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Do public subsidies stimulate private R&D spending?

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Abstract

The objective of this paper is to contribute to the empirical literature that evaluates the effects of public R&D support on private R&D investment. We apply a matching approach to analyze the effects of public R&D support in Spanish manufacturing firms. We examine whether or not the effects are different depending on the size of the firm and the technological level of the sectors in which the firms operate. We evaluate the effect of R&D subsidies on the subsidized firms, considering both the effect of subsidies on firms that would have performed R&D in the absence of public support and also the effect of inducement to undertake R&D activities. We also analyze the effect that concession of subsidies might have on firms which do not enjoy this type of support. The main conclusions indicate absence of "crowding-out", either full or partial, between public and private spending and that some firms – mainly small and operating in low technology sectors – might not have engaged in R&D activities in the absence of subsidies.

JEL classification: O38; L1; C21

Keywords: R&D; Subsidies; Matching estimator

1. Introduction

A long-standing result in industrial organization is the suboptimality of firms' R&D expenditures as a consequence of market failures associated with innovation activities. The presence of externalities creates a gap between private and social profitability of these activities and therefore firms spend less on R&D than is socially optimal (Arrow, 1962). Public intervention tries to solve this problem. In fact, one of the explicit targets of many governments is to increase the amount of resources allocated to R&D activities. Along this line, the European Commission has established the objective of increasing R&D to 3% of GDP by 2010.[2]

Financial support (subsidies, fiscal incentives and/or loans) constitutes the principal instrument for stimulating industrial R&D, and it has been actively used to promote innovation and R&D activities in most OECD countries. Particularly, subsidies have come to be, after regional aid, the largest type of industrial support in developed countries (Nezu, 1997). The main purpose of these incentives is to reduce the effective

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[2] This objective was assumed at the European leaders' meeting held in Barcelona in March 2003 and is explicit in the European Commission Communication (2002) "More Research for Europe: towards 3% of GDP" (http://ec.europa.eu/research/era/pdf/com3percent_en.pdf).

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cost of R&D and therefore to increase firms' R&D spending. However, to what extent they induce firms to increase their R&D investment is an open question that should be analyzed in depth. Although economists and policy-makers agree on the need to stimulate innovative activities, and also on the interest of evaluating public R&D policies, there is a lack of evaluating programs, perhaps due to the complexity of implementing some methods.

The main concern of this paper is to assess, using a matching approach, the effectiveness of public R&D funding in enhancing firms' spending on R&D, analyzing whether the effects are different depending on the size of the firms and on the technological level of the sectors in which the firms operate. First of all, we evaluate the effect of subsidies on the R&D effort (R&D expenditure over sales) of firms that have received them and we also provide some results regarding the total amount of R&D expenditures. We consider both the effect on firms that would have performed R&D activities in the absence of public support and also the effect of inducement to undertake R&D activities on some firms. This inducement effect is often ignored because most papers use samples that include only innovating firms. Furthermore, we analyze the effect that concession of subsidies might have on firms which do not enjoy this type of support.

Our study contributes to the empirical literature – which is discussed in the next section – on the analysis of the existence or non-existence of a crowding-out effect; that is, do public funds substitute or complement private R&D expenditures? This is relevant because a full crowding-out effect implies a complete substitution of private by public funds, and this means that firms' total R&D expenses would be the same with or without subsidies. Partial crowding out occurs if firms raise their total R&D, but this amount is smaller than the subsidy itself. In both cases, far from achieving the objective of increasing firms' private (own) R&D expenditures, public support would have the opposite effect. Many works analyze only the presence or absence of full crowding out. In this paper, we are able to identify the existence or absence of partial crowding out, as data availability allows us to distinguish between total and private firms' R&D. Moreover, we identify differences in subsidy effectiveness according to firms' size and industry type.

To evaluate the effect of subsidies, we implement the bias-corrected matching estimator recently proposed by Abadie and Imbens (2006); this estimator improves the standard nearest-neighbor matching estimator. Matching estimators have been widely used in recent years to evaluate different types of public policies.[3] They are intuitive methods – based on the comparison of the results obtained by the participants in a program with those obtained by a "comparable" non-participant control group – that do not require the specification of any functional form.[4] Moreover, they are easier to understand and easier to implement than other methods, and these constitute advantages that could encourage policy-makers to evaluate the effectiveness of R&D instruments. Although they are not a substitute for more structural econometric models, they may complement them, especially as a first approximation to the matter. In fact, as Imbens (2004) points out, they are a natural starting point in the evaluation of any policy.

In this paper, we discuss the relevance of taking into account the persistence of the innovative activity in the matching procedure. In another case, the estimated effects would be biased and the political recommendations inspired by these estimated effects might not be reasonable. We also discuss the importance of using information about non-R&D performing firms and of analyzing the effect on private (own) R&D variables instead of total R&D variables. To our knowledge, there is no paper that uses matching approach and discusses all of these questions.

We apply this methodology to evaluate the effect of R&D subsidies granted to Spanish manufacturing firms during the 1990s. The effectiveness of public R&D instruments is an especially relevant issue for Spain. Spain has to overcome a notably unfavorable situation as it is currently ranked near the bottom of the UE-15 countries in terms of technological intensity.[5] This circumstance should promote an active technological policy in order to reduce the gap with the European average. In fact, Spain is one of the OECD countries with the most generous financial incentives (OECD, 1998), particularly fiscal incentives and subsidies.[6]

[3] This methodology has been largely employed in the evaluation of labor policies (see Heckman et al., 1999).

[4] The main contribution of the bias-corrected matching estimator proposed by Abadie and Imbens (2006) is that it reduces the bias due to the fact that it is impossible to find identical firms.

[5] In Spain, total R&D spending was 0.98% of the GDP in 2000, while the EU-15 average was 1.93% (and the EU-25 average 1.88%) (Source: Eurostat).

[6] The OECD (1998) report compares the importance of fiscal and direct aid for firms' R&D, analyzing the percentage of firms' R&D that is publicly financed and an index of fiscal generosity (beta-index) in different OECD countries. Spain's relative position in both types of incentives is higher than the average.

The data used in this paper is an unbalanced panel of Spanish manufacturing firms observed from 1990 to 1999. The data come from a random sample of manufacturing firms drawn by industries and size strata. This sample supplies a wealth of information on a wide number of firms' characteristics, including many R&D variables (in particular, firms' R&D expenditures and subsidy amounts). The sample includes more than nine thousand observations from 2214 firms.

Our results suggest the absence of a crowding-out effect, either full or partial, between public and private R&D expenditure, though the presence of subsidies hardly stimulates private R&D spending of firms engaged in R&D activities in any case. Nevertheless, we detect that public financing is more effective in firms of low technology sectors and small size, probably due to the inducement to perform R&D in a number of these firms. Additionally, we show that, if we do not take into account the persistence of the innovative activity in the matching procedure, the estimated effect would be considerably higher. Moreover, we compare our results with those of other studies which apply the same approach to data from different countries, and also with the results of González et al. (2005), which apply a semistructural econometric model to the same data.

The paper is organized as follows. Section 2 reviews a selection of papers on the effect of subsidies on firms' R&D decisions. Section 3 describes the data and presents some evidence on R&D activities and subsidies in Spain. Section 4 briefly outlines the estimation method and Section 5 presents the results. Finally, Section 6 summarizes the main conclusions. Appendix A provides further information for evaluating subsidy effectiveness. Variable definitions and descriptive statistics are included in Appendix B.

2. R&D and public incentives: what do we know?

The main public financial support for encouraging firms' R&D activities are tax incentives and direct government funding. Some papers have focused on the analysis of the role of fiscal incentives (see, for example, the survey by Hall and Van Reenen, 2000), but there are more that have studied the effects of direct financial aid on R&D in an attempt to reveal whether or not these incentives stimulate firms' own spending on these activities. In particular, the question that has received the most attention is whether public financing increases firms' R&D expenditures or, on the contrary, whether there is a crowding-out effect.

Existing evidence on the effect of subsidies is still modest and controversial, though in recent years there has been a notable increase in microeconometric works. David et al. (2000) carry out an extensive revision of this literature, finding substitution effect between public and private R&D in one-third of the studies analyzed.[7] They point out that the proportion of studies that detected substitution of public by private funds is even higher among those conducted at the highest level of disaggregation (9 of the 19 studies conducted at firm or factory level) and in those based on data from the USA (9 of 21 studies). This survey does not offer a general conclusion about the relationship between public and private R&D, arguing several reasons: firstly, the multiplicity of approaches that appear in the literature; secondly, the different level of data disaggregation employed; and, lastly, the variety of modes and purposes of government R&D funding.

Later articles also present conflicting answers in the evaluation of the effectiveness of public subsidies. In particular, Wallsten (2000) uses a simultaneous model of spending and subsidies for a sample of US firms and finds no effect of the subsidies, detecting full crowding out. On the contrary, Lach (2002) and Hussinger (2003) obtain less unfavorable results. Lach (2002) identifies a positive increase in R&D spending of small firms and a non-significant effect in large firms, using a panel data of Israeli firms. Hussinger (2003) uses a semiparametric model of sample selection with a sample of German manufacturing firms and obtains a positive effect on firms' R&D spending.

Evidence of subsidy efficiency using Spanish data is scarce. Busom (2000), applying a two-step sample selection econometric model to a subsample of 145 firms that received financial support from CDTI[8] in 1988, obtains, on average, a positive effect, though she does not reject a full crowding-out effect in 30% of the firms. González et al. (2005), using data from the same panel of manufacturing firms that we use in this paper, propose a semistructural framework to explore the effect of subsidies on firms' R&D decisions, in particular on the decision of whether or not to perform innovative activities as well as on the associated effort level.[9] The main results indicate no substitution effect of private spending by public funds, though the subsidies go

[7] Another survey of interest is that of Klette et al. (2000), which focuses attention on the effect of four state support programs for R&D projects related to high-technology sectors.

[8] Center for Industrial Technological Development (*Centro para el Desarrollo Tecnológico Industrial*).

[9] This work tackles the problems of sample selection and of endogeneity of subsidies by means of a model of firms' R&D decisions that takes into account, among other factors, their ex-ante expectation on the subsidies.

mainly to firms that would have performed R&D activities anyway.[10]

In the most recent international studies, there is a widespread tendency to apply matching estimators, using firm data, to analyze the effect of R&D subsidies. These similarities may facilitate the comparability of the results, especially if the R&D policies analyzed have similar characteristics, but the use of data with different features may complicate it. Samples often only include R&D performers' data and/or have no information about the amount of subsidies. In the former case, it is not possible to consider the potential effect of subsidies on the inducement to carry out R&D activities; in the latter, as it is not possible to determine which part of firms' R&D expenses correspond to firms' own expenses, the presence of partial crowding out cannot be assessed. Moreover, most samples do not have information about lagged variables which would allow us to consider the persistence of the innovative activity.

Among the published studies that employ this methodology are Almus and Czarnitzki (2003) and Czarnitzki and Licht (2005), which use data from a survey of innovating German manufacturing firms, Duguet (2004), which uses a pool of French R&D-performing firms and Herrera and Heijs (2007), which use a sample of Spanish R&D-performing firms. None of these papers is simultaneously able to consider the inducement effect, to analyze full and partial crowding out and to take into account R&D persistence. Only Czarnitzki and Licht (2005) explicitly take into account the inducement effect, given that their sample includes some innovating firms that do not perform R&D. Only Duguet (2004) uses lagged R&D effort to consider R&D persistence, while the first two articles use rougher indicators (R&D department dummy, number of patent applications). All of these papers reject the presence of full crowding out, but only Duguet (2004) is able to confirm the absence of partial crowding out, as he uses information on the subsidy amounts.[11]

Therefore, the most recent articles seem to agree on the absence of a full crowding-out effect of subsidies, but there is less evidence with regard to the subsidy contribution to private R&D effort increase (or decrease). Our paper contributes to this discussion, paying attention to the potential effect of subsidies on the inducement to undertake R&D activities, and also the effect on firms that would engage in these activities anyway. Moreover, we will highlight the relevance of considering the persistence of R&D activities.

3. R&D and subsidies in Spanish manufacturing firms

The data used to carry out this research comes from a survey financed by the Spanish Ministry of Industry, the Survey on Firm Strategies (*Encuesta Sobre Estrategias Empresariales*). The data set consists of an unbalanced panel of Spanish manufacturing firms observed during the period 1990–1999.[12] After eliminating the observations for which all the necessary information is not available, the sample includes a total of 9455 observations from 2214 firms.[13]

The survey contains information on firms' total annual R&D expenditures, which include the sum of internal and external R&D expenses and the imports of technology (payments for licences and technical assistance[14]). The data also involves information regarding public R&D funding in the form of subsidies that have contributed to the financing of firms' R&D activities. We consider a firm to be subsidized if it has received some financial support from any of the public programs available.[15] In what follows, we present some evidence regarding R&D expenditures and subsidies, with special attention to heterogeneities relating to firm size and sector of activity.[16]

Table 1 shows the percentages of firms that perform R&D activities according to firm size. The table also shows the proportions of R&D-performing firms

[10] With regard to other types of financial aid, Heijs (2003) analyzes the effect of soft loans on research projects using Spanish firm data. His qualitative analysis, based on surveys to the firms, shows that 85% of the firms declare an increase in their total R&D expenditure equal to the support obtained, while 15% declare that public funds substitute private investment.

[11] Appling the same methodology, Czarnitzki and Fier (2002) analyze the effect of the subsidies in the German service sector, also obtaining a significant effect. Other papers along this line are Kaiser (2006), Aerts and Czarnitzki (2005) and Lööf and Heshmati (2005).

[12] At the beginning of the survey, firms with fewer than 200 workers were sampled randomly by industry and size strata retaining 5%. Firms with more than 200 workers were all requested to participate, and the positive answers initially represented approximately a self-selected 60% of firms within this size. To preserve representation, samples of newly created firms were added every subsequent year.

[13] As we need some lagged variables, the sample contains observations from 1991 to 1999, and we discard the observations of firms that appear in the data set just 1 year.

[14] Some R&D programs provide subsidies for these kinds of expenditures.

[15] The survey includes information regarding public financing received from three sources: the central administration, regional administrations (the autonomous communities) and other organisms.

[16] The percentages and averages in the tables are obtained by treating observations as a pool of data.

Table 1
Firms with R&D activities and supported firms (by size)

	Observations	With R&D (%)	With subsidies (%)
Firm size			
≤20 workers	3080	9.1	6.1
20–50 workers	2270	20.4	14.4
50–100 workers	741	35.5	21.3
100–200 workers	843	53.5	20.6
200–500 workers	1797	71.7	23.8
>500 workers	724	84.8	30.5
Total	9455	35.5	21.6

Table 2
R&D effort with and without subsidies (by size) (averages of non-zero efforts, in %)

	With subsidies		Without subsidies
	Total effort	Private effort	Effort
Firms size			
≤20 workers	5.52	3.49	2.18
20–50 workers	3.42	2.55	1.73
50–100 workers	5.55	4.04	1.80
100–200 workers	3.41	2.64	1.89
200–500 workers	4.12	3.56	1.62
>500 workers	3.39	3.01	1.71
All firms	3.91	3.25	1.76

that receive subsidies. Performance of R&D activities increases systematically with firm size, from 9% for the smallest firms to 85% for the biggest, and concession of subsidies does not seem to be random by size, either. While only 6% of the smallest performing firms receive some type of subsidy, this percentage rises to 30% in the performing firms with more than 500 workers.

Table 2 depicts technological effort according to firm size.[17] For the group of firms that received subsidies, it is necessary to distinguish between total and private R&D effort. The latter is obtained by deducting the quantity received as subsidies from firms' total R&D expenditures.

Firstly, the table shows that the difference between total and private R&D effort for subsidized firms is on average 0.66 percentage points, the difference being lower for the group of firms with more than 200 workers. This result suggests that, though the amount of subsidies is greater for the bigger firms, it is smaller in relative terms. Secondly, it may be noticed that the private effort of subsidized firms is notably higher than the effort of firms without subsidies; on average, the difference is 1.5 percentage points. This, however, may be the consequence of the stimulating effect of subsidies or may simply be due to the subsidies being directed to firms that, even without subsidies, would make a higher-than-average technological effort. The objective of our paper is precisely to contribute to clarifying this question. Lastly, there does not seem to be any direct relationship between firm size and the difference between private effort with and without subsidies.

Table 3 presents the differences by sector in the proportions of firms with R&D activities and in the proportions of subsidized R&D-performers. The table provides aggregate information from the observations corresponding to high and medium-high technology sectors and from those corresponding to low and medium-low technology sectors.[18] The table also provides disaggregate information corresponding to the 6 high and medium-high technology sectors (of the 18 into which the manufacturing activity has been divided).[19] The percentage of R&D-performing firms differs considerably between the two groups of sectors. While 65% of the firms undertake R&D activities in the first, this percentage falls to 25% in the second. There are also notable differences in the obtaining of public support. The percentage of firms in high and medium-high technology sectors that have received subsidies is 26%, while only 18% have been subsidized in the low and medium-low technology sectors. The *chemical products* sector is the most innovative, while *other transport equipment* is, proportionally, the sector with more subsidized firms (followed closely by the *chemical products* sector).

Table 4 shows average R&D efforts by sector of activity. First to be noticed is the higher average R&D effort (total and private) of firms in high and medium-high technology sectors, and that the difference with the less technological sectors is greater in the subgroup of subsidized firms. Secondly, it can be seen that the gap between total and private efforts of subsidized firms is also greater in the sectors of higher technology: 0.76 against 0.52 percentage points. Lastly, in both cases, it is evident that

[17] All effort averages have been calculated using the observations with positive R&D expenditures, eliminating atypical observations corresponding to firms that declared in t (33 observations) or declared in $t-1$ (30 observations, 10 of them with subsidies in the period t) a subsidy amount higher than the associated yearly R&D expenditures. These are atypical probably due to accounting imperfections in the temporal allocation of subsidies.

[18] To classify the sectors according to their technological level, the standard classification of the Spanish "Instituto Nacional de Estadística", INE, has been used. For further details, see: http://www.ine.es/daco/daco42/daco4217/lstsectcnae.doc.

[19] For further details regarding the sector classification employed, see Table B1 of the data Appendix B.

Table 3
Firms with R&D activities and supported firms (by sector)

	Observations	With R&D (%)	With subsidies (%)
Low and medium-low technology	6981	25.2	17.8
High and medium-high technology	2474	64.6	25.8
Chemical products	631	73.4	32.8
Agricultural and industrial machinery	478	53.1	15.0
Office and data processing machinery	76	59.2	17.8
Electrical goods	695	70.1	25.5
Motor vehicles	398	62.1	20.6
Other transport equipment	196	52.0	39.2

the private effort of subsidized firms is greater than the effort of firms without subsidies. The difference is almost 2 percentage points in the high technology group, and little more than 0.5 percentage points in the low technology sectors. However, it is again necessary to perform a detailed analysis to detect whether or not this is due to a greater effectiveness of the public grants in the more technological sectors.

The notable heterogeneity by sector and size detected in both the probability of receiving subsidies and the R&D effort points out the relevance of taking into account these firms' characteristics in the matching procedure.

4. Estimation method

In this paper, we apply matching estimators in order to evaluate the effectiveness of R&D subsidies. In particular, we are interested in studying whether subsidized firms have a better outcome in terms of their own R&D effort (and expenditure) than non-subsidized firms.

Matching estimators are widely used to evaluate economic policy interventions. These estimators are based on the comparison of the results obtained by the participants in a program, the treated group, with those obtained by a "comparable" non-participant control group. Under some assumptions, the difference in outcomes between these two groups may be attributed to the program or treatment.

Let T_i be a dummy variable which takes the value one if firm i receives a subsidy. Let $Y_i(0)$ be the R&D effort of firm i if it had not obtained subsidies, and $Y_i(1)$ the R&D effort of the same firm if it had obtained subsidies. Clearly, if both results were simultaneously observed, the effect of the subsidies on the R&D effort of firm i, $Y_i(1) - Y_i(0)$, would be directly observable. The population average of this effect could be obtained as $E[Y(1) - Y(0)]$, and its sample counterpart as $(1/N)\sum_{i=1}^{N}[Y_i(1) - Y_i(0)]$, where N is the number of firms.

Additionally, we could obtain the subsidy effect on the subpopulations of subsidized and non-subsidized firms. If N_1 is the number of subsidized firms and N_0 the number of non-subsidized, $N = N_1 + N_0$, the population and sample average effects of subsidies for the subsidized firms are $E[(Y(1) - Y(0))|T = 1]$ and $(1/N_1)\sum_{i|T_i=1}[Y_i(1) - Y_i(0)]$, respectively. Similarly, we can define the population and sample average effects of the subsidies for the controls as $E[(Y(1) - Y(0))|T = 0]$, and $(1/N_0)\sum_{i|T_i=0}[Y_i(1) - Y_i(0)]$.

Table 4
R&D effort with and without subsidies (by sector) (averages of non-zero efforts, in %)

	With subsidies		Without subsidies
	Total effort	Private effort	Effort
Low and medium-low technology	2.24	1.72	1.20
High and medium-high technology	5.15	4.39	2.44
Chemical products	6.98	6.52	2.42
Agricultural and industrial machinery	5.21	4.00	2.28
Office and data processing machinery	1.58	1.26	1.56
Electrical goods	4.37	3.22	2.66
Motor vehicles	2.56	2.28	2.29
Other transport equipment	4.53	3.43	2.75

The main problem with the above measures is that $Y_i(1)$ and $Y_i(0)$ are not simultaneously observable. That is, the R&D efforts of the same firm in both situations, receiving and not receiving the subsidy, are not simultaneously observable. Therefore, to measure the effect of subsidies, we need to estimate or approximate the counterfactual.

If obtaining subsidies were random, we could estimate the subsidy effect on R&D effort as the difference between the average effort of subsidized firms and the average effort of unsubsidized firms. However, a more plausible assumption is that subsidies are not randomly distributed. For example, larger firms or those with a long history of R&D activities are more likely to obtain them. In this case, the unobserved outcomes could be approximated using the average of outcomes corresponding only to firms with "similar" characteristics, that is, firms with "similar" values of some pre-treatment variables or covariates, X. To apply this procedure, in order to ensure that matching estimators identify and consistently estimate the treatment effect, we assume two conditions.

(1) *Unconfoundedness*: Conditional on the covariates $X=x$, the outcomes ($Y(0)$, $Y(1)$) are independent of the assignment to treatment T. This implies that:

$$E[Y(0)|T=1, X=x] = E[Y(0)|T=0, X=x]$$

$$\text{and} \quad E[Y(1)|T=1, X=x] = E[Y(1)|T=0, X=x]$$

(2) *Overlap*: Conditional on $X=x$, the probability of obtaining a subsidy is bounded away from zero and one. That is, $c < P(T=1|X=x) < 1-c$, with $c > 0$. This is an identification assumption which means that for the subsidized (non-subsidized) firms with a given covariate pattern, there would be "similar" non-subsidized (subsidized) firms with which to compare them.

The unconfoundedness assumption implies that, conditional on some characteristics (covariates), the subsidies assignment is random, so differences in outcomes between treated and controls can be attributable to the subsidies. Therefore, the selection of the set of characteristics X becomes a key element in the application of matching estimators. The acceptance of the unconfoundedness assumption cannot be directly tested, but the availability of ample information is important in order to define a vector of covariates X that makes the assumption more plausible. It should include variables that determine the probability of obtaining a grant, or this probability directly (Rosenbaum and Rubin, 1983). Additionally, some authors (Imbens, 2004) highlighted the interest of introducing lagged outcomes.

Another relevant issue is that if X contains some continuous variable, it is impossible to find twin firms, that is, firms with exactly the same characteristics. The literature has proposed different procedures to circumvent this problem. In this paper, we use the bias-corrected nearest-neighbor matching estimator, recently proposed by Abadie and Imbens (2006). For each firm i, the standard nearest-neighbor matching estimator searches for the most similar firm with the opposite treatment; that is, the firm with the set of covariates X at the nearest distance,[20] and uses the outcome of the firm so selected (or the average outcomes of the selected ones if there are ties) to estimate the non-observed outcome of i ($\widehat{Y_i(0)}$ if i is a subsidized firm, $\widehat{Y_i(1)}$ if i is a non-subsidized firm).

Abadie and Imbens (2006) demonstrate that the standard matching on a multidimensional vector of covariates can lead to a substantial bias when the matching is not exact. They propose a bias-corrected matching estimator to reduce this bias, adjusting the estimated non-observed outcome of i for the difference between the covariates for unit i and its match. In order to implement their estimator, two steps are necessary. When we are interested in the estimation of $\widehat{Y_i(0)}$, the first step is to regress (by OLS) the outcome variable on the covariates, using the sample of selected controls. In the second step, the estimated coefficients are used to predict the outcome for i and its match. To obtain $\widehat{Y_i(0)}$, the difference between these two estimated values will be added to the observed outcome of the match. When we are interested in the estimation of $\widehat{Y_i(1)}$, in the first step the regression will be carried out using the sample of the matches selected for the controls.[21]

Finally, to estimate the effect of subsidies on subsidized firms, we obtain the sample average subsidies effect in the subpopulation of granted firms, denoted by SATT[22]:

$$\text{SATT} = \frac{1}{N_1} \sum_{i|T_i=1} [Y_i(1) - \widehat{Y_i(0)}]$$

[20] Let $||x||V = (x'Vx)^{1/2}$ be the vector norm with positive definite matrix V. We define $||z-x||V$ as the distance between the vectors z and x, with V being the diagonal matrix constructed from the inverses of the variances of each element of X.

[21] For a detailed explanation of the bias-corrected matching estimator and its implementation in STATA, see Abadie and Imbens (2006) and Abadie et al. (2004).

[22] Sample Average Treatment effect for the Treated.

Similarly, to estimate the effect that granting could have on non-subsidized firms, we obtain the sample average treatment effect for the controls, SATC[23]:

$$\text{SATC} = \frac{1}{N_0} \sum_{i|T_i=0} [\widehat{Y_i(1)} - Y_i(0)]$$

In the next section, we detail the vector of covariates X used in this paper and we present the main results.

5. Results

The vector of covariates X that we used in the matching procedure includes several variables.[24] The first is the estimated probability of obtaining a subsidy (the propensity score), which is the standard variable used to select the controls in most papers. Secondly, we consider the lagged outcome, that is, the lagged private effort.[25] The notable persistence that characterizes R&D activities makes it advisable to include this variable to avoid the bias that its absence might produce. Similar R&D pre-treatment behavior between each treated observation and its selected control is important to correctly evaluate the effects of subsidies. Thirdly, we include the lagged subsidy dummy in order to take into account the persistence of the granting of subsidies. In this way, treated and selected controls will have the same status with regard to subsidy concession in the previous year. Lastly, we impose that, for each firm, the most similar firm is going to be searched for within the same sector of activity, stratum of size and time period.[26] The data scarcity within some sectors and size strata force us to consider just 12 sectors, 2 sizes (under and above 200 workers) and 2 periods of time.[27]

Notice that the vector of variables X includes discrete and continuous variables. The matching will always be exact in the sector, size and period dummies, and it will be exact in more than the 95% of the cases (often in 100%; see below) in the lagged subsidy dummy.[28] However, as it is not possible to find observations which take identical values in the relevant continuous variables (probability and lagged R&D private effort), we will match observation i with the observation with the opposite treatment whose vector of continuous characteristics is found nearest to the vector of continuous characteristics of i (see endnote 20).[29]

We employ two different groups of observations to select the controls for the SATT estimator: first of all, only observations with R&D activities; and secondly, the full sample which includes observations with and without R&D expenditures. In the first case, we evaluate the stimulus of subsidies on the effort considering that all subsidized firms would have performed R&D activities in the absence of subsidies. In the second case, we also take into account the potential effect of subsidies on the inducement to undertake R&D activities.[30]

In what follows, firstly, we summarize the probit specification used to estimate the probability of getting subsidies; secondly, we compare the treated and control groups of observations, before and after the matching, and then we discuss the results we obtain regarding subsidy effectiveness.

5.1. Probability of receiving subsidies

The probability of receiving public financing is obtained from the estimation of a probit model which follows González et al. (2005).[31] The dependent variable takes the value one if the company has got public funding, and zero in the other case. The vector of explanatory variables includes firm characteristics that may influence the probability of getting public funds.

Firstly, we included a dummy variable which takes the value one if the firm has received a subsidy in the previous period. This variable tries to capture the per-

[23] As our sample includes non-R&D performers and it is not possible to determine which of them will be induced to undertake these activities, the estimator SATC (Sample Average Treatment effect for the Controls) is obtained for a subset of N_o which correspond to the unsubsidized R&D-performers (this subset contains 2191 observations).

[24] Definitions of variables can be found in Appendix B, which also includes some descriptive statistics.

[25] When we analyze the effect of subsidies on R&D expenditure, we include as lagged outcome variable the lagged private expenditure.

[26] We will consider each observation in our sample as if it were a different firm.

[27] We aggregate some of the 18 sectors into which the manufacturing activity was initially divided (sectors 1 + 4, 6 + 7, 8 + 9, 10 + 11 + 12, 13 + 14, detailed in Table B1), in accordance with the standard industrial aggregation of the Spanish "Instituto Nacional de Estadística", and we consider 2 periods of time, 1991–1995 and 1996–1999, depending on the multiannual R&D public programs. For the SATC estimator, instead of 12 sectors, we just consider 2 groups of sectors: low and m-low tech sectors; and high and m-high tech sectors.

[28] There are a small number of cases for which there are no observations with the opposite treatment that satisfies all the discrete conditions (size, sector, period and lagged subsidy dummy). We take this into account when we apply the bias-correction procedure.

[29] In case of a tie, the (bias-adjusted) average of the outcomes of the tied observations is used as the estimate of the unobserved outcome of i.

[30] As we already pointed out, most studies restrict the potential control group to R&D-performing observations.

[31] Blanes and Busom (2004) also analyze the determinants of participation in R&D subsidy programs using data from the same survey.

Table 5
Estimate of the probability equation

Dependent variable: indicator of R&D subsidies	Coefficients (t-ratios)
Constant	−2.83 (−12.7)
Subsidy dummy $t-1$	1.89 (23.9)
Number of workers $t-1$	0.04 (4.3)
Capital growth	0.18 (3.3)
Age	0.04 (2.6)
Technological sophistication	2.48 (5.7)
Foreign capital dummy	0.17 (2.3)
Domestic exporter dummy $t-1$	0.47 (7.8)
Firm with market power dummy $t-1$	0.03 (0.5)
Abnormal subsidy dummy[a]	−0.79 (−3.8)
Industry, region and time dummies[b]	Included
Estimation method	Probit
Number of firms	2214
Number of observations	9455
Correctly predicted observations[c]	
Zeroes	0.84
Ones	0.83

Source: González et al. (2005).
[a] Dummies to account for a total of 33 subsidy coverages higher than yearly expenditure.
[b] 17 industry dummies, two particular region dummies (Navarre and Basque Country), and yearly dummies for period 1992–1999.
[c] Using 0.055 as critical value.

sistence in the concession of public support (grants that spread to several periods, renewal of previous grants, etc.). Secondly, we introduce relevant characteristics of the firm such as size (number of workers), capital growth (in equipment and machinery goods), age (experience), and an indicator of using advanced technology in production. They can be relevant for the eligibility of the firm and therefore for the firm's decision on whether or not to apply for grants. Thirdly, two indicators of firm internationalization – the presence of foreign capital and the exporting character of firms – and one indicator of the market power of the firm are included. They can influence the decisions of the granting agencies due to politico-economical reasons. Finally, three sets of dichotomy variables take into account sector heterogeneity (industry dummies), differences in regional R&D policies (region dummies) and cyclical changes (yearly dummies). Additionally, a dummy controls for some atypical subsidies.[32]

Table 5 shows the results of the probit estimation. The percentage of correctly predicted zeroes and ones implies an acceptable goodness of fit.[33] The results indicate that persistence is significant and that the process of conceding grants seems to favor bigger firms, firms which have higher capital growth, more experienced firms, more technologically advanced firms and firms that have more contact with foreign markets. However, having significant market power does not imply differences in the receiving of subsidies. The sector dummies reveal the existence of heterogeneity among industries, and the region dummies show a greater probability of receiving subsidies in two regions.

We used the estimated parameters to obtain the prediction of the probability for all the observations of the sample (the propensity score).

5.2. Comparison between treated and controls

In order to analyze the similarity between treated and controls, Table 6 presents the means of relevant variables, and Figs. 1 and 2 present the kernel densities of the propensity scores and the lagged private efforts before and after the matching.

Table 6 provides information about the variables included in the probability equation previously estimated, and about the two continuous covariates included in X (lagged private effort and probability of receiving subsidies). The table includes the mean values of the variables in several subsamples: the group of supported firms or treated group (first column), the groups of non-supported firms used as potential controls (columns 2 and 4) and the groups of the controls finally selected applying the matching procedure (columns 3 and 5). For each variable, we compare the mean for the treated with the means for each of the remaining subsamples using a two-tailed t-test. The results of the tests are summarized with a star (or two), indicating that we do not reject the equality of the means.

Table 6 shows that the group of treated appears highly different from the groups of potential controls, but the similarity between treated and controls after the matching provides sensible results; the differences have been significantly reduced.

Another method to evaluate the quality of the matching is to compare not only the average values of variables but the whole distribution. Fig. 1 presents the kernel density estimates of the probability of receiving subsidies and of the lagged private effort. As we can see, the kernels show great differences between the groups of subsi-

32 A variable dummy is introduced for 33 observations corresponding to subsidy amounts higher than the associated yearly R&D expenditures, probably due to accounting imperfections.

33 The critical values have been adjusted as the sample has only 8% of ones.

Table 6
Mean comparison of supported firms, non-supported firms and selected controls

	Supported firms	R&D performers		All firms	
		Non-supported firms	Selected controls	Non-supported firms	Selected controls
Number of workers $t-1$	448.39	295.95	438.48**	148.03	424.09**
Capital growth	0.10	0.10**	0.08**	0.09**	0.08**
Age	9.39	6.49	10.14**	0.48	9.57**
Technological sophistication	0.05	0.04	0.05*	0.02	0.05*
Foreign capital dummy	0.33	0.42	0.45	0.19	0.42
Domestic exporter dummy $t-1$	0.65	0.50	0.57	0.39	0.58*
Firm with market power dummy $t-1$	0.53	0.59*	0.62	0.38	0.61
Subsidy dummy $t-1$	0.63	0.07	0.62**	0.03	0.63**
Private effort $t-1$	2.39	1.43	2.06*	0.51	2.07*
Probability of receiving subsidies	0.45	0.09	0.44**	0.04	0.44**
Number of observations	630	2569	630	8241	630

* We do not reject the null hypothesis (equality of the means) in a two-tailed t-test at the 1% level of significance between the supported firms and the subsample of firms indicated at each column.
** We do not reject the null hypothesis (equality of the means) in a two-tailed t-test at the 5% level of significance between the supported firms and the subsample of firms indicated at each column.

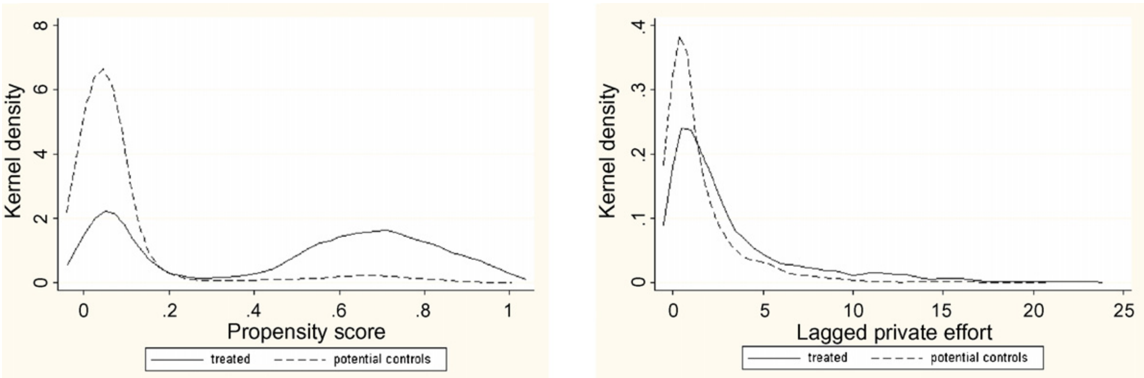


Fig. 1. Propensity score and lagged private effort of treated and potencial controls considering only R&D observations.

dized and non-subsidized R&D-performing firms for both variables: the distribution of non-supported firms is more concentrated in small values of the lagged private effort and the propensity score. Nevertheless, the kernels are very similar when the comparison is made with the selected controls (Fig. 2).

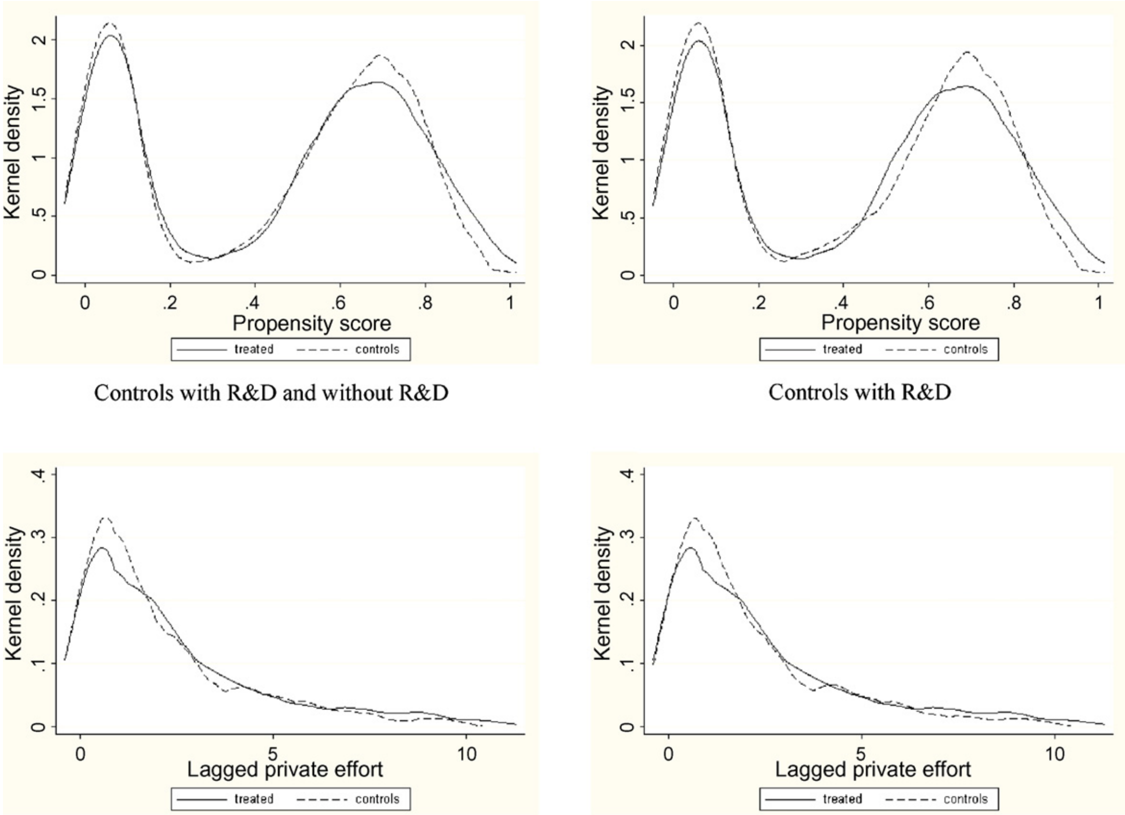
5.3. Subsidy effectiveness

Tables 7 and 8 present the estimated effect of subsidies on subsidized firms (SATT estimators) considering as performing variable the R&D effort (Tables A1 and A2 in Appendix A present the SATT estimators, considering the R&D expenditure as performing variable).[34]

Table 9 presents the potential effect of subsidies on non-subsidized firms (SATC estimators). The tables indicate the number of observations included in the group of treated and in the group of potential controls employed to obtain each estimator,[35] the percentage of exact matching for the lagged subsidy dummy, and at which level of significance we do not reject the hypothesis that the mean of the continuous variables does not differ between the treated and the selected controls.

[34] As can be detected, the general conclusions are the same independently of the outcome variable considered. Then we discuss mainly the results obtained for the R&D effort.

[35] In order to assure overlap, we discard some observations with outlying covariate values. We restrict the estimation to the region of common support of the propensity score, and additionally we eliminate a few observations with extremely large lagged private effort (greater than the mean plus twice the standard deviation of this variable for the sample of non-zero efforts). See Imbens (2004) on how to address limited overlap.



Controls with R&D and without R&D

Controls with R&D

Controls with and without R&D

Controls with R&D

Fig. 2. Propensity score and lagged private effort of treated and selected controls.

Table 7 shows the effect of subsidies on private and total R&D effort of subsidized firms, considering only observations with R&D activities to be potential controls. The first result to emphasize is that subsidies have no effect on stimulating the private R&D effort of performing firms, but the effect on the total R&D effort of these firms is positive and significant. This result indicates that no crowding-out effect exists, i.e., firms add the amount of subsidies to their private budget, not substituting private R&D investment by public funds,

Table 7
Subsidy effects

	All	≤200 workers	>200 workers	Low–m-l tech.	High–m-h tech.
Private effort[a]	0.09 (0.7)	−0.07 (−0.3)	0.17 (1.0)	0.06 (0.4)	0.19 (0.8)
Total effort[a]	0.72 (4.5)	0.92 (3.0)	0.62 (3.4)	0.59 (3.3)	0.90 (3.5)
t-Tests on the equality of means[b]					
Probability	**	**	**	**	**
Private effort $t-1$	*	*	**	**	**
Percentage of exact matching (subsidy dummy $t-1$)	99	100	98	96	100
Potential control group (number of observations)	2569	1182	1387	1418	1151
Treated group (number of observations)	630	205	425	287	343

Average treatment effect for the supported firms. Control group: observations with R&D.

[a] Coefficients and *t*-ratios.

[b] Asterisk (*) indicates that we do not reject the null hypothesis (equality of the means) in a two-tailed *t*-test at the 1% level of significance between the supported firms and the selected control firms and asterisk (**) indicates that we do not reject the null hypothesis (equality of the means) in a two-tailed *t*-test at the 5% level of significance between the supported firms and the selected control firms.

Table 8
Subsidy effects

	All	≤200 workers	>200 workers	Low–m-l tech.	High–m-h tech.
Private effort[a]	0.35 (2.4)	0.59 (2.3)	0.24 (1.5)	0.55 (3.5)	0.29 (1.2)
Total effort[a]	0.98 (6.0)	1.58 (5.4)	0.70 (3.8)	1.07 (5.5)	1.01 (3.9)
t-Tests on the equality of means[b]					
Probability	**	**	**	**	**
Private effort $t-1$	*	**	**	*	**
Percentage of exact matching (subsidy dummy $t-1$)	100	100	100	100	100
Potential control group (number of observations)	8241	6236	2005	6218	2023
Treated group (number of observations)	630	205	425	287	343

Average treatment effect for the supported firms. Control group: all observations.
[a] Coefficients and *t*-ratios.
[b] Asterisk (*) indicates that we do not reject the null hypothesis (equality of the means) in a two-tailed *t*-test at the 1% level of significance between the supported firms and the selected control firms and Asterisk (**) indicates that we do not reject the null hypothesis (equality of the means) in a two-tailed *t*-test at the 5% level of significance between the supported firms and the selected control firms.

Table 9
Subsidy effects

	All	≤200 workers	>200 workers	Low–m-l tech.	High–m-h tech.
Private effort[a]	−0.05 (−0.3)	−0.14 (−0.4)	0.01 (0.1)	0.14 (0.8)	−0.23 (−1.0)
Total effort[a]	0.40 (2.3)	0.58 (1.5)	0.25 (1.6)	0.45 (2.2)	0.38 (1.5)
t-Tests on the equality of means[b]					
Probability	**	**	**	**	**
Private effort $t-1$	**	**	**	**	**
Percentage of exact matching (subsidy dummy $t-1$)	100	100	100	100	100
Control group (number of observations)	2191	918	1273	1129	1062
Treated group (number of observations)	621	176	445	254	367

Average treatment effect for the non-supported R&D-performing firms.
[a] Coefficients and *t*-ratios.
[b] Asterisk (*) indicates that we do not reject the null hypothesis (equality of the means) in a two-tailed *t*-test at the 1% level of significance between the non-supported firms and the selected treated firms and Asterisk (**) indicates that we do not reject the null hypothesis (equality of the means) in a two-tailed *t*-test at the 5% level of significance between the non-supported firms and the selected treated firms.

but public funds do not significantly stimulate private expenditures.[36] The conclusions are similar when the SATT estimator is obtained separately for the subsamples of small and big firms, and for the subsamples of firms in high and low technological sectors.[37]

Although subsidized firms on average carry out higher private efforts than unsubsidized firms (see Tables 2 and 4), when the group of comparison is not all firms but the similar ones, the difference disappears. This means that subsidies are not assigned randomly. It seems that public agencies subsidize mainly the most R&D-engaged firms.

This general result is similar to that obtained in González et al. (2005) (hereafter, GJP), which uses the same data set but applies an econometric censured model. That paper establishes that subsidies only encourage a modest increment in the privately-financed effort of firms that would perform R&D in any case, and that the effect increases with the size of the subsidy. In particular, for subsidies running from 20 to 60%, the private effort would increase by about 2–7%. In this paper (when we do not take into account the inducement effect), we estimate a non-significant increase in private effort of 0.09, which implies an average increase of about 4%.

It is remarkable that if we do not include the lagged outcome as a covariate – that is, if we do not select firms

[36] Table A1 corroborates this result.
[37] To analyze the robustness of our results, we can compare them with the results obtained when increasing the number of matches we consider for each observation. Using the 4 nearest-neighbour observations for each treated, the results confirm the non-significant effect of subsidies on R&D private effort and on R&D private expenditures when we use only observations with R&D as potential controls, either for the sample of all treated or for the different subsamples considered.

with a similar R&D effort in the previous year – the effect of subsidies on private effort would be significantly higher (the value of the SATT estimator would be 0.65 with a *t*-ratio of 3.3). This result suggests that if we do not consider the persistence of innovation, we will overestimate the effect of subsidies.

Table 7 also shows that subsidies are responsible for an average increase in total effort of 0.72 percentage points,[38] and that this effect is slightly higher in firms with fewer than 200 workers and in high-tech sectors, that is, in the groups of firms with a higher average R&D effort.[39]

Table 8 shows the effect of subsidies on private and total R&D effort of subsidized firms, considering observations with and without R&D activities to be potential controls. In this case, the average effect on private effort is positive and significant. In particular, subsidized firms present a private effort 0.35 percentage points higher than the non-subsidized ones. Table 8 also reveals that the effect is significant in the group of small and low-tech firms, not in the big and high-tech firms. Probably for small firms and firms in low-tech sectors, access to public financing plays an important role in the decision to undertake R&D activities.[40],[41]

One explanation could be that the sunk costs associated with R&D activities imply that small firms find it more difficult to carry out this type of activity, partially due to financial restrictions. Subsidies may contribute to some firms – mainly small firms – surpassing the thresholds of profitability of these activities, helping them to fill the negative profitability gap that could exist in their absence. Something similar seems to happen with firms in low-tech sectors. Although the difference between the R&D effort of subsidized and non-subsidized firms is greater in the high-tech subsample (Table 4), our analysis finds a positive and significant effect of subsidies only in the low-tech sectors and when the potential control group includes all observations. This suggests that, on the one hand, the agencies mainly subsidize firms that would make a higher-than-average technological effort anyway and, on the other hand, the inducement effect of subsidies greatly affects firms in low-tech sectors.

Given the selected controls, it seems that the induction effect is not negligible. 17% of subsidized observations are matched with non-R&D observations. Moreover, the induction effect varies considerably across size and sector: the percentage increases to 30% in the case of small firms, while for big firms it is 10%; and in low-tech sectors it reaches 28%, while it is 7% in high-tech sectors. Therefore, it can be pointed out that a significant number of R&D performers (17% of subsidized observations means 4% of the observations with R&D expenditures) would not have undertaken R&D if they had not received public support.

GJP (2005) obtain a slightly higher percentage of R&D performers induced by subsidies to undertake R&D (6% instead of our 4%). There are several reasons for the difference between the results of both papers. Firstly, in GJP, the percentage is related to the number of firms predicted to perform R&D, while in this paper, the percentage is relative to the firms that we observe performing R&D. Secondly, the methodology applied in GJP allows us to consider that subsidies (the expected subsidies) can influence even the behavior of firms that do not receive them,[42] while matching methodology prevents this possibility. In any case, results seems to be quite similar.

Lastly, Table 9 illustrates the potential effect of subsidies on non-subsidized firms. In this case, we restrict the analysis to observations with R&D, as it is not possible to identify which of the non-performers will be induced to undertake R&D activities (obviously a subset of them).[43] The table shows that the effect on private

[38] Herrera and Heijs (2007) estimate that subsidies increase total effort of R&D-performing firms by 1.8, more than double our estimator, 0.72. We think that their results overestimate the subsidy effects mainly due to not considering the lagged outcome as covariate.

[39] Analyzing the differences by size, Table A1 reveals that the increase of total expenditure is higher in big firms, but, in relation to the size, implies a lower increase in R&D effort as Table 7 shows. This means that although big firms receive bigger subsidies, they are not so big in relation to their size. On the other hand, the increase of total expenditures is higher in high-tech sectors than in low-tech sectors, probably due to the higher subsidies they receive.

[40] Table A2 in Appendix A presents the results for the R&D expenditure. For this variable, the effect is also significant only for the small firms and the firms in the low-tech sectors, but the effect is not significant when we consider the full sample of all the treated. This can be due to the great heterogeneity of expenditures among firms of very different sizes.

[41] Using the 4 nearest-neighbor observations for each treated, although the effects on R&D effort increase slightly for big firms and firms in high tech sectors, results confirm the existence of a positive effect of subsidies on R&D expenditure only for small firms and firms in low-tech sectors. The ATT estimator on R&D effort is 0.28 (*t*-ratio 2.0) for big firms and 0.35 (*t*-ratio 1.8) for high-tech firms, but the ATT estimator on R&D expenditure is 18.9 (*t*-ratio 0.2) for big firms and 13.9 (*t*-ratio 0.1) for high-tech firms.

[42] The expectation of obtaining subsidies can influence R&D decisions even though the firm does not obtain them in the end.

[43] In order to assure overlap, we restrict the estimation to the region of common support of the propensity score, and additionally we eliminate observations with extremely small lagged private effort (most of them

effort is not significant; that is, the non-subsidized firms would not have increased their private R&D effort if they had received subsidies. Besides, the effect on total R&D effort shows a lower increment than that obtained for the subsidized firms. If the non-subsidized firms were supported, they would probably receive, on average, lower subsidies than those obtained by the subsidized firms. In any case, these results should be viewed with caution since the number of treated from which to select the "similar" observations for the controls is certainly very scarce.

Finally, using the SATT estimators of Table A2, we can approximate the increase of the aggregate total R&D expenditures promoted by subsidies. We can also calculate which part of this increase is due to the firms induced to undertake R&D (considering the treated observations matched with controls without R&D). We relate this value to the aggregate total expenditure in absence of subsidies, that is, the total expenditure of non-supported firms plus the estimated expenditure for the supported firms that would have undertaken R&D in any case (considering the treated observations matched with controls with R&D).

We estimate an increase in the aggregate R&D expenditures of 10.7% for the small firms, and of 6.0% for big ones, while the subsidies obtained by the small firms amount to 5.4% of their total R&D expenditures (4.3% for the big firms). The increment estimated for the small firms can be decomposed into 6.4% coming from firms performing R&D in any case and 4.3% coming from firms induced to perform R&D. The increment estimated for the big firms can be decomposed into 5.0 and 1.0%, respectively.

These figures are very similar to those obtained in GJP (2005): a 10.8% increment for small firms (6.9% from firms stimulated to perform R&D), 5.9% for the big firms (0.9% from firms stimulated to perform R&D).

Additionally, we estimate the increase of the aggregate total R&D expenditures, separately considering firms in high-tech sectors and firms in low-tech sectors, and we obtain a higher estimated increment for the low-tech sectors (11.1%, 3.9% coming from firms induced to perform R&D) than for high-tech sectors (5.4%, 0.3% coming from firms induced to perform R&D).

To summarize, the results lead to the conclusion that there is no crowding-out effect of private funds by public funds and that public financing in Spain seems to induce some increase in private technological effort in small firms and firms in low-technology sectors, probably due to the inducement to perform R&D in a number of these firms.

6. Conclusions

This paper provides a contribution to the discussion on whether or not public R&D funds crowd out private investment in R&D. We discuss to what extent grants induce firms to increase their private R&D efforts (and expenditures), applying a matching approach to a sample that provides ample information about Spanish manufacturing firms. We first discuss the effect of subsidies on R&D-performing firms and, secondly, we analyze the overall effect, taking into account the effect of inducement to undertake R&D activities. Finally, we evaluate the effect that subsidies might have on non-subsidized firms if they were subsidized.

Moreover, we discuss the use of matching estimators to analyze the effectiveness of public R&D support. This methodology is easier to understand and has lower implementation costs than other approaches, but since the analysis depends on observables, the availability of ample information – in particular, lagged outcome variables – is a key element for ensuring that the results are reliable.

Our results suggest that there is no crowding-out effect in Spanish manufacturing firms, neither total nor partial. That is, firms do not substitute public funds with private R&D investment, but public funds do not significantly stimulate private expenditures of firms that would carry out R&D activities in the absence of subsidies. The estimated subsidy effects on private R&D effort suggest that R&D performers add the amount of subsidies to their private budgets. This general result may be compared with the results obtained in other studies that apply the same methodology. Along this line, Duguet (2004) also obtains absence of total and partial crowding-out and a non-significant effect of the subsidies on private effort of R&D performers, using a sample of French firms. In the case of Germany, Almus and Czarnitzki (2003) and Czarnitzki and Licht (2005) find that the average total R&D effort of subsidized firms is significantly higher; that is, there is no full crowding out, but it is not possible to discard partial crowding out as the information on the quantity of subsidies is not available in their samples.

It is interesting to note the role of the lagged outcome in the estimation of the subsidy effects. If we do not include the lagged effort in the matching procedure, that is, if we do not take into account the persistence of R&D activities, the estimated effect of subsidies on private

controls). This, in fact, means that we have developed the analysis for firms that are R&D performers in two consecutive periods.

R&D effort would be significantly higher, suggesting the presence of an upward bias. Nevertheless, none of the papers that apply matching methodology to analyze subsidy effectiveness discusses this question explicitly.

On the other hand, the estimated effects change appreciably when we consider the effect of induction to perform R&D activities. In this case, the impact of subsidies on private effort becomes positive and significant. On average, subsidized firms are found to perform a private R&D effort 0.35 percentage points higher than non-subsidized firms. This effect is not negligible as the average R&D effort of the "similar" non-subsidized firms (the selected controls) is 2.1%.

This induction effect is not considered in most papers that use matching to analyze subsidy effectiveness, often due to the absence of information about non-R&D performers. Czarnitzki and Licht (2005) take this effect into account and, as in our case, find that the effect of subsidies is higher when the inducement effect is considered. However, the magnitude of subsidy effects on total effort seems to be higher in German firms (especially in East German firms) than in Spanish firms, both when the induction effect is considered and when it is not. This result may reflect a higher subsidy effectiveness in German firms, but it is also compatible with more generous subsidy schemes in Germany together with lower effectiveness (partial crowding-out).

Lastly, our results imply that the potential effect of subsidies on the private effort of non-subsidized performing firms is not significant; that is, the non-subsidized performing firms would not have increased their private R&D effort if they had received subsidies.

We compare our results with those obtained in González et al. (2005), which applies a semistructural econometric model to the same data set, and we obtain very similar results regarding the effect of subsidies on the private R&D effort of firms engaged in R&D activities even in absence of subsides. We also obtain similar results regarding the increase in aggregate R&D expenditures, but the percentage of R&D performers induced by subsidies to undertake R&D is slightly lower in this paper.

To sum up, our results indicate no crowding-out effect of public R&D support, neither full nor partial, and that public financing is more effective in small firms and firms which operate in low-technology sectors, probably due to the inducement to perform R&D in a number of these firms. However, this must not lead us to recommend redirecting public funds toward these groups of firms, as the social profitability associated with the R&D projects carried out by these firms should be evaluated.

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Appendix A. Effects of subsidies on R&D expenditure. See Tables A1 and A2 on the next page

Appendix B. Variable definitions and descriptive statistics

After deleting the firms' data points for which some variable needed for the empirical analysis is missing, we retain a panel with 9455 observations (and the lagged observations needed for some variables). In what follows, we briefly define the variables employed. Table B1 gives some descriptive statistics.

Total R&D expenditures: Total amount of the cost of intramural R&D activities, payments for outside R&D contracts, and expenditures on imported technology (patent licenses and technical assistance), in thousands of €1995.

Private R&D expenditures: Total R&D expenditures minus the amount of total public R&D subsidies, in thousands of €1995.

Total R&D effort: Ratio of total R&D expenditures to sales.

Private R&D effort: Ratio of private R&D expenditures to sales.

R&D dummy: Dummy which takes the value one if total R&D expenditures is positive.

Subsidy: Total amount of public R&D subsidies, in thousands of €1995.

Subsidy dummy: Dummy which takes the value one if the subsidy is positive.

Age: Firms' average founding year (1975) minus the founding year of the firm. This variable is included in the subsidy probability equation divided by 10.

Capital growth: Real growth rate of an estimate of the firm's capital in equipment, goods and machinery.

Domestic exporter: Dummy variable which takes the value one if the firm is domestic (less than 50% of foreign capital) and has exported during the year.

Table A1
Subsidy effects on R&D expenditure

	All	≤200 workers	>200 workers	Low–m-l tech.	High–m-h tech.
Private expenditure[a]	52.9 (0.7)	32.1 (1.5)	54.1 (0.4)	103.2 (1.6)	42.4 (0.3)
Total expenditure[a]	258.6 (3.1)	107.8 (4.2)	321.4 (2.4)	249.5 (3.1)	293.9 (2.2)
t-Tests on the equality of means[b]					
Probability	**	**	**	**	**
Private expenditure $t-1$	**	**	**	*	**
Percentage of exact matching (subsidy dummy $t-1$)	98	100	98	97	100
Potential control group (number of observations)	2561	1191	1370	1409	1152
Treated group (number of observations)	653	210	443	284	369

Average treatment effect for the supported firms. Control group: observations with R&D.
[a] Coefficients and *t*-ratios.
[b] Asterisk (*) indicates that we do not reject the null hypothesis (equality of the means) in a two-tailed *t*-test at the 1% level of significance between the supported firms and the selected control firms and Asterisk (**) indicates that we do not reject the null hypothesis (equality of the means) in a two-tailed *t*-test at the 5% level of significance between the supported firms and the selected control firms.

Table A2
Subsidy effects on R&D expenditure

	All	≤200 workers	>200 workers	Low–m-l tech.	High–m-h tech.
Private expenditure[a]	71.1 (0.9)	59.4 (2.7)	75.8 (0.6)	120.4 (2.0)	54.5 (0.4)
Total expenditure[a]	276.9 (3.4)	135.2 (5.3)	343.1 (2.7)	266.7 (3.5)	305.9 (2.3)
t-Tests on the equality of means[b]					
Probability	**	**	**	**	**
Private expenditure $t-1$	*	**	*	*	**
Percentage of exact matching (subsidy dummy $t-1$)	100	100	100	100	100
Potential control group (number of observations)	8300	6312	1988	6273	2027
Treated group (number of observations)	653	210	443	284	369

Average treatment effect for the supported firms. Control group: all observations.
[a] Coefficients and *t*-ratios.
[b] Asterisk (*) indicates that we do not reject the null hypothesis (equality of the means) in a two-tailed *t*-test at the 1% level of significance between the supported firms and the selected control firms and asterisk (**) indicates that we do not reject the null hypothesis (equality of the means) in a two-tailed *t*-test at the 5% level of significance between the supported firms and the selected control firms.

Table B1
Variable descriptive statistics

	All observations ($N = 9455$)				Observations with R&D ($N = 3295$)[a]				Observations with subsidies ($N = 684$)[b]			
	Mean	Standard deviation	Minimum	Maximum	Mean	Standard deviation	Minimum	Maximum	Mean	Standard deviation	Minimum	Maximum
Total R&D effort (×100)	0.78	2.1	0	27.5	2.21	3.0	0.0	27.5	3.91	4.4	0.01	27.5
Private R&D effort (×100)	0.72	1.96	−17.9	25.6	2.07	2.82	0	25.6	3.25	3.9	0	24.9
R&D dummy	0.36	–	0	1					1	–	1	1
Total R&D expenditure	368.9	1682.2	0	50410.7	1054.0	2719.5	0.01	50410.7	2257.9	4300.1	2.3	50410.7
Private R&D expenditure	351.6	1639.1	−622.7	50336.4	1007.7	2654.5	0	50336.4	2034.8	4159.7	0	50336.4
Subsidy	17.3	132.1	0	5248.6	46.3	216.7	0	5248.6	223.1	432.5	0.6	5248.6
Subsidy dummy	0.08	–	0	1	0.21	–	0	1	1	–	1	1
Capital growth	0.09	0.3	−3.5	7.3	0.10	0.3	−1.7	6.3	0.09	0.2	−1.4	1.45
Age	0.79	16.0	−23	35	7.21	16.9	−23	35	10.5	16.0	−23	35
Foreign capital dummy	0.19		0	1	0.40		0	1	0.32		0	1
Firm with market power dummy $t-1$	0.38		0	1	0.57		0	1	0.51		0	1
Technological sophistication	0.02	0.05	0	0.52	0.04	0.06	0	0.49	0.06	0.08	0	0.49
Domestic exporter dummy $t-1$	0.40		0	1	0.52		0	1	0.65		0	1
Number of workers $t-1$	168.4	336.2	1	6731	337.2	446.0	1	6731	499.9	663.7	10	6731
Industry dummies												
1. Ferrous and non-ferrous metals	0.02		0	1	0.04		0	1	0.05		0	1
2. Non-metallic mineral products	0.07		0	1	0.06		0	1	0.06		0	1
3. Chemical products	0.07		0	1	0.14		0	1	0.21		0	1
4. Metal products	0.11		0	1	0.08		0	1	0.09		0	1
5. Agricultural and industrial machinery	0.05		0	1	0.08		0	1	0.05		0	1
6. Office and data processing machinery	0.01		0	1	0.01		0	1	0.01		0	1
7. Electrical goods	0.07		0	1	0.14		0	1	0.17		0	1
8. Motor vehicles	0.04		0	1	0.07		0	1	0.07		0	1
9. Other transport equipment	0.02		0	1	0.03		0	1	0.06		0	1
10. Meats, meat preparation	0.03		0	1	0.01		0	1	0.01		0	1
11. Food products and tobacco	0.11		0	1	0.07		0	1	0.03		0	1
12. Beverages	0.02		0	1	0.03		0	1	0.01		0	1
13. Textiles and clothing	0.12		0	1	0.07		0	1	0.07		0	1
14. Leather, leather and skin goods	0.04		0	1	0.02		0	1	0.03		0	1
15. Timber, wooden products	0.07		0	1	0.02		0	1	0.01		0	1
16. Paper and printing products	0.08		0	1	0.04		0	1	0.03		0	1
17. Rubber and plastic products	0.06		0	1	0.06		0	1	0.04		0	1
18. Other manufacturing products	0.01		0	1	0.01		0	1	0.01		0	1

Table B1 (*Continued*)

	All observations ($N=9455$)				Observations with R&D ($N=3295$)[a]				Observations with subsidies ($N=684$)[b]			
	Mean	Standard deviation	Minimum	Maximum	Mean	Standard deviation	Minimum	Maximum	Mean	Standard deviation	Minimum	Maximum
Region dummies												
Navarre	0.02		0	1	0.03		0	1	0.04		0	1
Basque Country	0.07		0	1	0.10		0	1	0.20		0	1
Size dummies												
≤20 workers	0.33		0	1	0.08		0	1	0.02		0	1
21–50 workers	0.24		0	1	0.14		0	1	0.08		0	1
51–100 workers	0.08		0	1	0.08		0	1	0.08		0	1
101–200 workers	0.09		0	1	0.13		0	1	0.13		0	1
201–500 workers	0.19		0	1	0.38		0	1	0.42		0	1
>500 workers	0.08		0	1	0.19		0	1	0.27		0	1
Time dummies												
1991	0.08		0	1	0.08		0	1	0.07		0	1
1992	0.11		0	1	0.10		0	1	0.10		0	1
1993	0.11		0	1	0.11		0	1	0.09		0	1
1994	0.11		0	1	0.11		0	1	0.10		0	1
1995	0.12		0	1	0.11		0	1	0.13		0	1
1996	0.11		0	1	0.11		0	1	0.11		0	1
1997	0.12		0	1	0.11		0	1	0.13		0	1
1998	0.13		0	1	0.14		0	1	0.14		0	1
1999	0.12		0	1	0.13		0	1	0.13		0	1

[a] Observations with non-zero R&D effort and with total R&D expenditures at t and $t-1$ greater than (or equal to) subsidies amount.

[b] Observations with subsidies and with total R&D expenditures at t and $t-1$ greater than (or equal to) subsidies amount.

Firm with market power: Dummy variable which takes the value one if the firm reports a significant market share and the market has fewer than 10 competitors.

Foreign capital: Dummy variable which takes the value one if the firm has foreign capital.

Number of workers: This variable is included in the subsidy probability equation divided by 100.

Technological sophistication: Dummy variable which takes the value one if the firm uses automatic machines, or robots, or CAD/CAM, or some combination of these procedures, multiplied by the ratio of engineers and university graduates to total personnel.

Industry dummies: Set of 18 industry dummies.

Region dummies: Set of 17 autonomous community (regions) dummies.

Size dummies: Set of 6 dummy variables.

Time dummies: Set of yearly dummy variables.

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