-1 (one- four-year lags)	C	No	Additionally in the S-4 and L-1 (one-two and four year lags) but Substitution three-year lag. Inverted-U shape, increasing up to an average subsid. rate of about 10%, and decreasing beyond. Over a level of 20%, additl publ. money substit. for priv. fund.	[4,78; 37,00]
Hyvonen and Tokonen (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. exten. fn.	Regress. Tobit ML, OLS, CLAD	Different sources (All the agencies prov. public SME support)	A	No	S-1	L	Yes (Dep. external finance) that are dependant on [Moder- ator innovat. of small firms is constrained by access to exten. finance. Gov. funding is able to alleviate such constraints	[2,86; 16,14]	
Janz <i>et al.</i> (2003)	German and 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)	E.G.	A	No	S-1	L	No	N.S. (both countries)	[0,33; 13,89]
Sørensen <i>et al.</i> (2003)	Denmark	1974-95	Industry: 6 [manuf.]	Real private R&D expend.	Real Public Costs of Innov. Support (dummy var.)	Regress. (MG, PMG)	N.G. (Danish Agency for Trade and Industry)	A	No	L-1 (long-run equilib. rdat.)	L	No	Additionally [estimated elasticity: 0.062]	[0,22; 1,33]
Aerts and Czarnitzki (2004)	Belgium (Fland)	1998-2000	Firm: 776 observ. [manuf. serv.]	(log) Priv. R&D expend. (log) Priv. R&D exp./Turn. × 100	Matchng (RS -Prob. Kened)	Matching (RS -Prob. Kened)	E.G. R.G. EU	A	No	S-1	L	No	Additionally [treatment effects: 2.2-2.8% for R&D intensity. Full and partial crowding-out effects are rejected]	[0,75; 7,38]

Table 1. Continued.

Author(s)	Country	Period	Unit of analysis	Dependent variable	Independent variable	Method	Source of funding ^a	Subsidy R&D ^b history ^c	Subsidy Time lag ^d	Shape of the effect ^e	Finance: const ^f	Main findings	Citations ^g
Zarnitzki and Hussinger (2004)	Germany	1992-2000	Firm: 3779 firm-year 1) obs. [manuf.]	Total Private R&D exp. (Tot R&D/Sal. x 100/2) Net-am of R&D subs. (Net-am. of R&D/Sales x 100)	Prob. of receive subsidies (dummy var.)	Matching (PS, NN)	E.G.	A	No S-1	L	No	Additionally [treatment effects: 1, 1.15 (1.89); 2) 0.90 (0.97)]	[4.00; 8.00]
Duguet (2004)	France	1985-97	Firm: 1032-1672 [manuf. serv.]	Maint. or not the priv. R&D to sales (dum. var.); Growth rate R&D to sal.	Probab. of receive a subsidy (grants) (dummy var.)	Logit/ Kernel	F.G. (Ministries: Defense, Industry and Research)	A	Yes S-1 (yearly estim.)	L	No	Additionally [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: 1064 [manuf. serv.]	(log) The average annual growth rate of R&D-personnel	R&D subs. ratio (i.e. FFF-subsid share in total R&D-exp.)	Regress. (FE, Partial Adjust)	E.G. (Austrian Fed. R&D-sup. schem.-FFF)	A	No S-0/-1 (one-year lag)	L	No	Additionally in the S-4 and L-1 (one-year lag) [estimated elasticity: 0.02 in the S-4 and 0.06 in the L-1]	[0.00; 1.75]
Kaiser (2004)	Denmark	2001	Firms: 1101 [manuf. serv.]	Private R&D expend./Sales	Prob. of receive public R&D sup. (dummy var.)	Regr. (Prob. OLS IV) Matching (PS - Prob. NNM Kern. Stratif)	E.G. (Ministry of Econ. and Business Affairs)	A	No S-1	L	No	N.S.	[1.13; 4.88]
Streicher et al (2004)	Austria	1997-2002	Firm: 495; 2194 firm-year observ.	Total Private R&D expend.	Public subsidies (FFF-regress. (FE, OLS))	Regress. (FE, Partial Adjust)	E.G. (Austrian Industrial Res. Prom. Fund -FFF)	A	No S-1	L	No	Additionally [the funding coefficient is about 1.26-1.54]	[0.38; 2.25]
Ali-Yakko (2005)	Finland	1996-02	Firm: 441; 1640 firm-year obs. (Tech. Ind.)	Private funded R&D	Public R&D subsid. granted (amount of public funding)	Regress. (OLS IV)	E.G. (Finnish Tech. Agency TEKES)	A	No S-0/-1 (one-year lag)	L	Yes (L-1 debt) [Mod. Var.]	Additionally in the S-4 and L-1. Public R&D funding increases firms' total R&D expend. even in non-financially constrained firms	[0.00; 4.57]

Table 1. Continued.

Author(s)	Country	Period	Unit of analysis	Dependent variable	Independent variable	Method	Source of funding ^a	R&D ^b	Subsidy history ^c	Time lag ^d	Shape of the effect ^e	Finance constr. ^f	Main findings	Citations ^g
Ehnbjörger (2005)	Finland	1994-96 1998-2000	Firm: 2462 firm-year observ. [manuf. serv.]	(1) Total priv. innov. exp./Sal. (dummy var.)	Prob. of receiv. public funding (dummy var.)	(1) Matching (PS - Prob. Kernel NNM)	F.G. (National Technology Agency- TEKES)	A	No	S-1	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]
Gonzalez <i>et al.</i> (2005)	Spain	1990-99	Firm: 2214 [manuf.]	(log) Total R&D expend./Sales	Total amount of public subsidies (grams)/Total R&D expend.	Regress. (Tobit ML)	N.G. (CDTI) R.G. EU	A	No	S-1	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-1/-1 (one-year lag)	L	No	Additionality in the S-1 and L-1 (one-year lag), particularly in mature firms	[0:57; 2:86]
Loef and Hestmati (2005)	Sweden	1998-2000	Firm: 770 [manuf., serv.]	R&D expend. per employee	Prob. of receiv. public R&D subs. (grams) (dummy var.)	Matching (PS - Prob. NNM Kernel)	F.G.	A	No	S-1	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 R&D expend. for ind. R&D (in a state)	Per capita Federal R&D (dummy var.)	Regress. (FE OLS)	F.G.	A	No	S-1	L	No	N.S.	[0:71; 3:71]
Arts and 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-1	L	No	(1) Additionality [Subsidized firms spend between 50% and 100% more on R&D]	[0:67; 2:83]

(2) Additionality: Full and partial crowding-out effects are rejected [treatment effect: 0.85-1.34%]

Table 1. *Continued.*

Author(s)	Country	Period	Unit of analysis	Dependent variable	Independent variable	Method	Source of funding ^a	R&D ^b	Subsidy history ^c	Time lag ^d	Shape of the effect ^e	Finance const. ^f	Main findings	Citations ^g
Czarnitzki and Licht (2006)	Germany	1994, 96, 98, 2000	Firm: 6462 obs. [manuf.]	(log) Tot. priv. R&D exp.; (log) firm. expend.; Tot. R&D exp./S&I × 100.	Prob. of receive public R&D subsidies (dummy var.)	Matching (PS - Prob. NNM)	FG; R.G; EU	A	No	S-1	L	No	Additionally: Both R&D inners and inno. inners 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 and Heijs (2006)	Spain	1998-2000	Firm: 681 [manuf.]	Private R&D exp./Sales × 100	Prob. of receive public R&D sub. (grams)	Matching (PS - Log. NNM)	N.G; R.G; EU	A	No	S-1	L	No	Additionally [treatment effect: 1.85%]	[0.17; 5.17]
Zhu <i>et al.</i> (2006)	China (Shang)	1993-2002	Industry: 32 [manuf.]	Private industr. R&D expend.	Gov. direct fundings (grams)	Regress. (First diff. GMM)	FG.	A [AR and D]	No	S+L-1 (one-year lag)	C	No	Additionally: In the S-1 and L-1: inverted U-shaped relationship between Gov. funding and R&D investment	[0.83; 2.00]
Clusen (2007)	Norway	1999-2001	Firm: 1074	(log) Am. priv. intern R&D exp. (log) Res. exp. Dev. exp.	(log) 'Far from', 'Close to' the market subsidies	Regress. (2SLS IV)	Diff. Source. (SND, NRC, Ministers, to' the market FUNN, EU)	A S [AR; D]	No	S-1	L	No	Additionally: '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] N.S. in German firms	[0.40; 4.20]
Czarnitzki <i>et al.</i> (2007)	Germany, Finland	1996, 2000	Firm: 1043 (Ger.) 1459 (Fin.) [manuf. serv.]	Priv. R&D expend./Sales × 100	Public funding (dummy var.)	Matching (PS - Prob. NNM)	FG; Projeckttrag Takes (Fin.)	A	No	S-1	L	No	Additionally: In Finnish firms	[3.00; 14.60]
Czarnitzki and Toole (2007)	Germany	1998-2000	Firm: 702, 925 P.C.S. obs. [manuf.]	(log) Priv. R&D expend. (log) Priv. R&D expend./Sales	Public R&D subsidy awards	Regress. (Tobit)	Diff. Source. (FG; R.G; EU)	A	No	S-1	L	No	Additionally [the marginal increase in R&D from receiving a subsidy is 39%]	[0.60; 4.80]

Table 1. *Continued.*

Author(s)	Country	Period	Unit of analysis	Dependent variable	Independent variable	Method	Source of funding	R&D ^a	Subsidy history ^b	Time lag ^c	Shape of the effect ^d	Finance constr. ^e	Main findings	Citations ^g
Dong and Strobl (2007)	Rep. of Ireland	1998–2002	Plant: 828–4192 obs: Dom. Foreign [manuf.]	Priv. R&D (log) Publ. R&D (log) Priv. exp. per employ. [manuf.]	(log) value of subs. Public R&D (log) value of subs. Small/Med-Lat.	Matching (PS –Prob.) Regr. (DID)	E.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 and Schmidt (2008)	German. Belgium (Fland.)	1998–2000, 2002–04	Firm: 3,902 (Ger) 1,471 (Fland); 4,565 obs. (Ger.) 1,665 (Fland) [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. (CDD/DCS)	F.G. R.G. EU	A	No	S-t	L	No	Additionality (R&D intensity of Ger (Firm.) funded firms is 76% to 100% (64% to 91%) higher than R&D intensity of non-funded firms]	[1,50, 14,50]
Aerts and Thor-waerh (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. (1V)	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	[0,00, 0,25]
Bloch and Graversen (2008)	Denmark	1998–2005	Firm: 1,569 obs. [manuf. serv.]	Private R&D exp.	Prob. of receiv. public R&D subs. (grants); Amount public subsid. receiv.	Selection (Heckman) Regress. (OLS, Boot, IV)	F.G. (Diff Sources) E.U.	A	Yes	S-t	L	No	Research expend. Additionality [A 1% increase in public funding yields 0.08–0.11% increase in private R&D]	[0,00, 0,50]
Gonzalez and Pazo (2008)	Spain	1990–99	Firm: 221,4, 9455 obs. [manuf.]	(Lagged) Priv. R&D exp./Sales Total R&D exp./Sales	Prob. of receiv. public financing (dummy var.)	Matching (PS –Prob. Bias-corr. NNM)	Diff Sources: (N.G., R.G. EU)	A	No	S-t	L	No	Additionality [0.22 for total effort. Slightly higher effect in small and medium-sized and in high-tech firms] [0.35 for Private effort. Significant effect in small and low-tech firms]	[5,50, 22,00]

Table 1. *Continued.*

Author(s)	Country	Period	Unit of analysis	Dependent variable	Independent variable	Method	Source of funding ^a	R&D ^b history ^c	Subsidy lag ^d	Shape of the effect ^e	Financ. constr. ^f	Main findings	Citations ^g
Hussinger (2008)	German	1992–2000	Firm: 3744 observ. [manuf.]	Private R&D expend. per employee	Prob. of receiv. public R&D funding (dum. var.)	Selection (Probit PS Heckman Cosslett Newey Robinson)	F.G. (BM/BF)	A	Yes S-4	C	No	Additionality: Unshaped relationship. The effect of past subsidies is negative up to some threshold level, above which it has a positive effect	[1,50; 22,75]
Ozcelik and 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./Oup.	Regress. (Tab. FE RE IV GMM DID) Matching (PS – Log. NMM DID)	F.G. (TTGV TTDEB)	A	No S-4	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 and Reinhardt (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, procure)	Regress. (VLS DV LSDVC)	F.G.	A	No S-4/L-4 (one-year lag)	L	No	Additionality in the S-4 and L-4 [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]

Table 1. *Continued.*

Author(s)	Country	Period	Unit of analysis	Dependent variable	Independent variable	Method	Source of funding ^a	R&D ^b	Subsidy history ^c	Time lag ^d	Shape of the effect ^e	Financ. constr. ^f	Main findings	Citations ^g
Achhoff (2009)	Germany	1994–2005	Firm: 3583, 8528 R&D exp. firm-year obs. [manuf. serv.]	(log) Total R&D exp. (Sal. × 100)	Prob. of receiv. public R&D subsid.	Matching (PS – Prob. Multinom.)	F.G. (DPP Scheme)	A	Yes	S-1	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]
Berube and Mahan (2009)	Canada	2005	Establish.: 2785 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 (dummy var.)	Matching (PS – Prob. NMM)	F.G.	A	No	S-1	L	No	Additionality [Firms that receive grants and tax credits instead of only tax credit are more innovative]	[0.00; 10.67]
Herrera and Martinez (2009)	Spain	1995–99	Industry: 12 [manuf.]	Priv. R&D exp. Priv. R&D expend./Sales	Public R&D funding	Regress. (not specified)	Diff. Source. (not specif.)	A	No	S-1	L	No	Additionality for priv. R&D expend. [I 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]
Carrizicki <i>et al.</i> (2011)	Belgium (Fland.)	1999–2007	Firm: 952 firms, 3686 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-1/L-1 (one-year lag)	L	Yes (Work- ing Cap) [Mod. Var.]	Additionality for 'Research' and N.S. for 'Development'. Public subsidies directed at 'Research' induced alleviate financial constraints	[0.00; 12.67]

Notes: ^aThis 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). ^bThis column shows how the effect of private R&D spending is explored, i.e., aggregatedly (A) or separately (S). In this latter case, we also distinguish between Research (R), Basic Research (BR) or Applied Research (AR) and Development (D). ^cThis column indicates whether the study provides information on a firm's subsidy history. ^dThis column shows whether the study considers short-term (S-1) and/or long-term (L-1) effects. ^eThis column shows whether the shape of the subsidy effect is assumed to be Linear (L) or Curvilinear (C). ^fThis 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. ^gThis 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 ^a	48 (63.15%)	15 (19.74%)	13 (17.11%)	76 ^b (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 ^b

Notes: ^aLower refers to studies performed at business unit- and plant-level or below.

^bThe 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.

group of countries considered (see Table 2). Studies of developing countries, in addition to Özcelik 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 (Howe and McFetridge, 1976; Shrieves, 1978; Mansfield and Switzer, 1984; Leyden *et al.*, 1989; Leyden and Link, 1991; Klette and Moen, 1998; Wallsten, 2000; Duguet, 2004; Ali-Yrkkö, 2005; Koga, 2005 and Aerts and Thorwarth, 2008).

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, that is, 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. Görg and Strobl, 2007; Aerts and Thowarth, 2008; 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

3. 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 has 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.

3.1 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. In addition, 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 (Wallsten, 2000; Lööf and Hesmati, 2005; Aschhoff, 2009).

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) also 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 alternative 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.*

3.2 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 than 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.*

3.3 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. Hall, 1992; Hao and Jaffe, 1993; Himmelberg and Petersen, 1994; Brown *et al.*, 2008; 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. Carpenter and Petersen, 2002; Ughetto, 2008; Czarnitzki *et al.*, 2011) 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; Scellato, 2007; Ughetto, 2008; Czarnitzki *et al.*, 2011). 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 (Ughetto, 2008; Czarnitzki and Hottenrott, 2010; Takalo and Tanayama, 2010; Czarnitzki *et al.*, 2011). Moreover, the intangible nature of R&D hinders the use of collateral by innovative firms to secure their borrowing (Bester, 1985; Berger and Udell, 1990; 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.*

3.4 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 (Nelson, 1959; Link, 1982; Robson, 1993; Diamond, 1999; Clausen, 2007; Aerts and Thorwarth, 2008) 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 under-investment 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.

3.5 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).

3.6 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 alternative 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.*

4. 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.

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Notes

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, e.g. Irwin and Klenow, 1996; Lerner, 1999; Wallsten, 2000), the Japanese research consortia (see, e.g. Branstetter and Sakakibara, 1998), or the IT programme supported in Norwegian high-tech firms (see, e.g. 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 (Hall, 1992; Long and Ravenscraft, 1993; Czarnitzki *et al.*, 2011).
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. Egelin *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, e.g. 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 %. 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.

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