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Public subsidies to business R&D: do they stimulate private expenditures?

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Abstract. The purpose of this paper is to obtain new evidence about a fundamental question of empirical studies on technology policy. Is public R&D a complement to or a substitute for private R&D? We examine, at an industry level, the relationship between private R&D expenditures and public subsidies in Spain, using panel data and controlling the interindustry differences in technological opportunities. The results suggest that public subsidies have complemented private R&D. This is an interesting result because technology policy was reoriented in the 1990s with a reduction of direct government subsidies for R&D and an increase in tax incentives.

1 Introduction

The capacity of firms for innovation is considered to be one of the most important factors in improving the productivity and competitiveness of the manufacturing system. From this arises the interest in determining the effectiveness of public policy directed towards encouraging the research and development (R&D) activities of firms. Even though it is currently thought (OECD, 1999) that the capacity of firms to innovate depends on the institutional system in which they are located as a whole, direct individualised support measures make up a substantial part of public expenditure on R&D.

The existing broad consensus on the worth of publicly funded support for R&D is based upon the existence of market failures (Arrow, 1962) that create a gap between the private benefits and social benefits derived from R&D activities, which means that private resources allocated to R&D activities will be below the social optimum (Klette et al, 2000). Nevertheless, even though the existence of market failures is widely accepted as a justification for public support programmes for firms, it is necessary to demonstrate that these public subsidies and other actions in technology policy are effective. To do this it must be shown that the principle of financial additionality is fulfilled. This principle demands that public subsidies to firms really are transformed into an increase in their research and innovation effort, and that they do not merely substitute for private expenditure that would have been made in any case. The support must also respond to criteria of efficiency: in other words, the research financed by public subsidies must be at least as productive, in terms of innovative results, as that financed privately by the firm itself. Although the first condition apparently presents few difficulties in evaluation, in practice it has been found that it is not easy to achieve clear results. Also, it should be pointed out that although financial additionality is a fundamental concept in the justification of public support to business R&D activities, as an indicator of policy efficiency and success (David et al, 2000; Rye, 2002), it is not

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the only form of the additionality of technology policy. To analyse only financial or input additionality is to leave out other effects of governmental support to private R&D, such as behavioural and output additionality (Buisseret et al, 1995; Rye, 2002). The concept of behavioural additionality is linked to changes in the company's understanding of R&D due to policy action; output additionality is related to the additional commercial effects of new products, processes, or services and to the socioeconomic impacts in general—the ultimate goal of technology policy. Therefore, a comprehensive evaluation of the effects of technology policy would need to include consideration of the different forms of additionality, which would, in turn, require the use of complementary methods and would be faced with information-availability constraints.

In this paper we present an applied analysis of industry-level information for Spain, with the object of examining whether public support to R&D fulfils the principle of financial additionality or whether, on the other hand, a substitution effect, in which private funds are replaced by public financing, exists. The use of industry-level information allows the distribution of subsidies to be seen for a large number of sectors, and for a sufficiently long period of time, to permit differentiation between them according to their technological content and to allow the dynamic effects of the R&D activities themselves to be included. The remainder of this paper is organised in the following way. First, the conceptual framework for the analysis of the effects of the public financing of R&D, and the international evidence gained from applied analysis at industry-level information, is presented. Second, an applied analysis is carried out with the aid of panel data. Third, the results obtained are presented, with corresponding conclusions.

2 Public subsidies for R&D—conceptual framework and empirical evidence

In spite of the conviction that there are more than enough logical reasons for the existence of market failure, and that real evidence of it can be seen, studies that have attempted to verify the stimulating effect of public policy on growth and productivity have produced quite disappointing results. The majority of the studies (Capron, 1992; Capron and Van Pottelsberghe, 1997; Griliches, 1995) have suggested that the impact of publicly financed R&D contributes to increases neither in output nor in productivity, whereas privately financed R&D does. As an alternative approach, some studies have attempted to find out whether the effect of public financing of R&D is better measured through its stimulating impact on private expenditure on R&D.

There are various types of evaluation of R&D policy that can be carried out, depending on the objective and the available data. Capron and Van Pottelsberghe (1997) propose a distinction between four types of ex post evaluation, according to the effect and degree of aggregation, looking at: (1) the *stimulus effect*, or impact on the R&D effort of the firms; (2) the *productivity effect*, or impact on the economic performance of firms; (3) the *spillover effect*, or changes in the results of industries; and (4) the *global effect*, which represents the impact on the economy as a whole. In this paper we are mainly concerned with the first of these effects—the stimulus effect.

The question of whether public support complements or substitutes for privately funded R&D is a fundamental matter in the design of technology policy. From a theoretical point of view, there are arguments to support both hypotheses. The existence of support for R&D could constitute a stimulus to firms to begin R&D, or to increase the resources they assign to R&D, as publicly funded support reduces marginal costs and increases the profitability of R&D projects. On the other hand, public support of R&D could reduce private effort in R&D, as firms could substitute their own financing of projects that they would carry out in any case with public financing.

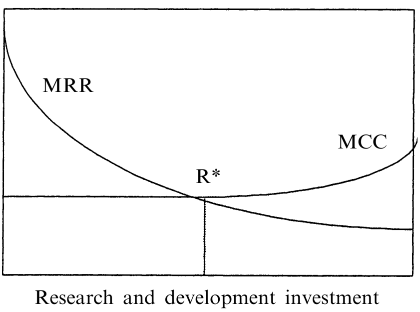
The absence of clear answers and the contradictory results of the empirical studies available until now partly result, in the opinion of David et al (2000), from the lack of an appropriate conceptual framework. Their proposal is to adopt a conceptual schema that identifies the whole group of hypothetical determinants of private investment in R&D that also allows these determining factors to be connected to economic relations, including public policy.

To begin, it is unreasonable to expect the same effects to result from all the different possible modes of public support. Governments use fiscal incentives as much as direct support to firms to encourage investment in R&D. Fiscal incentives do not discriminate between particular projects, and it can be expected that they will cause fewer crowding-out effects, but also fewer spillover effects, given that the firms tend to prefer to invest in those projects that offer a greater degree of appropriability and a shorter cost-recovery period.

With direct support, whether in the form of R&D contracts that are publicly financed but carried out by private entities, or in the form of subsidies to firms to carry out specific projects, it is possible to expect greater crowding out but also more spillover effects. It can be supposed that the projects selected by the government represent a high level of social interest and, in some cases, that government will adjust the support to the diffusion of the results. The substitution effect could arise for various reasons: if the projects that are financed publicly are sufficiently interesting to the firms, the firms would finance them themselves with their own resources. But there could also be a disincentive to investment in R&D for those firms that do not receive support. The firms that do not enter the R&D-support programmes may lower their profit expectations or wait for spillovers from the programmes of others.

Another effect that may frustrate the objective of stimulating privately funded R&D could be that the price of the factors used in R&D increases if their supply is inelastic in the short term. Given that there is a fixed supply of qualified specialised personnel, any increase in direct support of R&D could be transformed into increases in the cost of salaries, with little impact, or even a negative impact, on the amount of private R&D (Goolsbee, 1998).

David et al (2000) propose a simple but useful schema for the analysis of the possible impacts of public policies, or other shocks, on private R&D investment. If it is supposed that, in a given period, every firm has a set of feasible projects, the function MRR, which has a downward slope, would represent the marginal rate of return of the investment in R&D of all the possible projects in order, from the largest to the smallest. It is assumed that the firm is able to calculate the expected rate of return for each project, and use this to rank the projects in descending order. Therefore, as investment in R&D increases, the firm successively begins projects with lower expected rates of return (figure 1).



MRR marginal rate of return on investment
MCC marginal cost of capital

Figure 1. Equilibrium level of R&D investment.

The marginal cost of capital invested (MCC) can be expected to increase, especially if the firm were to resort to external loans of an increasing size. Because of this, MCC has an upward slope because when the amount of R&D investment increases, the firm will have to move from using its own funds to external financing (David et al, 2000). The firm would have incentives for starting R&D projects while the expected rate of return on capital of every additional unit of expenditure was above the cost of this capital. In figure 1 this is shown as point R*.

Public policy can contribute to increase in private effort, either by raising the level of expected rate of return, which implies shifting the MRR curve to the right, or by reducing the cost to the firm of the investment, which will also shift the MCC curve to the right. The magnitude of the effects of public financing on private expenditures in R&D depends on the slopes of MCC and MRR, and therefore the elasticities of these functions determine the final outcome of technology policy.

The expected private marginal rate of return curve does not only depend on the volume of resources already invested in R&D, but also on a series of variables such as the technological opportunities associated with the specific activity of the firm, the expected demand, and the institutional conditions for appropriation of the results of the research. The marginal cost of capital function also depends on the level of resources already employed, and another vector of variables that would include the support policy of the government which, in turn, affects the cost supported by the firm; the macroeconomic conditions and the state of the capital market, that affect the cost of obtaining internal and external capital, as well as the availability of risk capital.

It is usually more difficult to evaluate the impact of government policy on MRR than on MCC. Neither can the same effects be expected on MRR and on MCC from support in the form of granting R&D contracts as can be expected from subsidies. Public financing in the form of contracts would have a relatively greater impact on the expected rate of return (MRR), whereas subsidies would affect the MCC more. Among the circumstances that may determine the movement of MRR to the right would be the expected exploitation of spillovers by the firms (for example, the effects of learning and the acquisition of durable equipment thanks to obtaining financing for R&D projects) or the positive signal sent out by the disposition of the government to finance projects. With subsidies assigned to projects initiated by the firms, the effect of signalling future demand is not so clear, but these subsidies would, on the other hand, move the MCC curve in a relatively more predictable manner.

We pointed out above that there are various circumstances that offset the stimulation effect of support (increase in costs, expectations of spillovers, disincentivation of firms not supported), but effects may also occur because of the way in which public agencies function. Public agencies could finance projects with a high private rate of return and relatively little risk in order to bolster the image of the programme being applied. This would sharpen the substitution effect and increase the incentive to form lobby groups to put pressure on the resources of the government.

The net effect of public financing may depend, in every case and in every industry, on the characteristics of the activity, on the market, or on the prevailing technological opportunities. David and Hall (2000) identify four basic parameters of the system that determine the net effect on an aggregated scale of public support to firms. The additionality effect dominates the substitution effect when: (a) the relative size of public expenditure in total R&D input is smaller; (b) the greater is the elasticity of supply of research personnel; (c) the greater is the relative weight of subsidies in relation to contracts in the total direct financing of firms; and (d) the greater is the elasticity of the slope of the MRR curve.

The effects of public financing on private investment in R&D have been analysed in numerous applied studies without it having been possible to arrive at a conclusive answer, as is reported in various reviews (Capron 1992; Capron and Van Pottelsberghe, 1997; David et al, 2000; García-Quevedo, 2004). The existing econometric studies can be placed into three categories (David et al, 2000) in relation to the unit of analysis. In this way it is possible to distinguish between microeconomic studies, with data from firms, industry-level analyses, and macroeconomic studies.

The studies on an industry level, in the same way as studies using data from firms, attempt to estimate the effect of the public financing of R&D on private expenditure on R&D. A significant positive parameter indicates that the public financing of R&D stimulates private expenditure, whereas a negative parameter reflects a substitution effect. The existing results of the applied analysis at an industry level, as presented in the survey carried out by García-Quevedo (2004), show the predominance of complementary or insignificant effects. In only one case of the twelve econometric estimations was a substitution effect between public financing of R&D and private expenditure on R&D reported. Drawing on the theoretical contributions, the models include other variables that influence the industrial effort in R&D. These variables are fundamentally, the degree of concentration, appropriability, technological opportunity, the degree of diversification, the volume of demand or its growth, and the private effort in R&D itself in previous periods, in order to incorporate the dynamic character of the innovation process. The models used can be represented by the following equation:

$$B_i = \mathrm{f}(P_i, Z_i)\,, \tag{1}$$

in which B_i is private expenditure on R&D financed by the firms themselves for each sector, i, P_i is public financing, and Z_i is the vector of the other variables that influence the sectoral effort in R&D.

The difficulties in obtaining suitable indicators for some of these variables and the interrelation that might exist between them limit the construction and estimation of these models. In particular, the different degrees of technological opportunity in the various industries can influence public as well as private expenditure on R&D, which limits the conclusions that can be drawn from the relation between the two variables (David et al, 2000). On the other hand, in industry-level studies, to consider the variable of the level of government support to be exogenous is a problem of less importance (Capron and Van Pottelsberghe, 1997; Guellec and Van Pottelsberghe, 2001) than it is in microeconomic analyses (David et al, 2000; Kauko, 1996). Whereas in samples of individual firms the problem of selection is very important (Busom, 2000), industry-level analysis is free of endogeneity in the selection of the sample. Analysis at an industry level has also the advantage that information is more available and consequently there is the possibility of comparing results between countries and across time, if a common methodology is used. Furthermore, in technology policy in OECD countries industry priorities are commonly established and analysis at an industry level allows the examination of the results of public subsidies for the different industries.

3 Public subsidies for R&D

3.1 The sectoral distribution of public support for R&D

In Spain public funding for private R&D was very scarce until the mid-1980s, with percentages below 5% of firms' total expenditure on R&D. From 1985 there was a notable expansion of the funds allocated by the public administration to the support of private R&D activities, and in 1989 the percentage reached 11.8%—closer to the average percentage of the European Union. This change was a result of the intention of the government to tackle the problem of internal insufficiency in the generation of technological resources. Nevertheless, public funding for private R&D has been significantly reduced during the last decade and currently represents a small percentage of the total funds that firms use for R&D. Data for 1998 show that public financing represented 6.6% of the total expenditure of enterprise on R&D—a percentage significantly below the averages for the OECD and the EU of 9.9% and 9%, respectively. The reduction in public funding that has occurred in Spain has also been seen in many other countries: in 1989, in the EU, the percentage of public financing was 14.2%. In evaluating these percentages, the considerable backwardness in technology and effort in R&D that separates Spain from the more advanced countries should be taken into consideration. More precisely, private expenditure on R&D in Spain in 1998 was 0.47% of gross domestic product (GDP)—much lower than the 1.15% across the EU and the 1.51% of the OECD countries.

To analyse, as a first step, the sectoral distribution of public support for R&D for each sector, the intensity of research carried out with firms' own funds was compared with the support that they receive. To do this two indicators were used. The first indicator is defined as the relative innovation effort (RIE) but, unlike the most common definition used, only financing with the firms' own funds is considered. The indicator is:

$$\mathrm{RIE} = \frac{B_i}{\sum_i B_i} \bigg/ \frac{V_i}{\sum_i V_i},$$

in which B_i is the private financing of entrepreneurial R&D activities in sector i and V_i is the value added of sector i. When the relative innovation effort of sector i is greater than one, this indicates an expenditure on R&D above the economic weight of sector i in manufacturing.

The second indicator is defined as relative government support (RGS), and is expressed as follows:

$$\mathrm{RGS} = \frac{P_i}{\sum_i P_i} \bigg/ \frac{B_i}{\sum_i B_i},$$

in which P_i is the financing from the government of business R&D in sector i. Data for public financing, provided by the OECD Science and Technology indicators database and the National Institute of Statistics (INE), are composed mainly of subsidies, but also include public contracts and nonreimbursable loans; it is not possible to distinguish between these components for sectors because of data-availability constraints. Moreover, these data do not include other forms of public support to business R&D, such as tax incentives. This information is not available at an industry level; neither are there any sectoral priorities in tax incentives.

The results of the calculations for the period 1989–98 are presented in table 1. The sectors have been grouped according to their innovation effort, in accordance with the latest classification proposed by the OECD, into four categories. This distinguishes between sectors of high, medium–high, medium–low, and low technology. During this period three sectors received more than 40% of the total public support to R&D: the aeronautical sector drew 22.6% of public financing, and just below that were machinery and shipbuilding.

The indicators show, from calculation of the coefficient of correlation (0.12), that there is a very little relation between sectoral effort in R&D and public support. It can also be seen that certain sectors have been particularly favoured by public support: shipbuilding; aircraft; wood and cork; instruments; and basic ferrous metals all have

Table 1. Private and public financing of research and development (R&D) in Spain; average values 1989 – 98 (source: OECD and National Institute of Statistics and compiled by the authors).

ISIC-3	Sector	B/V(%)	P/B(%)	RIE	RGS
2423	Pharmaceuticals products	7.46	4.73	4.26	0.52
30	Manufacture of office, accounting, and computing equipment	10.22	3.53	5.83	0.39
32	Radio, television, and communication equipment	12.53	5.19	7.16	0.57
353	Aircraft and spacecraft	12.68	41.64	7.24	4.57
High technology		9.80	9.67	5.59	1.06
31	Electrical machinery and apparatus	3.03	9.49	1.73	1.04
33	Medical, precision, and optical instruments	6.58	20.69	3.76	2.27
24 – 2423	Chemicals	2.04	4.92	1.17	0.54
29	Machinery and equipment	2.30	11.03	1.32	1.21
34	Motor vehicles	2.81	1.72	1.60	0.19
35 – 351–353	Other transport equipment	3.15	6.24	1.80	0.69
Medium – high technology		2.66	6.97	1.52	0.77
23	Coke and petroleum	1.72	4.25	0.98	0.47
25	Rubber and plastic products	1.34	3.47	0.77	0.38
26	Nonmetallic mineral products	0.52	7.99	0.30	0.88
271 + 2731	Ferrous metals	0.69	21.35	0.39	2.34
272 + 2732	Nonferrous metals	0.65	14.58	0.37	1.60
28	Metal products (except machinery and equipment)	0.53	11.75	0.30	1.29
351	Building and repairing of ships and boats	2.41	57.62	1.38	6.33
369	Manufacturing not elsewhere considered	1.44	7.76	0.82	0.85
Medium – low technology		0.87	13.41	0.49	1.47
15 + 16	Food, beverages, and tobacco	0.39	7.96	0.22	0.87
17	Textiles	0.47	9.28	0.27	1.02
18 + 19	Apparel, leather, and footwear	0.28	12.47	0.16	1.37
20	Wood and cork (except furniture)	0.06	27.19	0.03	2.99
21 + 22	Paper, publishing, and printing	0.30	8.48	0.17	0.93
361	Furniture	0.38	11.12	0.22	1.22
Low technology		0.35	9.02	0.20	0.99
15...36	Total manufacturing	1.75	9.11	1.00	1.00

Note. B, private finance of R&D; V, value added; P, public (government) finance of business R&D; RIE, relative innovation effort; RGS, relative government support.

values of the indicator RGS greater than 2. In contrast, the automobile; rubber and plastic; office, accounting, and computing equipment; and coke and petroleum sectors have very low values, below 0.5. Comparison of these results with those from other countries (Callejon et al, 2000) shows that the absence of a correspondence between private effort and public support for R&D is not a characteristic peculiar to Spain. Nevertheless, it can be seen that in Spain some very mature sectors which contribute little to growth find themselves relatively favoured by subsidies—is the case with iron and steel, shipbuilding, and footwear.

3.2 Econometric approach and results

In section 2 the conceptual framework put forward by David et al (2000) for the analysis of the effects of subsidies for R&D was described. From an applied point of view its use presents obvious difficulties. In particular, the use of models with panel data, which is especially useful in this type of analysis given the dynamic effects of

R&D, is confounded by a lack of information. Because of this there has been a tendency to use simpler approaches than that of David et al (2000) in empirical studies, such as a similar specification put forward by Lichtenberg (1987):

$$B = \mathrm{f}(P, S)\,, \tag{2}$$

where B is private financing of R&D, P is the public financing of private expenditure on R&D, and S (sales) constitutes an explanatory, and control, variable of the volume of expenditure on R&D. This equation is the reduced form of:

$$\text{supply:} \qquad C^{\mathrm{M}} = \mathrm{g}(B, P)\,, \tag{3}$$

$$\text{demand:} \qquad R^{\mathrm{M}} = \mathrm{h}(B, S)\,, \tag{4}$$

in which C^{M} is the marginal cost and R^{M} the marginal returns of firm innovations (Lichtenberg, 1987). This approach was used by Lichtenberg (1984; 1987) for an industry-level analysis with data from firms. Capron and Van Pottelsberghe (1997) and Van Pottelsberghe (1997) used a similar function for an analysis of industrial sectors of seven OECD countries with panel data for the period 1973–90.

To carry out the estimations, a panel of data, with the twenty-four industrial sectors previously presented for the period 1989–98, was constructed. The usual approach in the literature is to assume a logarithmic form:

$$\ln B_{it} = \beta_0 + \beta_1 \ln P_{it} + \beta_2 \ln V_{it} + \varepsilon_{it}\,, \qquad t = 1, \ldots, 10, \;\; i = 1, \ldots, 24\,, \tag{5}$$

in which B is the private funding of R&D, P is the public funding of private activity in R&D, as defined previously, and V is the gross industrial added value. All the variables have been deflated—the first two with the deflator of GDP, and V with the deflator corresponding to the gross industrial added value. Given that it seems reasonable to consider that private expenditure on R&D may respond to the effects of the public financing of R&D with a time lag (Capron and Van Pottelsberghe, 1997; Lichtenberg, 1984), estimations with delays for the variable PGID were also carried out. Time lag may occur because the possibility of financing R&D by obtaining public subsidies may encourage firms to decide on expenditure on R&D and this expenditure would materialise in later periods.

Before presenting the estimations, three matters deserve closer attention. First, a problem of simultaneity may exist between B and P, as the specific technological opportunity of the sectors affects both variables (David et al, 2000). Although this problem is more substantial with microeconomic data than with industry-level data (Capron and Van Pottelsberghe, 1997) it is better to correct for it. One possible way is by the use of dummy variables for the various sectors according to their technological content (Gannicott, 1984; Kauko, 1996). Also, the use of fixed effects in the estimation with panel data allows a specific constant term for each sector or, in other words, different levels of private expenditure on R&D for the various sectors. By the use of this procedure, the characteristics of the sectors that influence the level of expenditure on R&D that are assumed to be invariable in the period are included. The fixed-effects model is an appropriate specification for industry-level and country-level analysis, and its use is important in avoiding spurious correlation by minimising possible simultaneity effects (see Keller, 2002, for a similar argument).

Second, the effects of public financing may affect the various sectors in different ways, so it is convenient to examine the results for each sector, or various groups of sectors, according to their technological content. The small number of time-series observations limits carrying out estimations for each sector. For this reason the estimations (table 3 below) were carried out, grouping the sectors according to their technological content.

Third, another set of variables, with complex relations among them, influence the sectoral effort in R&D. The use of panel data and a fixed-effects model allows, as has been pointed out, the gathering of industry-specific characteristics, such as the level of appropriability and the degree of concentration or technological opportunity, which influence the level of expenditure on R&D. A lagged endogenous variable has also been included in order to take into account the dynamic aspect of R&D activities because of the influence that expenditures in previous periods have on the present level of resources allocated to R&D (Guellec and Van Pottelsberghe, 2001; Mansfield, 1964). Although the framework presented in section 2 is in the nature of a comparative static theory, as David et al (2000) point out, this formulation abstracts from important issues such as the time distribution of costs and benefits that innovations would generate, which may be treated by the use of dynamic models. For estimation purposes, not taking into account this explanatory variable may lead to a misspecification of the model. To introduce a lagged endogenous variable implicitly means that in firm-level R&D investment behaviour, public subsidies have short-run and long-term effects. The inclusion of lagged endogenous variables introduces inconsistency in ordinary least squares (OLS) estimators for the fixed-effects models of panel data. Because of this, use was made in this case, as suggested by Arellano and Bond (1991), of first differences and the two-step generalized method of moments (GMM) estimator. Together with the results of the estimation of the dynamic model—equation (5)—the Sargan test, and the tests for serial correlation are shown. The Sargan test allows confirmation that the combination of instruments used is appropriate. The tests for serial correlation allow the null hypothesis of the nonexistence of first-order serial correlation to be rejected although they do not permit the null hypothesis in the case of second-order serial correlation to be rejected, which allows the consistency of the GMM estimator to be guaranteed (Arellano and Bond, 1991).

The results (table 2, see over) show that the public financing of private R&D activities has a complementary effect on the resources that firms assign to R&D—positive and significant parameters were found in all the estimations. The inclusion of one-year and two-year lagged public support to R&D shows, in the same way as in Guellec and Van Pottelsberghe's (2001) work, that the reaction of the firms to public financing mainly takes place with a time lag of one year, whereas after two years the parameter are no longer significant. The sum of the significant parameters of the variable P allows the long-term effects of public financing of private expenditure on R&D to be obtained with elasticities that oscillate between 0.15 and 0.18. The estimated coefficients for public funding and for value added present values very close to those estimated by Guellec and Van Pottelsberghe (2001) in their regression. This fact may be interpreted provisionally as the case for public support to business R&D gains in strength. The introduction of the lagged endogenous variable, to gather the dynamic effects of the R&D activities, does not change the results significantly. In the estimations this variable is shown to be significant, although the value of the parameter is very low. In this case the value of the long-term elasticity is 0.21, that is calculated as $\sum \beta_j/(1-\alpha)$, β_j being the values of the parameters of the variable P and α the value of the parameter of B_{t-1}. Public support for R&D continues to be significant with a value for the parameters very similar to that in the fixed-effects models.

In the estimations the variation of B with respect to P was considered to be uniform for all the sectors. Nevertheless, some analyses suggest the existence of differences among sectors (Mamuneas and Nadiri, 1996), and even differences within the different sectors, in the most developed OECD countries (Van Pottelsberghe, 1997). Van Pottelsberghe (1997) found that in seven OECD countries (USA, Canada, Japan, Germany, France, Italy, and the United Kingdom) the efficiency of the subsidies in

Table 2. Analysis of the effects of subsidies for research and development (R&D) with t-statistics shown in parentheses: dependent variable $\ln B$—private funding of R&D.

Variable[a]	Pooled OLS[b]		Fixed effects		Two-step GMM[c]
	(1)	(2)	(3)	(4)	(5)
Constant	−3.994	−2.983			
	(−4.591)*	(−4.808)*			
$\ln P$	0.196	0.099	0.174	0.081	0.029
	(4.271)*	(2.100)**	(3.033)*	(2.233)**	(2.054)**
$\ln P_{t-1}$		0.158		0.148	0.175
		(2.964)*		(4.043)*	(13.484)*
$\ln P_{t-2}$		0.035		0.012	
		(0.747)		(0.352)	
$\ln V$	0.776	0.668	0.204	0.303	0.655
	(11.351)*	(13.579)*	(0.859)	(2.028)**	(5.520)*
D^{HT}	2.719	2.596			
	(11.627)*	(15.342)*			
D^{MHT}	2.088	1.850			
	(11.344)*	(8.219)*			
D^{MLT}	1.084	0.939			
	(6.760)*	(8.219)*			
$\ln B_{t-1}$					0.009
					(1.898)***
Adjusted R^2	0.643	0.824	0.754	0.923	
N	240	192	240	192	168
Wald test					2043.24*
Sargan test					21.64
First-order serial correlation					−1.84***
Second-order serial correlation					−0.82

* Statistically significant at 99% level of confidence, ** 95%, *** 90%.
[a] P, public financing of business R&D; $t-1$ and $t-2$ indicate time lags of 1 and 2 years; D are dummy variables with values of 1 for that sector (HT—high technology, MHT—medium–high technology, MLT—medium–low technology) and 0 otherwise; V, value added; B, private financing of R&D.
[b] OLS, ordinary least squares.
[c] GMM, two-step generalised method of moments (dynamic panel-data model).

stimulating private R&D was greater in sectors with a medium–high and medium–low technological content than in the other sectors. Consequently, it seems useful to examine whether any similar differences exist in the case of Spain. The limited number of time-series observations restricts the estimations for the separate sectors, and hence the estimations were made for each of the four *types* of sectors—grouped according to their technological content. In this case, dynamic models were not used. The previous estimation, for all the sectors, shows that the inclusion of a lagged endogeneous variable does not make any relevant changes to the results. In addition, the use of dynamic models is confronted with the low number of observations, particularly in the case of the sectors with a high technological content.

The results obtained reflect a complementarity effect in the majority of the sectors, with the exception of high-technology sectors (table 3). In sectors with medium–high and medium–low technological content in particular, subsidies to R&D provide an incentive to private expenditure on R&D.

Table 3. Analysis of the effects of subsidies for research and development (R&D), with t-statistics shown in parentheses, by sector—fixed-effects model: dependent variable ln$B$—private funding of R&D.

Variable[a]	Technology sector[b]							
	(1)	(1)	(2)	(2)	(3)	(3)	(4)	(4)
ln$P$	0.189	0.271	0.316	0.340	0.102	0.038	0.114	0.048
	(0.458)	(0.501)	(4.332)*	(5.329)*	(2.128)**	(0.888)	(1.902)	(0.751)
lnP_{t-1}		−0.126		0.114		0.110		0.156
		(−0.242)		(1.457)		(2.671)*		(2.613)**
ln$V$	−0.081	−0.357	0.059	0.146	0.560	0.521	0.977	0.852
	(−0.065)	(−0.247)	(0.325)	(0.684)	(2.174)**	(2.252)**	(2.588)*	(2.204)**
Adjusted R^2	0.221	0.144	0.891	0.889	0.741	0.801	0.900	0.912
N	40	36	60	54	80	72	60	54

* Statistically significant at 99% level of confidence, ** at 95% level.
[a] P, public financing of business R&D, V, value added.
[b] (1) high technology; (2) medium–high technology; (3) medium–low technology; (4) low technology.

Conversely, in high-technology sectors the parameter is not significant: that is, public financing has neither an additional effect nor a substitution effect on private resources in R&D, and therefore public financing contributes towards increasing R&D expenditures but does not stimulate any new private spending. This result is in agreement with that obtained by Van Pottelsberghe (1997) in the cases of Germany, France, and Italy. This seems to show, as David and Hall (2000) point out, that the effect on highly subsidised industries, such as the aeronautical industry in Spain, may be less than that on the sectors that receive lower subsidies. Also, a limited supply of qualified personnel may lead to an increase in the cost of salaries, but subsidies would have little impact on the real level of private expenditure on R&D. As Goolsbee (1998) points out, in the case of the United States, an increase in government subsidies leads to a considerable increase in the incomes of researchers although the number of hours worked increased much less. This effect on wages is greater in sectors such as the aeronautical or electronic industry. Analyses of the Spanish system of innovation have exposed the shortages of qualified personnel and the difficulties that firms face in recruiting scientists. This problem has led to the development of a specific programme to subsidise the recruitment of highly qualified researchers into firms (COTEC, 2004).

In spite of the absence of financial additionality, high-tech firms, especially start ups, face asymmetric information problems which limit their capacity to acquire external financing for R&D projects and this may justify public support (Rye, 2002). Also, as Luukkonen (2000) points out, financial additionality is not sufficient to reveal the usefulness of public technology support—other criteria, such as strategic value, have to be taken into account. Although financial additionality may be lower in high-tech sectors than in other sectors, the impact of R&D investment in high-tech firms on productivity and on economic performance is higher. More importantly, the R&D expenditures of high-tech industries generate spillovers, even when the R&D is publicly financed, which benefit all industries and the economy as a whole (Keller, 2002; Mamuneas, 1999). Also, as Grossman and Helpman (1991) point out, if spillovers are geographically bounded, as empirical results suggest (Keller, 2002; Klette et al, 2000), an R&D subsidy may eliminate the disadvantages that lagging countries have in high-tech industries. The analyses for the case of Spain (Banco de España, 2004; Martin 1999) show that the level of backwardness in R&D compared with the most developed countries of the European Union is not only caused by the lower presence of high-tech sectors in the industrial structure, but also particularly by lower R&D effort in all industries. These differences in R&D expenditures are especially significant in high-tech industries, which may explain the difficulties that these sectors face in increasing their participation in international markets and in the Spanish productive structure.

In summary, the findings support the use of public subsidies to reinforce technological business effort on R&D. This is an important result for public policy in Spain, which needs to improve private efforts in R&D substantially in order to reach the average R&D expenditure level of the most developed countries of the European Union, and to increase its economic growth potential.

Nevertheless, some cautionary remarks should be made. First, in this paper we have focused on the analysis of financial additionality. Although this is an important objective of public policy in guaranteeing its efficiency, other significant effects of R&D subsidies have not been considered. In particular, as has been pointed out, the effects on the productivity level of firms have not been analysed. Also, the possible existence of interindustry spillover effects has not been taken into account. These effects differ substantially between industries, and a main objective of public policy should be precisely that of providing an incentive for R&D projects in industries which will have greater effects on other firms and industries and on the economy as a whole. Furthermore, public subsidies to specific industries, such as low-tech sectors, may provide an incentive for a transformation process in these activities and increase their competitiveness, with significant additional economic and social effects in the medium and long term. Therefore, to use financial additionality as the only criterion may be to omit other important additionality aspects that have to be taken into account in the designing of public policy.

Second, as the above comments show, the evaluation of technology policy is faced with important difficulties. Although econometric methods appear to be the most appropriate for quantitatively assessing the effects of public subsidies to business R&D, they have drawbacks in guiding the implementation of technological policy and they have not been able to provide definite conclusions regarding the relationship of public financing and private expenditures on R&D (David et al, 2000; García-Quevedo, 2004). Therefore, a comprehensive evaluation of R&D policy requires the use of complementary methods, combining quantitative and qualitative approaches. This would provide more information on the various different effects of policy intervention and help to improve its effectiveness. Also, it would be useful to regard evaluation as an integral part of the design of technology policy, in order to improve knowledge of its effects.

4 Conclusions

Our objective in this paper has been to analyse the effects of public subsidies on private expenditures on R&D, with the purpose of evaluating the effectiveness of this instrument in Spanish technology policy.

Although financial additionality is not, as has been pointed out, the only form of additionality that should be taken into account in a comprehensive technology policy evaluation, the public financing of private expenditure on R&D should fulfil the principle of additionality to guarantee its efficiency. The applied analyses, national as well as international, that have been carried out up to now have not been able to provide a conclusive answer as to whether a relation of complementarity or a substitution effect predominates.

Departing from the framework proposed by David et al (2000), an econometric analysis has been carried out to examine whether public subsidies have an additional effect on private expenditures on R&D. As David et al (2000) point out, public policy can contribute to increase in private effort either by raising the expected rate of return or by reducing the cost to the firm of the investment in R&D.

Information-availability constraints and the difficulties found in estimating the parameters of the structural equations proposed in this framework have led, in applied analysis, to a single-equation approach with the estimation of the reduced form of the model—as in this paper. This approach, although it can not be used to estimate the effects on the reduction of the firm's investment costs and on the increase in its returns separately, has, nevertheless, suggested that public financing of R&D in Spain is stimulating new private expenditures.

In addition, we have estimated the effects of public subsidies on the private expenditures of the different industries, depending on their technological content. This has shown that the effect is not uniform across all the sectors and that in medium–high and medium–low technological content sectors particularly, the effects of public subsidies on private expenditures are more significant. This result reinforces the point of view that technological and industrial policy has to take the characteristics of the individual sectors into account, and needs to be applied differently according to the sector (European Commission, 2002). This also makes it desirable to develop sector-specific studies. Even though these would be faced with information constraints, they would allow the evaluation of technology policy to be improved.

The analysis of the case of Spain suggests, as explained above, that an additional effect has taken place. This result coincides with the conclusions reached in a study by Guellec and van Pottelsberghe (2001), with information from seventeen OECD countries, in which it was found that direct support showed an incentive effect as long as the level of support did not exceed a certain threshold (one still far above that reached by the policies of support for R&D in firms in Spain).

The results obtained for the case of Spain seem of particular interest at a time when a redefinition of technology policy is taking place, which has established priorities for a set of sectors (defence, information and communication technology, aeronautics and aerospace, biotechnology, railways, the environment and renewable energy, machine tools, and motor vehicles) in the Programa de Fomento de la Innovación Tecnológica (PROFIT—Programme for the Promotion of Technology Innovation), and which tends to reduce the level of public subsidies.

As has been mentioned, our analyses point toward a complementarity effect between the public financing of R&D and private expenditure, as have other microeconomic studies of the case of Spain (COTEC, 2000). Consequently, and faced with the technological backwardness that characterises Spain, it seems appropriate to reinforce technology policy with an increase in the volume of financial incentives for carrying out entrepreneurial R&D projects, at a time when the trend is to favour fiscal incentives to the detriment of subsidies (Piqué, 1999).

Studies based on information from many countries of the OECD (Guellec and van Pottelsberghe, 2001) point towards the possibility of a substitution effect between fiscal incentives and direct support. In other words, an increase in fiscal generosity concerning entrepreneurial expenditure on R&D implies a reduction in the additional effect of direct support to R&D projects. These data reinforce the idea even more that technological promotion policies should be designed in a form that is integral and coordinated.

Neither should we lose sight of the result according to which fiscal incentives have a very short-term, virtually contemporaneous, effect. This may indicate that, when provided with a fiscal incentive, R&D often concerns projects with little technological or innovative depth; this implies that there will be less effect on vital dynamic variables such as learning or the accumulation of R&D equipment and infrastructures.

The evidence available to the present, although still partial and fragmentary, points towards the usefulness of reinforcing direct support programmes for projects if the aim is the long-term fortification of the capacity of enterprise for innovation.

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