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The Effects of R&D Subsidies and Publicly Performed R&D on Business R&D: A Survey*

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Abstract

This literature review shows that a majority of studies find complementarity between R&D subsidies and private R&D expenditures. A minority finds incomplete crowding out. Full crowding out is found only for small parts of the respective samples or small sub-sectors of the economies considered. Publicly performed R&D stimulates private R&D. The exceptions from these dominant results concern firm size, interaction of policy instruments, and effectiveness of parts of publicly performed R&D. Important suggestions for future research derived from the literature review are use of dynamic models with time lags and taking into account the effects of country and firm heterogeneity.

Keywords: Research & Development, Business R&D, Subsidies, Public R&D.

JEL Classification: H25, O38.

1. Introduction

Growth of GDP per capita is driven mainly by technical change in the long run. Technical change is driven by business R&D (Helpman, 1992). Business R&D is likely to be sub-optimal without government support. Bringing private and public R&D as well as other market imperfections to an optimum would imply the optimal rate of technical change and growth. This paper surveys the literature regarding the effects of public R&D, performance, and financing through subsidies, and, to a limited extent, tax incentives for business R&D expenditures. As many articles state that there is no consensus on the effects of R&D subsidies on business R&D, results are far from homogeneous and there are no automatic effects to be

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expected; the question then is what the sources of different outcomes are. There is much less disagreement on the positive effects of tax credits and therefore we consider mainly R&D subsidies and public performance.

There are several reasons why the literature argues that governments should support R&D. Decisions on research and development activities of private firms suffer from market imperfections: monopoly, knowledge externalities and uninsurable uncertainty (Arrow, 1962). All these arguments point to the likely outcome of sub-optimally low R&D expenditures. Transaction costs also make markets imperfect: (i) in the financing of R&D, external funds are more expensive than internal funds for small and start-up firms. Agency costs are relevant, risks have to be compensated, creditors prefer debtors with the lower liquidation costs of other than R&D-intensive firms, and tax systems responding to these issues differ (Hall, 2002). (ii) In knowledge diffusion processes, there are information search costs (Lundvall and Borrás, 2005; Clausen, 2009). The above-mentioned transaction cost arguments are closely linked to the market imperfection of lack of insurance. They have led to the suggestion that government support could induce improvements because it is not a priori clear that markets are optimal from a societal perspective.

Moreover, governments have to decide on R&D regarding public tasks like defense, environmental issues, health, space and energy, and others called mission-oriented R&D (Mazzucato, 2018). Private businesses paid by governments carry out some of the mission-oriented R&D tasks, but public research institutions do other parts of mission-oriented R&D tasks. As a result, the provision of public goods and the corresponding mission-oriented R&D are done through government support.[1]

Optimal policies balance advantages and disadvantages. Judd (1985) shows that shifting more resources into R&D because of variety externalities implies shifting resources out of production. In the presence of fixed costs and imperfect competition, this aggravates the monopolistic imperfection of production. These imperfections may outweigh each other making policy interference redundant. Moreover, Aghion and Howitt (1992) show for quality ladders models that there may be a business stealing effect, which is a loss for competitors of successful inventors. However, most literature justifies R&D subsidies through (i) spillovers from firm to firm (Romer, 1990) and (ii) spillovers from firms to households' human capital formation (Ziesemer, 1991), (iii) intergenerational benefits of public knowledge accumulation (Antonelli, 2019) and (iv) the uncertainty arguments presented above.

When governments finance additional public R&D, the sources may be additional tax revenues and cutting expenditures for social support or old industries, all of which are a disadvantage for some people. The aspect of financing public R&D is beyond the scope of this paper. The crucial criterion for a successful policy is the shifting of more resources into R&D. Strong additionality, defined as more of both public and private R&D expenditures, may be desirable in general (Antonelli, 2019), but resources for R&D can also be enhanced through government subsidies that are larger than private reductions of R&D expenditure called incomplete crowding out. However, the success may be limited through issues of implementation if governments bias their decisions in favor of technologies, sectors or regions where only weak effects can be achieved.

Private and public R&D in principle may be complements or substitutes in the knowledge perspective because there may be cost reductions, spillovers, and duplications. In addition, private and public R&D may compete for researchers in high-skill labor markets (Goolsbee, 1998; Wolff and Reinthaler, 2008) unless each worker changing his/her R&D job can be replaced by an equally good one. Market imperfections with strategic interactions (Takalo *et al*., 2013a), knowledge complementarities and factor market competition, also from policy repercussions from abroad (Soete *et al*., 2020; Ziesemer, 2019), make it difficult to know whether too little or too much public R&D expenditure exist in practice. Empirical economic intuition suggests that there is too much public R&D spending if private R&D is crowded out strongly. If, however, additional tax credits, R&D subsidies and publicly performed R&D encourage private R&D to increase expenditures, this is seen as a social improvement because private R&D is supposed to be below optimum without policy according to the reasoning indicated above. Moreover, public R&D is under suspicion of being too low because of its link to public goods, limited tax revenues, and free-rider behavior. Increases of private and public R&D are therefore by default assumed to be a social improvement. However, it is far from clear that the design of policies takes all the problems into account in an adequate way and that distortions from purely political motivations are absent.

There are several possible constellations leading to deviations from an optimal resource allocation for public and private R&D financing or investment. If there is too little public R&D, business R&D may also be too low if they are knowledge or factor-market complements. If there is too little public R&D, this may create private interest in doing public R&D, and business R&D may try to fill a part of the gap if they are substitutes. If there is too much public R&D, business R&D could also be too large if they are complements. If there is too much public R&D, business R&D could be too low if they are substitutes. In this latter case, the question is whether a business R&D reduction is larger or smaller than the deviation of public R&D from its optimum.[2] This determines whether total R&D is larger or smaller than the optimum. These four constellations are theoretical possibilities. In the empirical literature, the common assumption is that (i) private R&D without R&D policy is below the optimum and (ii) public R&D has a positive impact on private R&D if they are complements, but (iii) a negative impact if they are substitutes. Questions of this paper therefore are (i) whether publicly performed R&D or subsidies enhance private R&D spending according to the empirical literature; (ii) if there is crowding out, whether it is complete or just partial leading to the envisaged increase in total R&D; (iii) what the sources of divergent answers in the literature are.

We do not include organizational (neither internal nor external) and behavioral[3] studies, which can fill articles on their own. Similarly, low-interest credit requires detailed argumentation on the treatment of heterogeneity of firms by creditors, again requiring a survey on its own linked to the specificities of capital markets for innovative activities. We omit studies on special sectors, such as energy and agriculture, because results are related to traditional exceptional policies such as production or input subsidies. Literature surveys discuss the question as to what triggers private R&D funding in section 2 and private R&D performance in section 3. Whereas surveys of the previous millennium were often pessimistic about the effects of R&D subsidies, Becker (2015) argues that especially econometric progress in regard

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to selection effects on the firm level has led to more optimistic results. Similarly, we argue here that dealing with panel heterogeneity most recently allows avoiding heterogeneity bias and identifying the sources of exceptions to the predominantly optimistic results.

In sections 2.1 and 2.2, we summarize the bulk of the literature, which looks at the effects of government funding through tax credits and R&D subsidies on business funding of R&D; in section 2.3, we look briefly at the effects of government funding through tax credits on business funding for R&D when subsidies are also an important instrument. In section 3, we look at the literature on the effects of government R&D performance on business R&D, which is much smaller; we summarize it in section 3.1 showing that it requires more research. Section 3.2 discusses government failure and learning in regard to public R&D. Section 4 briefly summarizes the results of the literature and leads to suggestions for improvement through additional research with emphasis on heterogeneity and dynamic methods.

2. Literature survey: The impact of R&D subsidies on private R&D expenditure

This section derives from the literature that tax credits, R&D subsidies and public R&D performance all lead to enhanced total R&D either through triggering additional private R&D or because of incomplete crowding out. The emphasis of the section, therefore, is on understanding the limits of this general line.

In these considerations, it is useful to distinguish between financing and carrying out (performing) R&D because the OECD R&D data and their users distinguish between private and public financing, and private and public performance. Concerning financing, the literature distinguishes between tax credits and R&D subsidies (sometimes in the special forms of start-up facilities and funds for small and medium enterprises, SMEs). Under tax credits, which are in principle available for all firms, having spent money on R&D is a pre-condition for getting tax reduction and therefore eligible expenditures cannot be withdrawn (Spengel *et al.*, 2017). Therefore, we touch upon the tax literature only cursorily.[4] However, rules for tax credits may be linked to revenue, size, and R&D of firms, as well as rules and problems of timing (Mohnen and Lokshin, 2010; Appelt *et al.*, 2016). In general, the literature assumes that these limitations are weaker for tax credit systems than for subsidies linked to government plans, programs, projects, and missions. These circumstances together make it possible that private R&D expenditures can be reduced to some extent, but more likely so through subsidies than through tax credits. On the other hand, an advantage of subsidies is that they relax credit constraints.[5] There are some links between subsidies and tax credits and therefore we need to look at the tax credit literature also a little bit.[6]

Most of the literature is looking at the effects of government funding on business funding with the more or less explicit question of whether or not too much government money is going to public R&D? An answer to this question should not only depend on the question of crowding out private R&D financing but also on the question of the effects of public R&D

performance on business R&D expenditure. Therefore, we also look at the literature on public R&D performance. The latter includes research by universities and public non-university research institutions. In terms of data, this is measured by gross expenditure on R&D minus R&D expenditure performed by the business. In contrast, the financing perspective would not include business financed research done in universities.

Empirical studies go back to the 1950s (García-Quevedo, 2004). They make statements regarding complementarity and substitutability or statistical insignificance, but conclusions on the degree of substitutability and complementarity are sometimes left to the reader.[7] This is important though, because, e. g., a 10% increase of public R&D may be responded to by a 1% reduction of private R&D, which, at about equal size of public and private R&D, would still imply a large overall increase, with business leaving some tasks to the government rather than becoming inactive. If, instead, business reduces R&D expenditure by the same amount that the government spends or even more we would have complete crowding out. A third case is that firms also spend more, and we have complementarity. We summarize the literature in Tables 1 to 6. The R&D financing literature can be divided into two branches: effects of R&D tax incentives and R&D subsidies. We focus more on the latter and deal with tax credits only briefly in section 2.1.

Table 1 lists literature from surveys and meta studies. Table 2 shows panel studies. We do this in chronological order in order to see whether there is progress over time in the sense of getting clearer results, starting with surveys from this millennium. Tables 3 to 5 cover Western, Southern, and other European countries. Table 6 lists non-European countries. Covering many countries implies looking implicitly at many institutional systems. Column 1 denotes the author(s) and year of the study. Column 2 indicates whether it is a survey, a meta-study or a panel study, or a country or firm-level study. Columns 4 and 5, sometimes merged, give the major result in one sentence only, and some additional information or comments. We mostly do not repeat the information of columns 4 and 5 in the text, because the literature is large, and the article is already long.

The subsequent text emphasizes the problems and the structure of the results in order to go from mere description to a structural understanding of the state of the art.

Table 1
SURVEYS AND META STUDIES (chronological order)

Author(s) (year)	Study type	Level	Result	Remarks
Hall and van Reenen, 2000	Survey	OECD tax systems: "a dollar in tax credit for R&D stimulates a dollar of additional R&D".		
Klette *et al.*, 2000	Survey	Complementary relationship between public and private R&D for selected studies.		
David *et al.*, 2000	Survey	33 studies.	Favour complementarity; a third of the 33 studies under review report substitution effects.	
José García-Quevedo, 2004	Meta-study of 39 studies	74 results for firms, sectors, countries	ambiguous; more than half of the studies has significantly positive effects.	

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Author(s) (year)	**Study type**	**Level**	**Result Remarks**
Correa *et al*., 2013	Meta study	37 studies 2004-2011.	Significantly positive additionality, coefficient 0.166-0.252.
Zúñiga-Vicente *et al*., 2014	Survey	Firm level.	Positive effects where time lags and credit constraints are taken into account.
Radicic, 2014	Broad survey	All levels	very little full crowding out indications.
Becker, 2015	Survey	Mainly manufacturing firms.	Positive effects in studies on (a). In the pre-2000 literature ... tax credits have a significant positive effect on R&D expenditure, ... considerable variation in the findings ... (b), (c), (d); later better econometrics on selection effects.
Dimos and Pugh, 2016	Meta regression analysis	52 studies published after 2000.	No crowding out, (e); no substantial additionality in patents and new products but increasing over time.
Beck *et al*., 2017	Survey	Firms.	Positive relation with private R&D; no crowding out.
Petrin, 2018	Survey (f)	EU, OECD, China, Taiwan	complementarity; positive but modest innovation effects; only one indication of complete crowding out in Radicic/Pugh 2017.

(a) Denmark (Bloch and Graversen, 2012); Finland (but not Germany patenting activities) (Czarnitzki *et al*., 2007), mainly small and medium firms (Hyytinen and Toivanen, 2005); Flanders (Aerts and Schmidt, 2008); France, reject crowding out, public subsidies on average increase private R&D (Duguet, 2004); Germany (Aerts and Schmidt, 2008; Czarnitzki and Hussinger, 2004; Hussinger, 2008), (more East than West (Czarnitzki and Licht, 2006)); Ireland, inverted u-shape (Görg and Strobl, 2007); Israel (Lach, 2002) (not for large but for small firms, with lag); Italy, (Carboni, 2011) rejects crowding out; Norway improved policy: pre-2000 none (Klette and Møen, 2012), post-2000 additionality (Henningsen *et al*., 2015); Spain (mainly participation effect (González *et al*., 2005); low tech (González and Pazó, 2008)); Turkey (Özcelik and Taymaz, 2008); UK: only low tech, high tech substitute (Becker and Hall, 2013).

(b) "More recent literature observes a shift away from the earlier findings that public subsidies often crowd-out private R&D to finding that subsidies typically stimulate private R&D."

(c) "University research, high-skilled human capital, and R&D cooperation also typically increase private R&D."

(d) One policy conclusion that can be drawn from all of these studies is that fiscal measures that reduce the user cost may be expected to increase private R&D expenditure. Overall, the average negative elasticity across the various studies appears to be around unity.

(e) This result is seen as lower bound in the literature (Beck *et al*., 2017).

(f) This very recent survey inevitably has overlap with ours. It is also more interested in tax credits and other output measures.

2.1. The effects of tax credits

In this sub-section, we briefly indicate that tax credits have positive effects on private R&D expenditures already in the short run. This study is brief on tax credits as they are relatively non-controversial except for the details of tax laws (CPB, 2014).[8] Firms obtain tax credit only for R&D expenditures really made. Hall and van Reenen (2000) report a clearly positive effect.

Jaumotte and Pain (2005) summarize as follows: "More generous tax reliefs for R&D are more frequently found to have a positive impact on the amounts of both R&D and patenting than higher levels of direct funding". CPB (2014) summarizes as follows: "The vast majority of studies surveyed in this report conclude that R&D tax credits are effective in stimulating investment in R&D. The estimates of the size of this effect are widely diverging. They are not always comparable across countries due to differences in methodology. Studies that are more rigorous find that one euro of foregone tax revenue on R&D tax credits raises expenditure on R&D by less than one euro".[9] This suggests incomplete crowding out. In a survey, Becker (2015) reports that more recently even more studies find a clearly positive effect although with a great variation in the details of the results. Beck *et al*. (2017) conclude, "The bottom line here is that there is a consensus in the empirical literature that tax credits have a significantly positive short-run effect on private R&D investment. By contrast, direct subsidies do not have short-run effects but have positive medium-run impacts". Rao (2016) finds positive short- and long-run effects for the USA 1981-91 using a new strategy to deal with simultaneity. Thomson (2017) points out that his estimates give a much higher elasticity for tax credits than earlier literature.

2.2. The effects of R&D subsidies

In this sub-section, we report from the literature that there is no complete crowding out of private R&D through R&D subsidies. Crowding out is either incomplete or additional private R&D expenditures are triggered. R&D subsidies, therefore, enhance total R&D expenditures.[10] The survey of Klette *et al*. (2000) finds complementarity between public and private R&D as one would expect it, dynamically, from Nelson (1959) and endogenous growth models (Shell, 1967; Ziesemer, 1991, 1995; Antonelli, 2019). David *et al*. (2000) have pointed out that articles published in the 1990s ignore the endogeneity problem.[11] As Becker (2015) points out, literature that is more recent often finds positive effects. This holds for performance and funding data (Jaumotte and Pain, 2005; see note (a) to Table 2); in particular for university R&D (Falk, 2006); when time lags (Lach, 2002; Toole, 2007; Herrera and Bravo Ibarra, 2010; Zúñiga-Vicente *et al*., 2014[12]) and credit constraints are taken into account (Meuleman and De Maeseneire, 2012; Zúñiga-Vicente *et al*., 2014); also for Turkey (Özcelik and Taymaz, 2008), but not so for South Africa (Czarnitzki and Lopes-Bento, 2012).[13] In line with this, García-Quevedo (2004) finds ambiguous results mostly in the older literature. During the crisis period 2007-2009, subsidies just prevent the reduction of R&D (Aristei *et al*., 2017; see also below Hud and Hussinger, 2015 and Barajas *et al*., 2017, all indicating similar reactions during the crisis). Becker (2015) attributes the more positive results to advances in econometrics, and a consideration mainly based on selection effects. Therefore, our intention to survey literature does not go into articles of the previous millennium.[14]

Now we discuss the exceptions and limits to positive results related to Tables 1 and 2 and its notes, with some references to Tables 3 to 6 below with the single-country studies. Guellec and van Pottelsberghe (2003) find negative effects when subsidies exceed 20% of the R&D expenditures but positive effects at lower rates. Görg and Strobl (2007) also find an inverted u-shape for firm-level data for Ireland, Dai and Cheng (2015) do so for China and Ugur and Trushin (2018) for the UK.

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Table 2
COUNTRY PANEL REGRESSIONS (chronological order)

Author(s) (year)	Study type	Level	Result	Remarks
Guellec and van Pottelsberghe dlP, (2003)	Panel regression	17 OECD countries	Inverted u-shape;	substitution for subsidies >20%
Jaumotte and Pain, 2005	Panel regression	19 OECD countries	" ... an expansion in publicly funded and performed R&D will raise the real wages of researchers employed in the private sector." (a)	
Khan and Luintel, 2006	Panel regression	16 OECD countries	Negative interaction effect of public and business. Total effect of public R&D positive.	
Falk, 2006	Panel regression	21 OECD countries	Public does not affect business R&D ... but university R&D does.	
Coccia, 2010	Panel	31 EU countr., 10-12 years	Public and private R&D are complementary.	
Cincera *et al*., 2011	Stoch frontier, Data Env Anal	OECD	Positive heterogeneous effect.	
Lee, 2011	Firm panel data	Nine industries in six countries	"Complementarity effect on private R&D for firms with low technological competence, for firms in industries with high technological opportunities and for firms facing intense market competition."	
Czarnitzki and Lopes Bento, 2012	Cross-country micro data	Belgium, Spain, Germany, Luxembourg	'Firms would have invested significantly less if they would not have received subsidies' but not in South Africa. (b)	
CPB, 2014	Multi country	Tax system	Econometrically more rigorous studies find positive effects of less than one Euro from 1 additional Euro tax reduction.	
Czarnitzki *et al*., 2014	Finland, Germany, Netherlands	Firm level projects	Highest profits, spillovers and application costs in German projects.	
Montmartin and Herrera, 2015	25 OECD countries	Macro	Publicly executed R&D has a positive effect; public support a negative effect and tax credit a positive effect.	
Radicic and Pugh, 2017	EU 28	National and EU programs for SME	Complete crowding out of output additionality from EU programs not rejected but avoided by national programs; no crowding out of input additionality.	
Aristei *et al*., 2017	Largest EU countries, 2007-2009	Manufacturing firms	Positive effect of R&D subsidies; hypothesis of full crowding-out is rejected in all countries; no additionality from firms, (c). Subsidy effectiveness is increasing over time.	

(*Continued*)

Author(s) (year)	Study type	Level	Result	Remarks
Deloitte, 2017	OECD-17 (G7, Non G7); OECD-17 +EU+ICL; 7EU+CHL +ISR	Country panels	... 1 % yields 0.2% across all samples with the exception of G7. Positive effect of education R&D.	
Van Elk *et al*., 2019	OECD	Country panel	Insignificant effects under panel homogeneity turn more positive when interaction effects allow for heterogeneity.	

(a) "An increase of 1 standard deviation in the share of non-business R&D in GDP (an increase of 0.06 percentage points for the average economy) raises business sector R&D by over 7% and total patenting by close to 4%." (Jaumotte and Pain 2005, p.38, for the performance definition of R&D). "… an increase of 1 standard deviation in the share of non-business R&D funded by the private sector (an increase of 1.4 percentage points for the average economy) will eventually raise business sector R&D by over 8% and total patenting by close to 2½ per cent …" (Jaumotte and Pain, 2005, p. 39, for the financing definition of R&D).

(b) 'Governments could foster R&D activities by extending innovation policies to currently not supported firms.... Our analysis does not uncover any systematic misallocation of public funding for the countries under review'.

(c) R&D subsidies 'thwarted the reduction of firm R&D efforts in the aftermath of economic crisis'.

Effects of R&D subsidies on business R&D are larger for small and medium-size firms than for large firms (Lach, 2002 for Israel; Hyytinen and Toivanen, 2005 for Finland; Huergo *et al*., 2016, and others presented in Table 3 to 6 below). This suggests that large firms have sufficiently large profits and do not depend on credit for their R&D investments; the literature emphasizes credit market imperfections and appropriability problems, but imperfect competition may relax or even avoid credit constraints through sufficiently high profits. R&D subsidies are linked to profits by models of González *et al*. (2005), Arqué-Castells and Mohnen (2015) and Takalo *et al*. (2013a, 2017). "Low profit margins (or limited availability of internal funds) seem to be an obstacle for R&D performance..." (Takalo *et al*., 2017). R&D subsidies may help to get beyond thresholds for continuation and entry (Arqué-Castells and Mohnen, 2015). Subsidies lead to more bank credit in some countries (Hottenrott *et al*., 2017b). Takalo and Tanayama (2010) find that subsidies relax the credit constraint, improve the screening, and provide signals to financiers. However, whereas informational signals may work, there is not a general certification effect, although subsidies work more strongly under credit constraints (Howell, 2017).

Participation is enhanced in Spain (González *et al*., 2005), and effects are stronger for low-tech firms in Spain (González and Pazó, 2008) and the UK, where high-tech firms substitute R&D expenditures leading to statistically insignificant effects (Becker and Hall, 2013). A recent multi-country study of Deloitte (2017) reports positive effects for all sub-samples but the G7. Further disaggregation seems necessary in order to consider the heterogeneity among the G7 countries. Zúñiga-Vicente *et al*. (2014) point out that there is a lack and need of dynamic considerations. Soete *et al*. (2020) share this view and use the vector-error-correction method for the Netherlands. Public R&D then has strongly positive effects, which are weaker if other countries also enhance public R&D.

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In Tables 3 to 6, we list country-specific studies in alphabetic order of the country names in column 2. We list only one very recent study on China (Dai and Cheng, 2015), which points to similar relations as other literature, whereas other literature emphasizes specific Chinese institutions, leading to a more specialized literature. We include some recent studies on the USA because policy ideas sometimes spillover from the USA to the EU and so do research ideas.

Table 3
COUNTRY LEVEL STUDIES, WESTERN EUROPE (alphabetic order by country name)

Author(s) (year)	Country	Level	Result: effect of additional public R&D	Remarks
Meuleman and De Maeseneire, 2012	Belgium	1107 subsidy requests	"Obtaining an R&D subsidy provides a positive signal about SME quality and results in better access to long-term debt."	
Hottenrott and Lopes-Bento, 2014	Belgium	SME	R&D subsidies trigger R&D spending and marketable innovations, especially from firms in international collaborations.	
Hottenrott *et al*., 2017a	Belgium	Firms	... a positive effect on R&D spending...	... increasing with market failure.
Neicu, 2016b	Belgium	Firms	Subsidies have positive effects on private R&D spending only in the presence of tax credits...	... tax credits and subsidies are complements.
Neicu *et al*., 2016	Belgium	Firms...	... apply tax credits more to research than to development when receiving subsidies...	... accelerate and scale up projects.
Czarnitzki and Delanote 2017	Belgium	Firms	Positive effects confirmed...	... but no new sales.
Czarnitzki and Lopes-Bento, 2013	Flanders	Firms	R&D subsidies, no full crowding out. Effects stable over time. R&D jobs are created.	
Serrano-Velarde, 2008	France	Firms, ANVAR program	Private R&D investment increases for small and decreases for large firms.	
Bedu and van der Stocken, 2015	France, Aquitaine		R&D subsidies trigger business R&D.	
Marino *et al*., 2016	France	Firms	... additionality only for a few top companies (subsidies > €10mill.); substitution for others (€145k-1.8mill); significant substitution for doses €20k-55k. Worse results after reform, 2004-2009.	Larger doses have no weaker effect, in contrast to other literature. Substitution is defined as negative growth rate differences from treatment.

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Author(s) (year)	**Country**	**Level**	**Result: effect of additional public R&D**	**Remarks**
Montmartin *et al*., 2018	France	Firms in NUTS3 regions	Only national subsidies have crowding-in effects...	... because of negative spatial dependence among regions.
Soete *et al*., 2020	Netherlands	Macro	... higher business R&D and time varying gains for decennia; high internal rates of return.	Scenarios without and with firm R&D shocks and symmetric foreign policy actions.
Haskel *et al*., 2014	UK	Industry	Universities get more private money if they had more public money earlier.	(a)
Economics Insight, 2015	UK; with survey	Macro and micro	A 1% increase in public expenditure on R&D will lead to between a 0.48% and 0.68% increase in private expenditure on R&D.	No time trend in control variables? (b)
Sussex *et al*., 2016	UK	Ten disease areas for the government, charity and private sectors	A 1 % increase in public sector expenditure is associated in the best-fit model with a 0.68% increase in private sector expenditure.	Biomedical and health R&D expenditure; 44% of the effect within one year.
Ugur and Trushin, 2018	UK	43650 R&D active firms	Inverted u-shape effect of subsidies on R&D...	... investment and employment, privately funded.

(a) Commissioned by CAMPAIGN FOR SCIENCE AND ENGINEERING.

(b) Commissioned by UK Dep BIS. The book has a long literature review and concludes: "The papers do generally find a positive relationship between public sector and private sector funding and the estimates tend to be between zero and one. This, however, is a relatively large range." Note that this range excludes even partial crowding out.

Most studies show complementary effects either directly in terms of money spent or indirectly in terms of additional patents, new products, or other effects clearly related to R&D,[15] that would not have been achieved under private reduction of R&D spending (Cohen *et al*., 2002; Jaffe and Le, 2015; Azoulay *et al*., 2019; Buchmann and Kaiser, 2019). Therefore, we focus again on the exceptions in the following.

(Continued) Many studies have emphasized that there is no consensus on the effect of R&D subsidies. The reason seems to be that heterogeneity prevents us from drawing simple conclusions (Ugur and Trushin, 2018). When studies differentiate the effects according to certain characteristics, full crowding out is found only at the extreme end or part of the spectrum of the related distributions (Radicic, 2014; Petrin, 2018). Examples are, alternatively or jointly,

— picking-the-winner selection procedures, single programs, and projects in a special social context, large grants or subsidies above a certain threshold;

— very small or very large firms, a certain percentage of the firms, firms in weak regions, firms, or sectors with low knowledge intensity, or

— the highest level of appropriability, high or low product market uncertainty, medium and/or high tech sectors.[16]

— Certain years, for example with crisis.

These parts of the sample are mostly small compared to the whole group of firms in a country. We can categorize these aspects into those of (i) programs[17], projects[18] and selection procedures for the subsidy allocation, (ii) firm characteristics of the subsidy recipients, (iii) markets and sectors for the R&D outcome, and (iv) specific periods.

Table 4
COUNTRY LEVEL STUDIES, SOUTHERN EUROPE (alphabetic order by country name)

Author(s) (year)	**Country**	**Level**	**Result: effect of additional public R&D**	**Remarks**
Parisi and Sembenelli, 2003	Italy	726 firms over the 1992–1997	Subsidy-investment elasticity for cost reduction is -1.5-(-1.77).	
Hall *et al*., 2009	Italy	7375 manufacturing firms.	Receiving a subsidy leads to higher R&D intensity; more for high tech firms, which perhaps receive higher subsidies.	
Colombo *et al*., 2011	Italy	247 Italian-owner-managed NTBFs in manufacturing and services	Positive effects if selective expert schemes certify quality...	... but not for automatic schemes.
Cerulli and Poti, 2012	Italy	Firms	Overall positive effects mainly through large firms...	... small firms often show crowding out .
Blasio *et al*., 2014	Italy	Firms	No effect of public R&D...	... after shortfall of money.
Bronzini and Iachini, 2014	Italy, North	Firms	Small firm invest more, large firms do not.	Competition based on scores.

(*Continued*)

Author(s) (year)	**Country**	**Level**	**Result: effect of additional public R&D**	**Remarks**
Bronzini and Piselli, 2016	Italy, North	Firms	1 patent for grants of €206k-310k.	More markedly for small firms.
Mariani and Mealli, 2018	Italy, Tuscany	Firms	Encouraged non-R&D firms to do R&D and upskill.	
Ilbeigi, 2017	Italy, Trento	Firms, local R&D program	Some crowding out	also additional spillovers.
Aiello *et al.*, 2017	Italy	SMEs	Supported firms have same patenting but more R&D spending.	
Busom, 2000	Spain	Firm level	... induces more effort...	For 30% of the participants full crowding out cannot be excluded.
González *et al.*, 2005	Spain	Firms	R&D subsidies enhance R&D with unit elasticity. Some firms would stop R&D without subsidies.	Most subsidies go to firms, which would do R&D anyway.
Gelabert *et al.*, 2009	Spain	Firm level	Effect of public support for R&D is three times larger for those firms reporting a level of appropriability below the median.	
Herrera and Ibarra, 2010	Spain	Firm level	R&D subsidies have positive effect on innovation inputs; time lags are important.	Larger firms get more but have smaller effect than SMEs.
Romero-Jordán *et al.*, 2014	Spain	SMEs	Tax credits have partial crowding out...	... of negative zero when some receive also public grants.
Arqué-Castells and Mohnen, 2015	Spain	Manufacturing firms	'One-shot trigger subsidies cause a substantial increase in... share of R&D firms and average R&D expenditures.'	'This effect shows persistence over time, but totally fades away after seven years.'
Huergo and Moreno, 2017	Spain	4407 firms ...	Higher participation; hypothesis of complete crowding out rejected...	... but not for large firms. European loans more effective.

(*Continued*)

Author(s) (year)	**Country**	**Level**	**Result: effect of additional public R&D**	**Remarks**
Barajas *et al.*, 2017	Spain	Firm level (CIS)	Positive effect of public support on participation and all intensities also during crisis.	Lower impact during crisis, in particular fixed R&D capital. Shift from process to product innovation.
Álvarez-Ayuso *et al.*, 2018	Spain	237 firms	Public support works well for firms with continuous investment. Tax credits are suitable for boosting investment;	especial incremental tax credit at low investment levels.

There is only one recent study after Wallsten (2000) that suggests complete crowding out where it remains unclear though how large the share of the US economy is for which this holds true (Ngo and Stanfield, 2017).[19] The argument for the US is that some firms are government dependent in terms of sales. The payment by the government includes R&D subsidies. Thirteen percent of all firms depend persistently on governments, on average for 11 years. They benefit from discretionary budget authority (DBA) meaning that US R&D expenditures are sub-parts of those of other labels. Competing firms who lose on government contracts fear losses, which would lead to lower salaries for managers. Therefore, managers cut down R&D expenditure because of special incentives to keep short-term profits high. In theoretical terms, in this case, governments introduce discrimination intentionally, which can be seen as the creation of a distortion, which leads to extreme management reactions in a specific agency setting, leading to a more than proportional reduction.

Table 5
COUNTRY LEVEL STUDIES, OTHER EUROPEAN (alphabetic order by country name)

Author(s) (year)	**Country**	**Level**	**Result: effect of additional public R&D**	**Remarks**
Widmann, 2017	Austria	Firms	A government research grant increases the propensity to file a patent application with the European Patent Office within 4 years by around 10 percentage points. Stronger effects appear for established firms of advanced age.	
Radas *et al.*, 2015	Croatia	SME	R&D subsidies affect innovation indicators	tax incentives affect only R&D employment.

(*Continued*)

Author(s) (year)	**Country**	**Level**	**Result: effect of additional public R&D**	**Remarks**
Čadil *et al*., 2017	Czech Republic	SME	Positive impact on personnel expenditure.	Negative impact on economic criteria.
Dvouletý *et al*., 2018	Czech Republic	Firms	Incubated firms reported on average lower values of personnel costs.	
Kaiser, 2006	Denmark	Firms	"Positive and statistically weakly significant effects of R&D subsidization on R&D intensity." Food industry receives most subsidies.	
Kaiser and Kuhn, 2012	Denmark	Joint ventures	Quick effects on patenting and employment, but not sales or productivity. No effects for large firms.	
Hünermund and Czarnitzki, 2019	European	SME	No treatment effects on patents from Eurostars program.	
Hünermund and Czarnitzki, 2015	European	SME	VCP grants; no average effect on growth, but higher effect with project quality.	
Takalo *et al*., 2013b	Finland	Project level	Targeted subsidies have social rate of return between 30 and 50%.	
Einiö, 2014	Finland	Firms	Positive impacts on R&D investment, employment, and sales from ERDF funding to regions.	
Czarnitzki and Fier, 2002	Germany	Service sector firm level	Complete crowding out rejected.	
Almus and Czarnitzki, 2003	Germany, East	Firms	Firms increase their innovation activities...	... by about four percentage points compared to no subsidies.
Czarnitzki and Toole, 2007	Germany	Manufacturing firm	R&D subsidies reduce the uncertainty effect of R&D investment.	
Reinkowski *et al*., 2010	Germany, East	Firms, 2003	"Subsidized firms indeed show a higher level of R&D intensity and a higher probability for patent application compared to non-subsidized firms... 2003."	"Highest increase in terms of R&D intensity is estimated for micro businesses with up to 10 employees."
Fornahl *et al*., 2011	Germany	Biotech firms	R&D subsidies focusing on single firms do not increase patent intensity, ...	... while subsidies which are granted to joint R&D projects do so to a certain extent.

(*Continued*)

Author(s) (year)	**Country**	**Level**	**Result: effect of additional public R&D**	**Remarks**
Alecke *et al*., 2012	Germany, East	SME	Positive effect on R&D intensity.	
Hud and Hussinger, 2015	Germany	Firms 2006-2010	Positive effect except... ... crowding out in 2009; 2010 positive but smaller effect than before crisis.	
Czarnitzki and Delanote, 2015	Germany	CIS firm panel	No complete crowding out; strongest effects on high-tech firms.	
Czarnitzki and Hussinger, 2018	Germany	Firm level, 1992-2000	Publicly induced R&D shows a positive effect on patent outcome.	
Plank and Doblinger, 2018	Germany	Firms energy R&D projects	Subsidies enhance value of patents...	... but not the number of citations.
Hottenrott *et al*., 2017b	Germany 2005-2009	Firm level	Grants make bank loans more likely and larger...	... more so in information opaque sectors.
Abdul Basit *et al*., 2018	Germany	Service firms	Subsidies increase marketing and organizational innovations and probability of applying for a copyright.	
Koehler and Peters, 2017	Germany	Firm level	Patent applications from subsidized firms have higher private value...	... than from firms not subsidized.
Koehler, 2018	Germany, 1994-2011	Firms in thematic programs	Positive effects on welfare and profits...	... as large as those from foreign spillovers.
Comin *et al*., 2018	Germany	Firms	Interaction with Fraunhofer Society increases human capital hirings, productivity, ...	... more in generation than implementation of technologies.
Buchmann and Kaiser, 2019	Germany	Biotech industry	Increased patent output...	... in Individual and collaborative research.
Clausen, 2009	Norway	Firm level	R&D subsidies stimulate research investment and quality of researchers, ...	... reduce the budget for development, but not for innovation other than R&D.
Grabińska and Stabryła-Chudzio, 2017	Poland	Country	Substitution; incomplete crowding out.	Pearson correlation coefficient of 0.86.

The result of stronger effects in small firms is confirmed for Danish joint ventures (Kaiser and Kuhn, 2012); North Italy, (Bronzini and Iachini, 2014; Bronzini and Piselli, 2016);

Spain: weaker effects in large firms and more overall participation (Herrera and Ibarra, 2010; Huergo *et al*., 2016; Huergo and Moreno, 2017; Barajas *et al*., 2017); and there are weak effects for large firms in a French program with crowding out (Serrano-Velarde, 2008).

Regarding large firms, the opposite is suggested for the US (Cohen *et al*., 2002), Italy (Cerulli and Potì, 2012) and France (Marino *et al*., 2016).

2.3. Subsidies in the presence of tax credits

A combination of subsidies and tax credits leads to more new products in Canadian plants (Bérubé and Mohnen, 2009), no crowding out in Spanish SMEs in Romero-Jordán *et al*. (2014) but crowding out cannot be ruled out for 30% of the sample of Spanish firms in Busom (2000). Montmartin and Herrera (2015) find a negative impact of subsidies for a macro-panel of 25 OECD countries. More recent evaluations by Huergo and Moreno (2017) and Barajas *et al*. (2017) find a low effect for large Spanish firms but exclude complete crowding out. Other sources do not have an impact on the effects of R&D subsidies in Flanders (Czarnitzki and Lopes-Bento, 2013). Busom *et al*. (2014) argue that tax credits and subsidies are imperfect substitutes for Spanish firms. Radas *et al*. (2015) find that subsidies are more important than tax credits for SMEs in Croatia. In contrast, Neicu (2016b) suggests that subsidies are only effective in the presence of tax credits in Belgium. Dumont (2017) suggests that they are weakening each other's effects for Belgium's firms. Neicu *et al*. (2016) show that users of tax credits focus more on research than development when they receive subsidies. Guellec and van Pottelsberghe de la Potterie (2003) and Montmartin and Herrera (2015) find that tax credits and R&D subsidies are substitutes in a study of 17 and 25 OECD countries respectively; there are spillovers to neighboring countries. Mulligan *et al*. (2017) offer a conceptual framework to evaluate policy mixes.

Table 6
COUNTRY LEVEL STUDIES, NON-EUROPEAN (alphabetic order by country name)

Author(s) (year)	Country	Level	Result: effect of additional public R&D	Remarks
Bakhtiari and Breunig, 2018	Australia	Industrial firms	R&D expenditure by academia has a positive influence on a firm's own R&D expenditure...	... within state boundaries. Government bodies outside academia have no positive effect.
Bérubé and Mohnen, 2009	Canada	Plant level	Grants lead to more new products...	... in the presence of tax credits. (a)
Dai and Cheng, 2015	China	Firms	Inverted-U correlation with private R&D investment	public subsidies follow an S-shaped relationship with the firm's total R&D.

(*Continued*)

Author(s) (year)	Country	Level	Result: effect of additional public R&D	Remarks
Koga, 2005	Japan	223 high-tech start ups	Publicly funded R&D promotes private R&D and is complement.	
Ziesemer, 2019	Japan	Macro	Cumulated non-business R&D capital stock has a positive impact on business R&D capital stock; GBAORD capital stock has no impact.	
Wallsten, 2000	USA	Firms in SBIR	One-to-one crowding out;	Cutting back avoided?
Cohen *et al*., 2002	USA	Manufacturing	An increase of 1 standard deviation in the share of non-business R&D in GDP (an increase of 0.06 percentage points for the average economy) raises business sector R&D by over 7% and total patenting by close to 4%.	The influence of public research on industrial R&D is disproportionately greater for larger firms as well as start-ups.
Toole, 2007	USA	Biomedical	Research by universities and non-profit organizations stimulates industry investment.	Time-series analysis for seven medical classes; strong role of time lags.
Azoulay *et al*., 2019	USA	Pharmaceutical and biotech firms (b)	A $10 million boost in NIH funding leads to a net increase of 2.7 patents.	Indirect evidence of limited withdrawal, if any.
Rao, 2016	USA	Tax credit 1981-1991	Positive effects on expenditure in short and long run.	With adjustment costs.
Lanahan *et al*., 2016	USA	Research fields at U.S. doctoral granting institutions	A 1% increase in federal research spending induces ... a 0.468% increase in private research funding.	
Lanahan, 2016	USA	US firms	State Match Program enhances chances getting SBIR support.	
Giga *et al*., 2016	USA	NASA SBIR	Firms with 1-5 employees with SBIR awards are twice as likely to produce patents; and generate twice as many patents;	the program does not show the same effect for larger firms (6 -500 employees).

(*Continued*)

Author(s) (year)	Country	Level	Result: effect of additional public R&D	Remarks
Corredoira *et al*., 2017	USA	Firms	Federal funds affect rate and direction of inventive activity according to citation analysis.	
Ngo and Stanfield, 2017	USA	Peers and non-peers of government dependent (gd) firms	Only firms that compete directly with gd firms contract investment in R&D; net reduction in industry R&D...	... caused by incentives for managers in real earnings management. (c)
Howell, 2017	USA	US firms	No crowding out; stronger effects under credit constraints, not explained through certification effect.	Firms subsequently attract venture capital.
Gaster, 2017	USA	SBIR/STTR	Total investment in SBIR/STTR of $6.25 billion generated; total revenues from products based on SBIR/STTR technologies of $28.9 billion. $8.8 billion in total taxes generated –more than the cost of the program. (d)	
Aysun and Kabukcuoglu, 2017	USA	US firms	Grants and subsidies reduce their dependence on external finance, their share of R&D spending increases (decreases) during a credit tightening (easing).	

(a) We do not include tax credit papers, unless papers combine them with other relevant aspects.

(b) Literature on single industries is limited here.

(c) "Government-dependent firms feature in a wide array of industries."

(d) Referring to TechLink.

3. Publicly performed R&D and government behavior

3.1. Publicly performed R&D and its effects on privately performed R&D

Articles dealing with this issue suggest predominantly that publicly performed R&D stimulates private R&D. Regarding the question of whether publicly performed (rather than financed) R&D triggers private R&D, our tables contain some results.[20] Cohen *et al*. (2002) show for US manufacturing firms that the influence of public research on industrial R&D is disproportionately greater for larger firms as well as start-ups. In contrast, Guellec and van Pottelsberghe de la Potterie (2003) conclude a panel study of 17 OECD countries saying

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“The defence component of government-performed research has a negative impact on business-funded R&D, civilian R&D has no impact”. Jaumotte and Pain (2005, p.38) find for the performance definition of the data that “An increase of 1 standard deviation in the share of non-business R&D in GDP (an increase of 0.06 percentage points for the average economy) raises business sector R&D by over 7% and total patenting by close to 4%.” Khan and Luintel (2006) find a positive effect of public R&D on productivity and a negative interaction effect with private R&D diminishing an overall positive effect (insignificant only for Belgium). Van Elk *et al*. (2019), using a similar approach to heterogeneity through interaction terms find mixed evidence in OECD panel studies with homogeneity assumption; results become more positive when the authors use interaction effects with public R&D. Falk (2006) shows that universities' R&D triggers additional business R&D in a panel of 21 OECD countries. Becker (2015) supports this result in a survey and explains it extensively. Toole (2007) finds a strong complementarity with a time lag of 3 years for public clinical research with decreasing elasticities adding up to a long-term elasticity of 0.40, and 8 years for public basic research which is u-shaped with long-term elasticity of 1.69. Cincera *et al*. (2011) mix the analysis of effects of R&D subsidies and publicly performed R&D on private R&D, BERD and R&D personnel, and analyze the causes of differences in its efficiency across OECD countries. Montmartin and Herrera (2015), in a study of 25 OECD countries find that publicly executed R&D has a positive effect. More public R&D is fruitful in Australia only if it goes to universities rather than other government parts (Bakhtari and Breunig, 2018). Deloitte (2017) finds a positive effect of education R&D on business-funded R&D in many regressions, but the effect of direct government R&D changes sign and statistical significance over the regressions. When education R&D is using the performance version of the data rather than the funding version, the positive correlation also may imply that firms give more money to universities because they outsource some of their own research tasks to them. We can then see the causality as two-way causality through parallel planning and funding of firms, which is closely related to consultancy, knowledge transfer, spillovers, distance, (re-)location and regional policy, as well as education activities of universities (Becker, 2015), and all reinforcing the funding of university research by firms' projects. Comin *et al*. (2018) match the project data of the Fraunhofer Society, a public research organization, with those of CIS to show positive effects of their interaction. Soete *et al*. (2020) for the Netherlands and Ziesemer (2019) for Japan find a positive effect of publicly performed R&D on domestic and foreign privately performed R&D, TFP and GDP. Both papers use a vector-error-correction model, where the lag length is important and analyze permanent shocks on public investment with all feedback effects.

3.2. Government failure and learning

Besides market failure, there may also be government failure. Buigues and Sekkat (2011) collect a number of related case studies. In the presence of market and government failure, institutional learning is of importance. Policy learning plays a role in the case of Norway, where no effects are found pre-2000 (Klette and Møen, 2012) but positive effects post-2000 (Henningsen *et al*., 2015). Moreover, much research has been done on the question of whether firms with more additionality have received most of the subsidies. Lööf and Heshmati (2005) report studies from several countries where this was not the case. Kaiser and Kuhn

(2012) suggest reconsidering the fact that large firms get most of the subsidies. Wanzenböck *et al*. (2013) suggest, “Attention of public support should be shifted to smaller, technologically specialized firms with lower R&D experience“. Mohnen (2018) discusses evidence-based policy and concludes “The evidence suggests that the impact of R&D tax incentives in terms of stimulating business R&D tends to be stronger for young companies and SMEs, and hence targeting young innovative companies, in particular, could be considered a valid option”. In line with these articles, Czarnitzki and Delanote (2015) argue, that the current policy focus on small, young, high-tech firm types is not ineffective.[21] Governments may have learned from this in some countries and cause more positive results. If government learning is limited, Matthew effects may produce self-perpetuating dynamics reinforcing inefficient policy strategies (Antonelli and Crespi, 2013). This might motivate the request for arrangements supporting more additionality. Moreover, there seems to be no uniquely best policy instrument when situations of countries and firms are heterogeneous; crucial aspects are credit constraints and productivity of firms, which in turn may vary between sectors (Haapanen *et al*., 2014).

4. Conclusions and lessons for future research

We have surveyed the literature on the effects of R&D subsidies and public R&D on business R&D for the period 2000 to the present. Summing up briefly, the overall judgement based on the criterion of (in-) complete crowding out is as follows. Two meta-studies find little additionality effects from government R&D expenditures whereas the third one in Table 1 by Correa *et al*. (2013) finds clearly positive results. They do not suggest complete crowding out. They average over studies, controlling for heterogeneity and publication bias.[22] The problem often is one of econometric identifiability of effects (Dimos and Pugh, 2016).

One approach to dealing with heterogeneity issues of countries is to consider only one country at a time. These studies suggest a positive effect of the public on private R&D expenditures; only two papers suggest full crowding out, one for the USA and one for the EU.

The surveys (see Table 1), country-year panel (Table 2) and firm panel analyses as well as the country-specific studies (Tables 3 to 6) are much less skeptical than the meta-studies and show more positive results with interesting study-specific differentiations. The most frequent result is that there is complementarity between public and private R&D for both tax credits and subsidies. A large group of papers suggests incomplete crowding out.[23] With some country-specific qualifications discussed below, these results hold for western, southern, other European and non-European countries alike.

The papers on the effects of R&D performance on business R&D, all find positive effects with the exception of Guellec and van Pottelsberghe de la Potterie (2003) who find a negative effect of defense and a neutral one for civilian R&D under the assumption of panel homogeneity.

We have categorized the firm heterogeneity leading to modifications of the majority of results as characteristics of (i) programs, projects, and selection procedures, (ii) subsidy

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receiving firms, (iii) markets and sector for the R&D outcomes, and (iv) specific periods. Aspects of systems of innovation and transformative change (Schot and Steinmüller, 2018) serve as control variables at best implicitly in these four groups of characteristics of heterogeneity and may be useful in the future when trying to clarify the controversial issues and explain heterogeneous results. Full crowding out is found mainly at the extreme end or part of the spectrum of the related distributions. Examples are picking-the-winner selection procedures, single programs, and projects in a special social context, large grants or subsidies above a certain threshold; very small or very large firms, a certain percentage of the firms, firms in weak regions, firms or sectors with low knowledge intensity, or the highest level of appropriability, high or low product market uncertainty, medium and/or high tech sectors; certain years, for example with crisis.

Several studies find decreasing effects or inverted u-shapes of additional R&D subsidies. R&D subsidies reduce problems from lack of profits and credit constraints and increase R&D participation especially in low-tech sectors. Most controversial is the question of whether or not large firms respond less to R&D subsidies; for France, Italy and the USA, there are also studies finding stronger effects for large firms. Moreover, it is not clear why R&D subsidies are substitutes for tax incentives in some studies, complements or independent in others. Finally, university R&D always has positive effects on business R&D or productivity. Which other parts of publicly performed R&D are most stimulating for private R&D is a question that is worth a follow up of the related studies surveyed here.

The literature explaining private R&D, performance or funded, mostly tests R&D subsidies and tax credits as explanatory variables (Becker, 2015). The literature using R&D regressors mostly tries to explain productivity, rates of return or patents (Petrin, 2018; Becker, 2015; van Elk *et al.*, 2019; Radicic, 2014; Khan and Luintel, 2006; Guellec and van Pottelsberghe de la Potterie, 2004). Therefore, the literature explaining private R&D through publicly performed R&D appears to be relatively small and should be extended in future research.

The literature summary teaches us that important aspects for our empirical analysis are dynamic models with adequate time lags, allowing for mutual interdependence of all variables, including feedback effects from foreign countries, and allowing for country and firm heterogeneity. Major suggestions for future studies are as follows. First, due recognition of lags makes a big difference in the literature. Then, dynamic models should be helpful. Second, besides public R&D stimulating business R&D, there is also the question of what the effects on productivity and growth are (Archibugi and Filippetti, 2018). That is a separate important literature referred to in the introduction; we exclude it from the survey –together with that on other than innovation-related indicators– as they can fill surveys on their own; van Elk e*t al*. (2019) have surveyed it; it will become more interesting if connected to the private-public R&D nexus. Third, not only all these effects (also from foreign competitors) matter but also their feedback mechanisms to each other do by way of generating multiplier effects. Fourth, long-term ex-post studies, suggested by Petrin (2018), would lead us to methods of time-series analyses. Fifth, research should consider the role of foreign public spillovers as suggested by Donselaar and Koopmans (2016) and first done by Soete *et al*. (2020)

and Ziesemer (2019). Dealing with these aspects all together implies dealing with input and output additionality (Grilli *et al*., 2018) and answer 'the (not yet resolved) puzzling question: are direct public R&D subsidies really impactful?' (Archibugi and Filippetti, 2018). The issue is not explaining productivity or other innovation indicators separately but rather in connection with business and public R&D as in Soete *et al*. (2020) and Ziesemer (2019). Finally, going beyond finding the consequences of heterogeneity of firms and countries, explaining the heterogeneity of the effects of R&D support may be an interesting research topic. Future research, which considers these aspects, seems to be promising for all the questions related to R&D support.

Notes

1. Salter and Martin (2001) and Antonelli (2019) critically review the fundamental rationale for R&D support.
2. Radicic (2014) gives a more extensive explanation of these cases.
3. See Neicu (2016a); Neicu *et al*. (2016).
4. We indicate below that the literature analyzing the joint effects of several instruments is small. We do not discuss tax-subsidy-law specialties such as incremental and gradual tax schemes, patent boxes, regional R&D policies, support of cooperation, compliance costs and other special areas, because their success indicators differ too much. Of course, the choice of the adequate instruments has an impact on the effectiveness of the policies, but each instrument is generating a literature on its own (Hall, 2019; Bloom *et al*., 2019; Pöschel, 2019).
5. Even without credit constraints, subsidies should in principle lead to cost reductions and more activity unless projects are lumpy and the number of projects going from unprofitable to profitable is low.
6. The instruments are discussed more extensively in Montmartin and Herrera (2015). Negassi and Sattin (2014) provide a meta study. The interaction between tax credit and credit constraints is analyzed by Kasahara *et al*. (2014).
7. Bohnstedt (2014) formulates the problem in terms of a theoretical Melitz framework.
8. A more in-depth treatment requires going deeply into the national tax system, which is beyond the scope of this paper.
9. See references there, which point to microeconomic studies. In addition, Finger (2008) finds a similar result. Guceri (2018) finds a positive impact on the number of researchers controlling for relabeling. Corchuelo and Martínez-Ros (2010) point out that mainly large firms use tax credits and have statistically significant effects in Spain.
10. We do not reinvestigate the surveys, but rather limit ourselves to taking their results and putting a couple of interpreting comments. This biases the number of studies towards more recent ones on purpose, as Cerulli (2010) and Becker (2015) point to the importance of using more sophisticated methods. By implication, studies, which we report in connection with surveys in Table 1, mostly do not appear as country-specific studies in Table 3 to 6.
11. Having endogeneity does not necessarily mean that there is a large bias (see Nakamura and Nakamura 1998 for the econometrics). In addition, when lags are taken into account the issue hardly matters (Lee, 2011).
12. As lags should always play a role, these authors' summary of only 60% of the studies finding a positive effect suggests that lags have often not been considered. Grilli *et al*. (2018), following the pessimistic interpretation of Zúñiga-Vicente *et al*. (2014), ignore the much more positive survey of Becker (2015).
13. We consider emerging economies only when they are related in some way to the EU or the related literature.
14. Diamond (1999), besides the older surveys mentioned here, is a rich source for older literature.

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15. We will not survey the literature where the dependent variables are macroeconomic or production related firm employment (Vanino *et al*., 2019), GDP per capita or productivity (Donselaar and Koopmans, 2016; Aguiar and Gagnepain, 2017). Innovation indicators will be mentioned only as an exception.

16. We do not go into the details of the choice of econometric methods. See Hujer and Radic (2005) on sample selection and footnote 9 above on endogeneity. Møen and Thorsen (2017) discuss econometric reasons for publication bias.

17. Blasio *et al*. (2014).

18. Vanino *et al*. (2019).

19. A different special case leading to a different literature is Catozzella and Vivarelli (2011). Whereas the literature tests for input or output additionality, they test for an increase in the sales/expenditure ratio, requiring that the numerator increases more than the denominator. Thus, even if input and output additionality are given, the criterion may not be fulfilled. Claiming an increase seems to be equivalent to requesting increasing returns to scale or profit rates. If actors do not have it, they fail. It seems more adequate to have yardsticks of policy evaluation, which allow also for constant and decreasing returns to scale and zero profits, because Graves and Langowitz (1996) and Coccia (2009) favor decreasing returns. Theoretically, increasing returns to scale or increasing profit rates lead to world monopoly in R&D.

20 Interesting results regarding publicly performed R&D affecting growth (instead of business R&D, the main topic of our paper) are the following two. Goel *et al*. (2008) find a higher rate of return for federal than non-federal R&D, and for defense compared to non-defense R&D. Duverger and van Pottelsberghe de la Potterie (2011) find that business and education R&D enhances growth, but other public R&D (government) does not.

21. An open issue here is the question whether high-tech support is in line with the principle of technological neutrality. To the extent that high-tech firms are credit constrained, the problem should be addressed directly with credit, not with subsidies. Other imperfections must be important as well to justify subsidies.

22. Meta regression analysis itself is controversial: "MRA aims at isolating average effects and by definition it tends to overlook the role of context-specific moderating factors that likely affects the outcomes of specific policy programs". (Grilli *et al*., 2018, p. 3). A detailed study of the methodologies in this area is Cerulli (2010).

23. Even if additionality is limited, the accumulation of knowledge spillovers adds social value (Antonelli, 2019).

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Resumen

La revisión de la literatura muestra que la mayoría de los estudios encuentran complementariedad entre las subvenciones a la I+D y los gastos privados en I+D. Son pocos los estudios que encuentran un efecto expulsión parcial. Únicamente en pequeñas muestras de las empresas analizadas o en pequeños subsectores de las economías se observa un efecto expulsión total. Es decir, la inversión pública en I+D estimula la inversión privada en I+D. Las excepciones a estos resultados se producen para un determinado tamaño de empresas, cuando existe interacción con otros instrumentos de política pública, o bien cuando las inversiones públicas en I+D no son eficientes. La revisión de la bibliografía sugiere la necesidad de estimar modelos dinámicos que incluyan retardos temporales y recojan los efectos de la heterogeneidad de los países y de las empresas.

Palabras clave: Investigación y Desarrollo, I+D empresarial, subvenciones, I+D público.

Casificación JEL: H25, O38.