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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 firms' size 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.

Keywords: R&D, subsidies, matching estimator
JEL Classification: O32,L1,C21

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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. In this line, the European Commission has established the objective of increasing R&D to 3% of GDP by 2010.[1]

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 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 firms' size and on the technological level of the sectors in which the firms operate. On the one hand, we evaluate the effect of subsidies on the R&D effort (R&D expenditure over sales) of firms that have received them. We consider both the effect on firms that would have preformed R&D activities in the absence of public support and

[1] 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://europa.eu.int/comm/research/era/listcom_en.html).

also the effect of inducement to undertake R&D activities on some firms. This inducement effect is often ignored because most works use samples that include only innovating firms. On the other hand, 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 not 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 and without subsidies. Partial crowding-out occurs if firms raise their total R&D, but by less than the amount of subsidies. In both cases, far from achieving the objective of increasing firms' private 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 also 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.

To evaluate the effect of subsidies, we implement the bias-corrected matching estimator proposed by Abadie and Imbens (2005). Matching estimators have been widely used in recent years to evaluate different types of public policies.[2] 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. Moreover, they are easier to understand and easier to implement than other methods, and these constitute important 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 question. In fact, as Imbens (2004) points out, they are a natural starting point in the evaluation of any policy.

In this paper we also discuss the relevance of taking into account in the matching proce-

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

dure the persistence in the innovative activity. In another case, the estimated effects would be biased and the political recommendations inspired by these estimated effects might not be reasonable.

We apply this methodology to evaluate the effect of R&D subsidies granted to Spanish manufacturing firms during the 90's. The effectiveness of public R&D instruments is an especially relevant question for Spain for two reasons. Firstly, 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.[3] This fact should promote a more active technological policy to reduce the gap with the European average. Secondly, Spain is one of the OECD countries with the most generous financial incentives (OECD, 1998), particularly fiscal incentives and subsidies.[4]

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, that supplies rich 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 in the matching procedure the persistence in the innovative activity, the estimated effect would be considerably higher.

The paper is organized as follows. Section 2 reviews a selection of papers on the effect

[3] 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).

[4] 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.

of subsidies on firms' R&D expenditures. Section 3 describes the data and presents some evidence about 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. An appendix of variables definition and descriptive statistics is included at the end of the paper.

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 works 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, Hall and Toole (2000) carry out an extensive revision of this literature, finding substitution effect between public and private R&D in one-third of the works analyzed.[5] They point out that the proportion of studies that detected substitution of public for 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 works also present conflicting answers in the evaluation of the effectiveness of public

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

subsidies. In particular, Walsten (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 the 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[6] in 1988, obtains, on average, a positive effect, though she does not reject a full crowding-out effect in 30% of the firms. González, Jaumandreu and Pazó (2005), using data from the same panel of manufacturing firms that we use in this paper, propose a structural 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 and on the associated effort level.[7] The main results indicate no substitution effect of private spending by public funds, though the subsidies go mainly to firms that would have performed R&D activities anyway.[8]

In the most recent international studies, there is a widespread tendency to apply matching estimators to analyze the effect of R&D subsidies, using firm data. 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. Often samples only include R&D-performers data and/or have no information about the amount of

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

[7] 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 about the subsidies.

[8] 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.

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 allow to consider the persistence in the innovative activity.

Among the studies that employ this methodology are Almus and Czarnitzki (2003) and Czarnitzki & Licht (2005), using data from a survey of innovating German manufacturing firms, and Duguet (2004), using a pool of French R&D-performing firms. None of these works 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 takes into account the inducement effect, given that their sample includes some innovating firms that do not perform R&D. Only Duguet (2004) use lagged R&D effort to consider R&D persistence, while the other two works use rougher indicators (R&D department dummy, number of patent applications). All of these works reject the presence of full crowding-out, but only Duguet (2004) is able to confirm the absence of partial crowding-out, as he has information on the subsidy amounts.[9]

Then, the most recent works seem to agree on the absence of 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 special 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 in the R&D activities.

3. R&D and subsidies in the 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 Empre-*

[9] 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 unpublished papers in this line are Kaiser (2004), Aerts and Czarnitzki (2005) and Lööf and Hesmati (2005).

sariales). The data set consists of an unbalanced panel of Spanish manufacturing firms observed during the period 1990-1999.[10] After eliminating the observations for which all the necessary information is not available, the sample includes a total of 9455 observations from 2214 firms.[11]

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). The data also involves information regarding public R&D funding in the form of subsidies received by the firms that have contributed to the financing of their R&D activities. We consider a firm as subsidized if it has received some financial support from any of the public programs available.[12] In what follows, we present same evidence regarding R&D expenditures and subsidies, with special attention to heterogeneities relating to firm size and sector of activity.[13]

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 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.[14] For the group of firms that

[10] 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.

[11] As we need some lagged variables, the sample contains observations from 1991 to 1999, and we do not use the observations of firms that appears in the data set just one year.

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

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

[14] 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

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, notice 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 work 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, on the one hand, and from those corresponding to low and medium-low technology sectors, on the other.[15] 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).[16] 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

allocation of subsidies.

[15] To classify the sectors depending on 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/daco4217/1stsectcnae.doc

[16] For further details regarding the sector classification employed, see Table A1 of the data appendix.

medium-low technology. The *chemical products* sector is the most innovative, while the sector which proportionately receives the greatest number of subsidies is *other transport equipment* (followed closely by the *chemical products* sector).

Table 4 shows average R&D efforts by sector of activity. Firstly, notice 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 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 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 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 the 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 as counterpart $1/N \sum_{i=1}^{N}[Y_i(1) - Y_i(0)]$, 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 $1/N_1 \sum_{i|T=1}[Y_i(1) - Y_i(0)]$, 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 $1/N_0 \sum_{i|T=0}[Y_i(1) - Y_i(0)]$.

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 the obtaining of 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, 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:

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

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

(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. Then, the selection of the set of characteristics X becomes a key element in the application of matching estimators. The acceptance of unconfoundedness assumption cannot be directly tested, but the availability of rich 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 with exactly the same characteristics. The literature has proposed different procedures to circumvent this problem. In this work, we use *nearest neighbor matching*. That is, for each firm i, we search for the most similar firm with the opposite treatment, the firm with the set of covariates X at the nearest distance.[17]

We use 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). More specifically, we apply the bias correction proposed by Abadie and Imbens (2005) to adjust the estimated non-observed outcome of i for the difference between the covariates for unit i and its match.[18]

Then, to estimate the effect of subsidies on subsidized firms, we obtain the sample average

[17] 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.

[18] For a detailed explanation of the bias-corrected matching estimator and its implementation in STATA, see Abadie e Imbens (2005) and Abadie et al. (2004).

subsidies effect in the subpopulation of granted firms, denoted by $SATT$:[19]

$$SATT = 1/N_1 \sum_{i|T=1} [Y_i(1) - \widehat{Y_i(0)}] \quad (1)$$

Similarly, to estimate the effect that granting could have on non-subsidized firms, we obtain the sample average treatment effect for the controls, $SATC$:[20]

$$SATC = 1/N_0 \sum_{i|T=0} [\widehat{Y_i(1)} - Y_i(0)] \quad (2)$$

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.[21] Firstly, the estimated probability of obtaining a subsidy (the *propensity score*), which is the standard variable used to select the controls in most works. Secondly, we consider the lagged outcome, that is, the lagged private effort. The notable persistence that characterizes R&D activities recommends including 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 evaluate correctly the effects of subsidies. Thirdly, we include the lagged subsidy dummy in order to take into account the persistence in 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 will be search within the same sector of activity, stratum of size and time period.[22] The data scarcity within some sectors and size strata force us to

[19] Sample Average Treatment effect for the Treated.

[20] As our sample includes non-R&D performers and it is no possible to determine which of them will be induce to undertake these activities, the estimator SATC is obtained for a subset of N_o which correspond to the unsubsidized R&D-performers (this subset contains more than 2500 observations).

[21] Definitions of variables can be found in the data appendix, which also includes some descriptive statistics.

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

consider just 12 sectors, 2 sizes (under and above 200 workers) and 2 periods of time.[23]

Notice that the vector of variables X includes discrete and continuous variables. The matching will be exact in the sector, size and period dummies, and as exact as possible in the lagged subsidy dummy.[24] However, as it is not possible to find observations which take identical values in the relevant continuous variables (estimated 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 note 17).[25]

We employ two different groups of observations to select the controls for the SATT estimator. On the one hand, only observations with R&D activities; on the other hand, 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 of firms that would have preformed 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.[26]

In what follows, first we summarize the model used to obtain an estimation of the probability of getting subsidies, and then we expose the results of the matching estimator.

Probability of receiving subsidies.

The probability of receiving public financing is obtained from the estimation of a probit model which follows González, Jaumandreu and Pazó (2005).[27] The dependent variable

[23] 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 the table A1), 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.

[24] The percentage of matches that exactly match this variable is in all cases greater than 95%, and often reaches 100% (see below).

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

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

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

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 persistence in the concession of public support. 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. 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. 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.[28]

Table 5 shows the results of the probit estimation. The percentage of correctly predicted zeroes and ones implies an acceptable goodness of fit.[29] 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.

Subsidy effectiveness

Tables 6 and 7 present the estimated effect of subsidies on subsidized firms (SATT estimators) and Table 8 presents the potential effect of subsidies on unsubsidized ones (SATC

[28] 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.

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

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,[30] the percentage of exact matching for the lagged subsidy dummy, and at which level of significance we can accept the hypothesis that the mean of the continuous variables does not differ between the treated and the selected controls.

Table 6 shows the effect of subsidies on private and total R&D effort of subsidized firms, considering only observations with R&D activities as 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 public funds for private R&D investment, but public funds do not significantly stimulate private expenditures. 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.

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

It is remarkable that if we do not include the lagged outcome as a covariate - that is, if we do not select firms 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 6 also shows that subsidies are responsible for an average increase in total effort

[30] 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.

of 0.7 percentage points, 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.

Table 7 shows the effect of subsidies on private and total R&D effort of subsidized firms, considering observations with and without R&D activities as potential controls. In this case, the average effect on private effort is positive and significant. In particular, subsidized firms present an effort 0.35 percentage points higher than the unsubsidized ones. Given the selected controls, it seems that the induction effect is not negligible. The 17% of subsidized observations (approximately 5% of the R&D data points) are matched with non-R&D observations. Then, it can be pointed out that a significant number of R&D performers would not have undertaken R&D if they had not received public support.

The induction effect takes place mainly in the group of small and low-tech firms, not in the big and high-tech, as can be detected in Table 7. Probably for small firms and firms in low-tech sectors, access to public financing greatly determines the decision to undertake R&D activities. 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 unsubsidized 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 and when the potential control group includes all observations. This suggests that, on the one hand, the agencies subsidize mainly 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.

Lastly, Table 8 illustrates the potential effect of subsidies on unsubsidized 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). The table shows that the effect on private effort is not significant, except for firms which operate in low technology sectors. However, these results should be viewed with caution since the number of treated from which to select the "similar" firms for the controls is certainly very scarce.

These results lead to the conclusion that there exists 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 work 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, 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, particularly more structural econometric methods, but since the analysis depends on observables, the availability of rich information 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 for 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 effect on private R&D effort suggests 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 works that apply the same methodology. In 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&R-performers, using a sample of French firms. In the case of Germany, Almus and Czarnitzki (2004) 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 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 unsubsidized 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) are able to take into account this effect and, as in our case, they 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 unsubsidized firms is not significant, except for firms which operate in low-technology sectors. However, these results should be viewed with caution since the number of treated from which to select "similar" firms for controls is certainly very scarce.

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.

Appendix A: Variable definitions and descriptive statistics.

After deleting the firms' data points for which some variable needed in the econometric exercise is missing, we retain a panel with 9,455 observations (and the lagged observations needed for some variables). In what follows, we briefly define the variables employed. Table A1 gives some descriptive statistics.

R&D Effort (Total Effort): ratio of total R&D expenditures to sales. Total R&D expenditures include the cost of intramural R&D activities, payments for outside R&D contracts, and expenditures on imported technology (patent licenses and technical assistance).

R&D dummy: dummy which takes the value one if R&D effort is positive.

Private R&D Effort: ratio of private R&D expenditures to sales. Private R&D expenditures are total R&D expenditures minus the amount of total public subsidies.

Subsidy: ratio of the amount of total public subsidies to total R&D expenditures.

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.

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

	Observations	With R&D (%)	With subsidies (%)
Firm size			
$\leq$ 20 workers	3080	9.1	6.1
20-50	2270	20.4	14.4
50-100	741	35.5	21.3
100-200	843	53.5	20.6
200-500	1797	71.7	23.8
>500	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			
$\leq$ 20 workers	5.52	3.49	2.18
20-50	3.42	2.55	1.73
50-100	5.55	4.04	1.80
100-200	3.41	2.64	1.89
200-500	4.12	3.56	1.62
>500	3.39	3.01	1.71
All firms	3.91	3.25	1.76

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 indust. machinery	478	53.1	15.0
Office and data processing machin.	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

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 indust. machinery	5.21	4.00	2.28
Office and data processing machin.	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

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
N^{o}of firms:	2214
N^{o}of observations:	9455
Correctly predicted observations[c]	
zeroes	0.84
ones	0.83

[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 1992-99.

[c] Using 0.055 as critical value.

Source: González, Jaumandreu and Pazó (2005)

Table 6.- Subsidy effects. Average treatment effect for the supported firms.
Control group: observations with R&D.

	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$_{t-1}$	*	*	**	**	**
% exact match. (subsidy dum.$_{t-1}$)	99%	100%	98%	96%	100%
Potential control group (n^{o}of obs.)	2569	1182	1387	1418	1151
Treated group (n^{o}of observations)	630	205	425	287	343

[a] Coefficients and t-ratios.

[b] ** indicates that the means do not differ with statistical significance in a two-tailed t test at the 5% of significance between the supported firms and the firms selected as controls, * indicates that do not differ at the 1% of significance.

Table 7.- Subsidy effects. Average treatment effect for the supported firms.
Control group: all observations.

	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)	1.00 (3.9)
t tests on the equality of means:[b]					
probability	**	**	**	**	**
private effort$_{t-1}$	*	**	**	*	**
% exact match. (subsidy dum.$_{t-1}$)	100%	100%	100%	100%	100%
Potential control group (n^{o}of obs.)	8241	6236	2005	6218	2023
Treated group (n^{o}of observations)	630	205	425	287	343

[a] Coefficients and t-ratios.

[b] ** indicates that the means do not differ with statistical significance in a two-tailed t test at the 5% of significance between the supported firms and the firms selected as controls, * indicates that do not differ at the 1% of significance.

Table 8.- Subsidy effects. Average treatment effect for the nonsupported R&D-performing firms.

	All	≤ 200 workers	>200 workers	Low- m-l tech.	High- m-h tech.
Private Effort[a]	0.08 (0.5)	0.16 (0.6)	0.01 (0.1)	0.36 (2.1)	-0.29 (-1.3)
Total Effort[a]	0.63 (3.8)	1.11 (3.3)	0.27 (1.8)	0.91(4.0)	0.29 (1.2)
t tests on the equality of means:[b]					
probability	**	**	**	**	**
private effort$_{t-1}$	**	**	**	**	**
% exact match. (subsidy dum.$_{t-1}$)	100%	100%	100%	100%	100%
Control group (n^{o}of obs.)	2596	1196	1400	1421	1175
Treated group (n^{o}of observations)	669	207	462	288	381

[a] Coefficients and t-ratios.

[b] ** indicates that the means do not differ with statistical significance in a two-tailed t test at the 5% of significance between the supported firms and the firms selected as controls, * indicates that do not differ at the 1% of significance.

Table A1.- Variable descriptive statistics

	All observations (N=9455)				Observations with R&D (N=3295)[a]			
	Mean	St. dev.	Min	Max	Mean	St. dev.	Min	Max
R&D Effort (×100)	0.78	2.1	0.0	27.5	2.21	3.0	0.0	27.5
R&D dummy	0.36	-	0	1				
Subsidy (×100)	2.24	14.7	0.0	440.0	4.46	13.3	0	100
Subsidy dummy	0.08	-	0	1	0.21	-	0	1
Private R&D Effort (×100)	0.72	1.96	-17.9	25.6	2.07	2.82	0	25.6
Capital growth	0.09	0.3	-3.5	7.3	0.10	0.3	-1.7	6.3
Age	0.79	16.0	-23	35	7.21	16.9	-23	35
Foreign capital dummy	0.19		0	1	0.40		0	1
Firm with market power dummy$_{t-1}$	0.38		0	1	0.57		0	1
Technological sophistication	0.02	0.05	0	0.52	0.04	0.06	0	0.49
Domestic exporter dummy$_{t-1}$	0.40		0	1	0.52		0	1
Number of workers$_{t-1}$	168.4	336.2	1	6731	337.2	446.0	1	6731
Industry dummies								
Ferrous and non-ferrous metals	0.02		0	1	0.04		0	1
Non-metallic mineral products	0.07		0	1	0.06		0	1
Chemical products	0.07		0	1	0.14		0	1
Metal products	0.11		0	1	0.08		0	1
Agricultural and ind. machinery	0.05		0	1	0.08		0	1
Office and data processing machin.	0.01		0	1	0.01		0	1
Electrical goods	0.07		0	1	0.14		0	1
Motor vehicles	0.04		0	1	0.07		0	1
Other transport equipment	0.02		0	1	0.03		0	1
Meats, meat preparation	0.03		0	1	0.01		0	1
Food products and tobacco	0.11		0	1	0.07		0	1
Beverages	0.02		0	1	0.03		0	1
Textiles and clothing	0.12		0	1	0.07		0	1
Leather, leather and skin goods	0.04		0	1	0.02		0	1
Timber, wooden products	0.07		0	1	0.02		0	1
Paper and printing products	0.08		0	1	0.04		0	1
Rubber and plastic products	0.06		0	1	0.06		0	1
Other manufacturing products	0.01		0	1	0.01		0	1
Region dummies:								
Navarre	0.02		0	1	0.03		0	1
Basque Country	0.07		0	1	0.10		0	1
Size dummies:								
<20 workers	0.33		0	1	0.08		0	1
21-50 workers	0.24		0	1	0.14		0	1
51-100 workers	0.08		0	1	0.08		0	1
101-200 workers	0.09		0	1	0.13		0	1
201-500 workers	0.19		0	1	0.38		0	1
>500 workers	0.08		0	1	0.19		0	1
Time dummies:								
1991	0.08		0	1	0.08		0	1
1992	0.11		0	1	0.10		0	1
1993	0.11		0	1	0.11		0	1
1994	0.11		0	1	0.11		0	1
1995	0.12		0	1	0.11		0	1
1996	0.11		0	1	0.11		0	1
1997	0.12		0	1	0.11		0	1
1998	0.13		0	1	0.14		0	1
1999	0.12		0	1	0.13		0	1

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

Table A1.-Variable descriptive statistics (continued)

	Observations with subsidies (N=684)[a]			
	Mean	St. dev.	Min	Max
R&D Effort (×100)	3.91	4.4	0.01	27.5
R&D dummy	1	-	1	1
Subsidy (×100)	21.5	22.2	0.1	100
Sbsidy dummy	1	-	1	1
Private R&D Effort (×100)	3.25	3.9	0	24.9
Capital growth	0.09	0.2	-1.4	1.45
Age	10.5	16.0	-23	35
Foreign capital dummy	0.32		0	1
Firm with market power dummy$_{t-1}$	0.51		0	1
Technological sophistication	0.06	0.08	0	0.49
Domestic exporter dummy$_{t-1}$	0.65		0	1
Number of workers$_{t-1}$	499.9	663.7	10	6731
Industry dummies:				
Ferrous and non-ferrous metals	0.05		0	1
Non-metallic mineral products	0.06		0	1
Chemical products	0.21		0	1
Metal products	0.09		0	1
Agricultural and ind. machinery	0.05		0	1
Office and data processing machin.	0.01		0	1
Electrical goods	0.17		0	1
Motor vehicles	0.07		0	1
Other transport equipment	0.06		0	1
Meats, meat preparation	0.01		0	1
Food products and tobacco	0.03		0	1
Beverages	0.01		0	1
Textiles and clothing	0.07		0	1
Leather, leather and skin goods	0.03		0	1
Timber, wooden products	0.01		0	1
Paper and printing products	0.03		0	1
Rubber and plastic products	0.04		0	1
Other manufacturing products	0.01		0	1
Region dummies:				
Navarre	0.04		0	1
Basque Country	0.20		0	1
Size dummies:				
<20 workers	0.02		0	1
21-50 workers	0.08		0	1
51-100 workers	0.08		0	1
101-200 workers	0.13		0	1
201-500 workers	0.42		0	1
>500 workers	0.27		0	1
Time dummies:				
1991	0.07		0	1
1992	0.10		0	1
1993	0.09		0	1
1994	0.10		0	1
1995	0.13		0	1
1996	0.11		0	1
1997	0.13		0	1
1998	0.14		0	1
1999	0.13		0	1

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

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