Barriers to innovation and subsidy effectiveness*

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Abstract

This paper explores the effects of R&D commercial subsidies by means of a model of firms' decisions about performing R&D when some government support can be expected. To estimate the parameters of interest we use an unbalanced panel sample of 1,800 performing and non-performing Spanish manufacturing firms. For the non-performing firms, we compute the trigger subsidies required to induce R&D spending (a measure of market failure). Among the performing firms, we can detect the ones that would cease to perform R&D if subsidies were eliminated. We also explore the change in the privately financed R&D effort of the performing firms. Results support the claim that market failures are real and subsidies stimulate R&D activities, but also show that actual subsidies go to firms that would have performed R&D otherwise.

Keywords: R&D, innovation, subsidies, thresholds, Tobit model

JEL Classification: O32,L11,C24

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1. Introduction

Public sectors of all industrialized countries spend considerable amounts of money in supporting commercial R&D of manufacturing firms. Firms apply for subsidies for research, and agencies choose the research to be funded. The economic justification of these programs lies in the presumable failure of the market to provide incentives to firms to allocate enough resources to innovative activities (Arrow (1962), Nelson(1959)). Positive externalities affecting other firms and consumers induce a divergence between the social and private returns of such activities.

Despite the spread of these subsidies, the evidence of their effects on firms' behavior remains relatively modest and controversial (see, for example, the survey on recent microeconometric evidence by Klette, Moen and Griliches (2000)[1]). Researchers are currently trying to determine whether subsidies stimulate R&D, in the sense that firms undertake projects that otherwise would not have been carried out, and also if the public funds crowd out the company-financed R&D expenditure. The answers are far from unanimous, often depending on the methodology employed. For instance, a recent firm-level econometric study by Wallsten (2000) using a sample of US firms claims that, controlling for grants endogeneity, no effort effect is detected and crowding out is present. On the contrary, the work by Lach (2000) with panel data on Israeli firms finds a positive long-run elasticity of company-financed R&D expenditures with respect to subsidies[2].

This paper is aimed at exploring the effects of R&D commercial subsidies by focussing on the modelling of firms' decisions when some government support can be expected: whether or not to perform R&D projects, and the associated level of R&D effort (R&D expenditure over sales). It tries to shed light on the questions of interest by constructing an explicit

[1] Or the related works by Hall and Van Reenen (2000), on fiscal incentives, and David, Hall and Toole (2000) on public/private R&D.

[2] Some evidence on the "additionality" of subsidies is also found by Toivanen and Niininen (2000) with Finnish firm data, while Busom (2000) finds some crowding out with a small sample of Spanish publicly granted firms. Parisi and Sembenelli (2001) have recently estimated highly elastic responses of R&D expenditures of Italian firms to the cost of funds.

theoretical framework to explain why and how the firms' investments can turn out to be inhibited, and employing a sample of highly heterogeneous firms to identify the model parameters (a sample that in particular includes both R&D performers, subsidised or not, and non-performers).

From the estimation of the model we derive profitability thresholds and gaps for the expenditure on innovative activities for every firm. For non-performing firms, the gap between their unobserved optimal R&D spending and the profitability threshold is a measure of the market failure. For these firms, we compute the trigger subsidies required to induce R&D spending. Among the performing firms, we can detect those that would cross back the profitability threshold and cease to perform R&D if subsidies were eliminated. In addition, we can assess subsidy efficiency for all the performing firms by exploring the changes in the privately financed R&D effort obtained as an effect of the grant.

Results claim that market failures are real and that subsidies can play a role in stimulating R&D activities, but also that actual subsidies in fact go to firms that would have performed innovative activities had they not received the subsidy. However, subsidies increase the private funds invested on R&D by these firms.

To model firms' decisions we consider each firm a competitor in prices in a product differentiated industry, which can shift the demand for its product by enhancing product quality through R&D expenditures. Demand characteristics, technological opportunities and set-up costs of R&D projects interact to determine a profitability threshold of spending. Below this threshold, R&D costs are not completely recovered in the market by means of the sales increment. Firms can then find it more profitable not to undertake innovative activities, but this decision can be modified if expected subsidies reduces the cost of R&D. The same framework explains how performig firms take into consideration the expected grants to determine the size of the R&D planned expenditures.

This framework naturally leads to a Tobit type modelling of the censored variable optimal effort, which is the way employed to estimate the model parameters. Before this, unobservable expected subsidies are estimated from data on ex-post observed grants. Subsidies are presumably granted by agencies according to the contemporary effort and performance of firms, and hence are endogeneous. This two-step procedure also allows us to obtain estimates that are robust with respect to the possible biases derived from this endogeneity.

To estimate the model we use an unbalanced panel of more than 1,800 Spanish manufacturing firms observed during the period 1990-97. The data come from a random sample drawn by industries and size strata, and hence results can be claimed to be valid for the whole industry. During the period, Spanish central and regional governments, as well as the European Union, maintained several commercial R&D subsidy programs which accounted for innovations' primary source of support. Firm sample behavior is, however, heterogeneous. Almost 20% of the firms with more than 200 workers and about 70% of the firms under this size do not report to perform formal R&D. And only a fraction of performing firms, increasing with firm size, obtains subsidies.

The rest of the paper is organized as follows. Section two summarises the theoretical framework. Section three presents the econometric model and explains how it can be used to measure the different subsidy effects. Section four describes the data set and the main facts about subsidies. Section five reports the econometric results and section six discusses the implied subsidy effects. Section seven concludes. Appendix 1 is devoted to some econometric details and Appendix 2 to describing the employed sample and variables.

2. R&D with set-up costs

This section characterises the R&D decisions of firms and relates them to subsidies[3].

Firm i competes in prices in a given product differentiated industry, facing a negatively sloped demand. Demand, however, can be shifted by enhancing the quality of the product. We will write demand as $\widetilde{q}_i(p_i, p_{-i}, s_i)$, where p_i stands for the own price, p_{-i} for the vector of prices of the rivals, and s_i for the level of quality, and we will suppose $\partial\widetilde{q}_i/\partial s_i > 0$ and $\partial\widetilde{q}_i^2/\partial s_i^2 \leq 0$. In what follows, we will assume that price competition can be taken as stable over time and subsumed in the relevant own-price demand elasticity, and hence we will write $\widetilde{q}_i(p_i, p_{-i}, s_i) = q_i(p_i, s_i)$. We will relax this assumption in the empirical exercise by

[3] The model follows Gonzalez and Jaumandreu (1998).

considering the possibility of eventual changes in competition. We also momentarily drop the subscript i for simplicity.

Quality can be improved by incurring R&D expenditures, denoted henceforth by x, according to some technological rules. In particular, to surpass the current industry standard quality $s(0)$, firm i must incur some set-up costs that we will denote by F. Beyond F, R&D expenditures affect quality according to the "production function" $s = s(x)$, where $\partial s/\partial x > 0$ and $\partial^2 s/\partial x^2 \leq 0$. Set-up costs usually stem from the indivisibility of some resources.

A firm can apply to have its R&D expenditures subsidized with public funds by a monetary fraction ρ. But the firm must take its decisions ex-ante (at the time of setting its R&D plans) and we assume that they are based on the firm's expectation about the subsidy that will be obtained, ρ^e. On the other hand, public subsidies can be associated to a higher level of expenditure efficiency, since they often give access to other facilities or advantages (e.g. access to public laboratories and researchers). By the same token, they could be hypothetically linked to less expenditure efficiency, for example because they ease liquidity constraints and hence discipline. Accordingly, we will parametrize the expected cost of a unit of efficient R&D as $(1-\rho^e)^\beta$, where β is a measure of subsidy efficiency[4].

Suppose now that production marginal cost is c. To set the product price and decide the pertinence and level of R&D expenditures, the firm must solve the problem

$$\max_{p,x}\ (p-c)q(p,s) - (1-\rho^e)^\beta x \qquad [1]$$

subject to

$$s = \begin{cases} s(0) & \text{if } x < F \\ s(x) & \text{otherwise} \end{cases}$$

which turns out to be a problem with a non-convex constraint. The equilibrium of the firm will be characterized by the pair (p^e, x^e) such that $(p^e, x^e) = \max\{\Pi(p^*, x^*), \Pi(p^{**}, 0)\}$, where $p^*$and p^{**} may diverge and (p^*, x^*) is the interior solution. That is, the firm will choose

[4]If $\beta = 1$ the obtained public funds leave unchanged the efficiency of the company-financed funds.

whether or not perform R&D activities according to an incremental profit-expenditures comparison condition.

Assume that firms can in any case obtain a non-negative profit performing R&D, that is, $\Pi(p^*, x^*) \geq 0$. Then, optimal non-zero effort of both performing and non-performing firms can be summarized in the unique expression

$$E^* \equiv \frac{x^*}{p^* q^*} = (\frac{s}{q}\frac{\partial q}{\partial s}\ \frac{x}{s}\frac{\partial s}{\partial x})\ /(-\frac{p}{q}\frac{\partial q}{\partial p}\ (1-\rho^e)^{\beta}) \qquad [2]$$

which results from rearranging the FOC interior conditions of [1], and is a Dorfman-Steiner type of condition (Dorfman and Steiner (1954)). Non-performing firms, however, would only choose this (local maximum) allocation if they hadn't a more profitable alternative.

Formula [2] shows that optimal effort increases with the elasticity of demand with respect to R&D expenditure, which can be conceptually decomposed in the elasticity of demand with respect to quality (demand conditions) and the elasticity of quality with respect to R&D expenditure (technological opportunities); with the degree of market power (the inverse of the price elasticity), and with the expected subsidy. This effort will only be observed in practice when it surpasses a threshold effort $\overline{E}$ jointly determined by the factors that influence the above elasticities, including the value of the set-up costs[5]. $\overline{E}$ is simply the level of R&D effort at which the firm would be indifferent to performing R&D or not in the absence of subsidies (the firm would obtain the same profit). Hence (expected) subsidies have two different effects. On the one hand, they can induce some firms to perform R&D. On the other, they enhance R&D expenditures of firms that would perform innovative activities in any case.

Underlying [2], we can assume the standard account of determinants of innovative activities (see, for example, Cohen (1995) or Cohen and Levin (1989)). When it comes to specifying the equations and interpreting the variable effects, it is important to keep in mind how we expect these elasticities to evolve across equilibriums. Let us briefly summarise the

[5] Given our assumptions, effort is expected to increase monotonically with the R&D expenditures.

partial effects expected according to the model[6]. Market power variables are expected to be associated with higher efforts but probably with a small or null effect on thresholds. Variables representing a high sensitivity of sales to R&D expenditure must induce lower thresholds and higher efforts. Variables measuring set-up costs are expected to increase effort (through elasticities) and thresholds.

3. Barriers to R&D and subsidy effects

In this section we show how the parameters of the previous model can be estimated with a Tobit type econometric model, and we present the estimation procedure. Then we define the measures of the effects of subsidies.

3.1 Econometric model

Take logs in [2] and let z stand for the vector of "reduced-form" variables that determine the value of the (log of) elasticities. We have the following semi-structural econometric relationship[7]

$$e^* = -\beta ln(1-\rho^e) + z\beta_1 + u_1 \qquad [3]$$

where $e^* = lnE^*$ and u_1 is a random disturbance.

According to our theoretical framework, e^* is a censored variable. Hence, to consistently estimate the parameters, we must take into account its observability rule. Let us specify this rule as

[6] These effects can be obtained by performing some comparative statics exercises. A useful particular model to perform such exercises is obtained by assuming $q(p, s(x)) = q_0(p)(1+\varepsilon \ln \frac{x}{F})$ and using $k = F/pq_0(p)$ as a measure of set-up costs.

[7] It can be called semistructural because the expected subsidies enter the effort equation in the way they appear in the first order condition, but elasticities -or their associated variables: price or margins, shares, etc...- are endogeneous variables of the underlying model that we replace by a set of reduced form determinants (i.e. the other explanatory variables).

$$e = \begin{cases} e^* & \text{if } e^* > \overline{e} \\ 0 & \text{otherwise} \end{cases} \qquad [4]$$

with

$$\overline{e} = z\beta_2 + u_2 \qquad [5]$$

where e represents observed effort and the equation for $\overline{e}$ specifies the thresholds including a random disturbance term u_2. Thresholds can be presumed to be a function of the same variables that determine elasticities, but the effects of these variables on $\overline{e}$ give the height of the "barriers" to the profitability of R&D. We will take firms as competing in heterogeneous environments and hence having idiosyncratic thresholds.

Equations [3], [4] and [5] define a Tobit type model, in which optimal effort e^* is taken as a partially observable variable, only observed when it stochastically surpasses the firm profitability threshold $\overline{e}$[8].

3.2 Estimation procedure

Estimation of the model first requires solving the problem of the unobservability of the expectation variable ρ^e. In fact, only ex-post granted subsidies are observable. Then, we will follow a two step procedure, first estimating the conditional expectation of subsidies and then substituting the estimated values for the unobservable expectations.

Let us write and decompose the expected subsidy as follows

$$\rho^e = E(\rho|y) = P(\rho > 0|y)E(\rho \mid \rho > 0, y) \qquad [6]$$

where $P(\rho > 0|y)$ stands for the probability of the grant, $E(\rho \mid \rho > 0, y)$ for the expected value of the subsidy conditional on its granting, and y for the vector of other conditioning variables. To deal with the high non-linearity of the expected subsidies, we will estimate these two conditional expectation functions, using firm observable characteristics as components of y, and we will use the fitted values to estimate ρ^e. We will estimate $P(\rho > 0|y)$ by

[8] Econometric models of censored variables with stochastic thresholds date back to Gronau (1973) and Nelson (1977).

means of a probit model and we will employ the best linear predictor $E(\ln \rho | \rho > 0, y) = y\gamma$ to construct an estimate of $E(\rho \mid \rho > 0, y)$[9],[10].

Subsidies are presumably granted by agencies according to the contemporary effort and performance of firms, and hence are endogeneous (their values are likely to be correlated with the random term u_1) . The two-step procedure used to obtain ρ^e will also allow us to consistently estimate the parameters of the effort equation in the presence of this endogeneity. It suffices to adequately select the variables y. The regressors used to estimate [6] must be valid instruments for ρ (that is, exogeneous or predetermined variables).

Substituting $\widehat{\rho^e}$ for ρ^e in the effort equation, we will estimate the whole model by maximum likelihood. The model turns out to be a type 2 generalized Tobit according to the classification in Ameniya (1985), where alternative identification conditions are discussed (see also Maddala (1983)). One of these conditions is the availability of at least one variable that enters the equation for the censored variable but can be excluded on theoretical grounds of the thresholds equation. This condition arises naturally in our model, where expected subsidies can be safely excluded from the determinants of thresholds[11]. In practice, we will also exclude other variables on statistical grounds. Technical details on the ML estimation procedure are given in Appendix 1.

3.3 Measuring profitability gaps and subsidy effects

Given parameter estimates of this model, one is ready to compute individual threshold estimates and to use them to assess the effects of subsidies when the firm is confronted with barriers to R&D.

Let us first define profitability gaps. We define profitability gaps as the difference be-

[9] We will assume that $v = E(\ln \rho | \rho > 0, y) - y\gamma$ is $N(0, \sigma^2)$. Then $E(\rho | \rho > 0, y) = \exp(y\gamma + \frac{1}{2}\sigma^2)$.

[10] The econometric procedure that we follow in this case openly differs from the one employed in the estimation of the effort equation. This is because here we are simply interested in the estimation of the conditional expectation of observed granted subsidies, and not in the expectation of a (theoretically defined) latent variable like the optimal effort e^*. In addition, "two-part" estimations of expressions like [6] perform very well in prediction (see, for example, Leung and Yu (1997)).

[11] This happens because effort thresholds for profitable technological activities are defined in terms of the total expenditure needed, independently of its composition.

tween the optimal effort in the absence of subsidy and the threshold effort. If negative, they give the R&D expenditure (in terms of % of sales) by which the firm falls short to undertake profitable innovative activities. If positive, they give the R&D expenditure (in terms of % of sales) that the firm would make, in the absence of subsidies, in addition to the minimum profitable amount. Notice that the two efforts that determine profitability gaps are unobservable but that our model measures the non-stochastic components respectively by $\exp(z\widehat{\beta}_1)$ and $\exp(z\widehat{\beta}_2)$[12].

With profitability gaps measured, we can evaluate the (actual and potential) roles of subsidies in the performance of innovative activities. Let us first focus on trigger subsidies. We define these subsidies as the value of the ρ^e's that would induce non-performing firms to undertake innovative activities (by filling their negative profitability gaps). These subsidies can be estimated as the values of ρ^e that solve the equations $-\widehat{\beta}ln(1-\rho^e)+z(\widehat{\beta}_1-\widehat{\beta}_2)=0$ for firms with $e=0$ (non-performing firms) and $-\widehat{\beta}ln(1-\widehat{\rho}^e)+z(\widehat{\beta}_1-\widehat{\beta}_2)<0$ (correctly predicted).

Let us then evaluate the role of a subsidy withdrawal. Some firms are likely to be performing innovative activities because the support effect of the expected subsidy fills in the negative profitability gap that would exist in its absence. We take these firms as the ones with $e>0$ (performing firms) and for which $-\widehat{\beta}ln(1-\widehat{\rho}^e)+z(\widehat{\beta}_1-\widehat{\beta}_2)>0$ (correctly predicted) but with $z(\widehat{\beta}_1-\widehat{\beta}_2)<0$ (negative profitability gap).

All this refers to the ability of subsidies to induce firms (potentially or effectively) to invest in R&D. But, according to the model, how do subsidies change the expenditure of firms that perform innovative activities? Firstly notice that R&D expenditures are expanded in the model to increment sales and, therefore, the rate of change in effort constitutes a lower bound for the rate of increase in expenditure[13]. Secondly, changes in effort depend

[12]Profitability gaps can be computed in a number of ways. Below we use the differences between the non-stochastic components of the effort and threshold equations, which give an intuitive measure of the gaps explained by systematic factors.

[13]Total R&D expenditure may be written as the product of effort by sales $x=Epq$. The change in expenditure may be conceptually decomposed in the sum of two changes: the change due to sales and the change in effort. An assessment of the sales effect of subsidies would only be possible with a more complete

on subsidies in a complex way, because all the elasticities in [2] may change with the firm equilibrium. We will use an approximate measure of the change in effort which becomes exact in the simplest case in which elasticities remain constant.

In addition recall that our model must be interpreted explaining ex-ante R&D expenditure, planned in advance by firms, taking into account the degree of uncertainty associated to subsidies. Plans are likely to be adjusted when firms know for sure if they will be granted or not, and the model does not say anything about how these adjustments will be carried out. Hence we must distinguish two bounds for the effects of a subsidy finally granted. First, the (minimum) effect associated to the ex-ante commitment of expenditures corresponding to the expected subsidy ρ^e. Second, the (maximum) effect associated to the granting of a subsidy ρ if ex-post adjustments were carried out with the same model and parameters. The true effect will probably lie in between. In what follows we disscuss the effects in terms of ρ^e, but formulae to apply with ρ are the same.

Call $E^*(\rho^e)$ total effort with subsidy and $E^*(0)$ total effort in its absence. Write $(1-\rho^e)E^*(\rho^e)$ for private effort when expenditures are subsidised. It is easy to check that

$$\frac{(1-\rho^e)E^*(\rho^e)-E^*(0)}{E^*(0)}=[(1-\rho^e)^{-(\beta-1)}-1]\lesseqgtr 0 \text{ if } \beta \lesseqgtr 1$$

Therefore, if subsidy efficiency β is unity, private effort will remain the same, and total effort will be augmented by the public effort fraction $\rho^e E(\rho^e)$. This means that private-financed expenditures would increase by the same amount as sales. On the contrary, if β exceeds unity, the subsidy will increase private effort, and total effort will become higher than the sum of the public fraction and private effort without subsidy. If β were less than unity, private effort would be reduced. We will use this type of formula to measure subsidy effort effects.

To measure this type of effects, other studies take the value of some derivatives. For example, Lach (2000) employs the derivative of private expenses with respect to subsidy in the equation used to estimate the factors influencing firm R&D expenditures. With sales controlled for, this derivative amounts to a linear partial effect (independent of the subsidy

specification of the demand (e.g. the price elasticity effects of innovation).

value and without demand induced effects). With our model, an average subsidy effect of this type can be computed by evaluating at some point the first term of the right hand of the identity

$$\frac{(1-\rho^e)x(\rho^e)-x(0)}{\rho^e x(\rho^e)-0}=\frac{(1-\rho^e)E^*(\rho^e)-E^*(0)}{\rho^e E^*(\rho^e)}+\frac{E^*(0)}{\rho^e E^*(\rho^e)}\frac{S(\rho^e)-S(0)}{S(\rho^e)}$$

where S is a shorthand for sales.

4. Data and description

The basic data set is an unbalanced panel of Spanish manufacturing firms surveyed during the period 1990-1997, which includes nearly 2,000 firms[14]. This sample can be considered approximately representative of manufacturing. At the beginning of the period, firms under 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 represented more or less a self-selected 60% of firms within this size. To preserve representation, samples of newly created firms were added every subsequent year. Exits from the sample come both from death and attrition, but they can be distinguished and attrition was maintained under sensible limits.

The survey provides information on the total R&D expenditures of the firms, including intramural expenditures, R&D contracted with laboratories or research centres, and technological imports, that is, payments for licensing or technical assistance. We consider a firm performing technological or innovative activities when it reports some R&D expenditure. The variable to explain is technological effort, defined as the ratio of R&D expenditures to firm sales. In explaining effort, we use the extensive information on the firms' activities covered by the survey (see the sample details on Appendix 2). In what follows, we summarise some facts about R&D expenditures and granted subsidies.

During the nineties, subsidies as a whole were the main incentive available for manufacturing firms to undertake research programs. Our subsidy variable refers to the total

[14] The survey was sponsored by the Spanish Ministry of Industry under the name "Encuesta sobre Estrategias Empresariales" (Survey on Firm Strategies).

amount of public financing received for each firm under different program headings[15].

Tables 1 and 2 report some facts about the degree to which Spanish manufacturing firms engage in formal R&D activities. Table 1 shows that the probability of undertaking R&D activities in a given year increases sharply with size (20% of the firms under 200 workers and 75% of firms with more than 200 workers), and that this probability has been increasing slightly over time for the firms of all sizes. Table 2 adopts another perspective by distinguishing permanent and stable performers during the period. Stable R&D performers are firms that report R&D expenditures every year they remain in the sample. Occasional performers are the firms that report R&D expenditures only some of the years they remain in the sample. Stable performance of R&D activities is strongly correlated with size.

Tables 3 and 4 report the main facts about grants. Table 3 shows that only a small fraction of R&D performers receive subsidies and that the proportion of subsidised firms increases with firm size, at least for the stable performers. Table 4 shows that the typical subsidy covers between 20% and 40% of the R&D expenditures and also that the rate of subsidised expenditure, unlike its granting, does not show a clear relationship with firm size (although the biggest firms tend to obtain smaller rates of coverage).

Tables 5 and 6 take a first look at the relationship between subsidies and effort, based on the R&D performers' data. Both tables show a positive association between the granting of subsidies and R&D effort, both in the whole period and year to year. The data tend to show even more than "additionality," in the sense that the difference between the subsidised and not subsidised efforts as a proportion of the former tends to be higher than the typical subsidy coverage. Therefore, data suggest the likelihood of positive effort effects of subsidies. But this can be solely the effect of other non-controlled variables or that the relationship is expected to go either way: firms with more effort are more likely to receive subsidies.

[15] Commercial R&D subsidies in Spain may have three sources. Firstly, the European Framework program, with a wide variety of subprograms (information, telecommunications, biotechnologies, aerospace...) but which reach a very small number of firms. Secondly, the Ministry of Industry programs, which include the subsidies granted by the specialised agency CDTI (Centre for Industrial Technological Development). Finally, the technological actions of regional governments.

Only the implementation of the econometric model can provide further insights on this relationship.

5. Econometric results

In what follows, we firstly detail the specification and estimation of the equations aimed at estimating the expected subsidy. Then, we comment the specification and estimation of the Tobit type effort model.

5.1 Expected subsidies

We estimate the unobservable firms' expectations ρ^e starting from the ex post observable granted subsidies, using the two equations specification given by [6]. Underlying the process by which subsidies are granted there is a complex process of some firms applying for subsidies and the relevant public agency granting the subsidies to a subset of them. The probability of obtainig a subsidy must then be seen as the product of the probability of applying for a grant by the probability of obtaining it [16], and the determinants of the probability of subsidy must be understood to reflect in part the likelihood of incurring the costs of applying.

We want to predict the expected result of this process by means of a set of variables which can be considered exogeneous or, at least, predetermined. We will use the same set of variables to estimate the conditional probability of receiving a subsidy, using a probit specification, and the conditional expected value of the (log of) subsidy when it is granted, using a linear equation estimated by OLS. The expected subsidy will be computed as the product of the predicted probability by the predicted conditional value for ρ.

In estimating the equations, we consider the following set of explanatory variables: firstly, the value of subsidy in the previous period, in order to pick up persistence, which can be based either on projects spread over several years or the renewal of grants by experienced firms; secondly, three indicators of the degree of commitment with R&D activities: lagged R&D effort, a dummy variable indicating whether the firm posseses R&D employment, and a dummy variable indicating whether the firm is an occasional performer; thirdly, a series

[16] We cannot separately identify the sample of non-applying firms.

of characteristics that may enhance the willigness to apply and/or the eligibility of firms: on the one hand, two dummies respectively indicating the presence of skilled labour and the size of the firm, as well as a variable reflecting the firms' experience with respect to the other firms in its industry (relative age); on the other, two indicators that can turn out to be significant mainly by politico-economic reasons of granting agencies: a dummy if the firm posseses foreign capital and another if the firm is an exporter. Finally, we add three sets of dummie variables to account for sectoral heterogeneity (industry dummies), differences in regional support policies (region dummies), and changes over time (time dummies).

Table 7 reports the results of the estimation. The fit of both equations is reasonable, with a good score of cases correctly predicted [17] and 85% of the variance of the subsidies' value explained[18].

Persistence turns out to be significant. Commitment positively influences probability but has a negative impact on the expected value of the subsidy. Firms with skilled labour, big size and a high productive experience also have more probability of obtaining subsidies but also of lesser amounts. Being an exporting firm positively influences probability and, less precisely, the value of the subsidy. Firms with foreign capital show less probability of obtaining a subsidy and a smaller expected value of the granted subsidies. Industry and region dummies are not individually significant in the probability equation, even if some sectors and regions tend to show significantly greater expected subsidies.

Althouh the characterisation of the granting process is not the main target of these estimations, they seem good enough to provide an stylised summary of it: the big, experienced, research committed and exporting firms are more likely to repeteadly obtaining grants for their innovative activities, but agencies seem to apply some criteria in expenditure coverage favouring the relatively newest and domestic firms.

5.2 Tobit Model

Let us now detail the specification of equations [3] and [5] -effort and threshold equations- of the Tobit model, taking into account our previous discussion of the factors influencing

[17] The critical value for the probability equation, given the high number of zeroes, is adjusted to 0.1.

[18] Five subsidies are predicted over 100% and we drop these observations in the following exercises.

the effort given by equation [2] and its observability.

We divide the explanatory variables in three groups: variables aimed at performing as indicators of market power, variables used to denote a high sensitivity of demand with respect to product quality and/or product quality with respect to R&D expenditure, and variables employed to approximate set-up costs and the heterogeneity of thresholds among firms. No variable can obviously be claimed to pick-up exclusively the type of effects of the heading under which it has been clasified, but the grouping is based both on theoretical considerations and the variables' performance in the regression, and it seems useful in order to summarise the empirical effects.

With the important exception of expected subsidies, in principle it must be admitted that the same variables can have a role in explaining the optimal efforts and the thresholds for profitable effort. This partly happens because we have to rely on indirect indicators of the underlying demand and technological determinants, but also for theoretical reasons: thresholds tend to depend on the same factors as effort although in a different way. However, in practice, we will find it both acceptable and useful to impose some exclusion and equality constraints to gain efficiency.

We firstly exclude a series of variables of the effort equation, using them only to explain differences among thresholds in the threshold equation. Most of these variables turned out to be in practice non-significant in the effort equation and the effect of some other can be argued to be already picked up by other variables in this equation. On the other hand, we impose a number of equality restrictions between coefficients of the two equations. They correspond to a few cases in which the difference between the coefficients of the two equations always tended to be statistically non-significant. Finally, we exclude the market power variables from the threshold equation. Our theoretical framework is not entirely conclusive as to whether these variables have to be expected to have a (small) role in this equation, but the exclusion constraint is clearly accepted statistically by our estimates.

Let us briefly detail the variables included in estimation and their expected roles. Three variables integrate the set of market power indicators: the firm' market share, a dummy variable that takes the value one if the firm' product may be considered differentiated and the advertising/sales ratio. The second and third variables may be seen as picking up different dimensions of the same source of market power (product differentiation). The first and third ones enter the equation lagged one period to avoid simultaneity biases.

Three variables are included to perform as indicators of a high sensitivity of demand with respect to product quality and/or product quality with respect to R&D expenditure. These variables are: the ratio of highly qualified workers to total employment, the number of product innovations reported by the firm divided by the number of workers (lagged), and a dummy variable that takes the value one if the market is considered to be in expansion.

Five variables are included to give an account of different aspects of set-up costs. We firstly include the average industry patents (excluding the patents obtained by the firm, a classic formal technological opportunities measure), the firm capital/sales ratio, and a dummy variable indicating whether the firm is an occasional R&D performer. We expect the two first variables to act as direct indicators of high fixed costs of R&D linked to specific technological product requirements. The occasional character of the R&D performance may be seen, instead, as an (indirect) indicator of an easy set-up of tecnological activities. On the other hand, a mergers dummy variable gives account of significant changes of the firm scale through "external" growth. Finally, we include a dummy variable representing concentrated markets (the variable takes the value one for markets with less than 10 competitors) interacted with the size of the firm. This variable tries to account for the fact that relevant set-up costs must be measured in terms relative to the firm scale. Big firms in concentrated markets are likely to experiment smaller set-up costs ratios.

In addition, we have found thresholds in practice to be sensitive to a small list of the firms, firms' market and firms' technology characteristics, all represented by dummy variables. The list includes the presence of foreign capital, a big dimension of the product market (national or international as opposed to local or regional), to be located in an autonomous community with strong spillovers, to be an exporting firm, to have a product sensitive to quality controls and to have a technologically sophisticated production process. All these variables are likely to reduce relative set-up expenses, and some of them will also enhance the demand for quality. Moreover, it will turn out to be very important to include a set of dummy variables of size, measured according to the number of employees, to control for a strong remaining threshold size effect.

Moreover in both equations we include a set of 18 sector dummies, to control for permanent differences arising from activities, and a set of time dummies, which we include constrained to have the same effects in both equations. Details on all the employed variables can be found in Appendix 2.

Table 8 reports the results of our preferred estimate of the model. As explained in Appendix 1, estimation is carried out by specifying the likelihood of a decision and an effort equation, from which the coefficients and standard errors of the threshold equation may be deducted. Blank spaces in the table denote the coefficients which have been constrained to zero in some of the equations. Notice that, in this case, the values of the coefficients consigned in the other two columns coincide in absolute value.

The estimate is robust to changes, its predictive power sensible, and the coefficient and statistics look reasonable. We briefly comment these characteristics in turn. The estimate of Table 8 is obtained by constraining the coefficient β and the market power variables to have the same value in the decision and effort equations of a more general specification. This amounts to excluding them from the threshold equation and it can be statistically accepted under a likelihood ratio test of 1.82[19]. In fact, the β values obtained in the two equations are very close before constraining it (1.65 and 1.48), and we take this as proof of validity of the specification. In particular, alternative specifications basically lead to maintain the rest of effects unaltered with an increase of the difference between the unscontrained β's. On the other hand, the inclusion of a dummy variable indicating likely competition changes (infered from firm reported price movements attributed to market changes) does not change the basic results without becoming statistically significant.

We can evaluate the goodness of the fit of the model according to its predictions. Recall that the model predicts that the firm will engage in R&D activities when the difference $\widehat{e}^{*}-\widehat{\overline{e}}$ is positive. Table 8 (bottom) reports the results of comparing the model predictions with

[19]Instead, the constraint that the σ's of the two equations are the same is rejected -when imposed jointly with the constraint on the coefficient β- by a likelihood ratio test value of 5.98.

the actual observations in the sample for three subgroups of firms: stable R&D performers, occasional performers and firms never observed performing R&D. The model accurately predicts the zero-one variable that denotes the presence of expenditures for the firms that never or always engage in R&D activities (97% and 85% of observations correctly predicted). The model is, however, much less accurate in predicting the yearly activity of the occasional performers. Prediction continues to be quite good when R&D expenditures are zero (71% of observations correctly predicted), but assigns erroneously negative predictions in half of the cases in which the firms show occasional expenditures. This is hardly surprising if we take into account the high degree of arbitrariness of some firm accounting practices in allocating costs over time and the lack of dynamic structure of the model.

The key variable, expected subsidy, is included in the form $-ln(1-\widehat{\rho^e})$, and must therefore attract a β coefficient around unity. The value effectively obtained is 1.58, which indicates a high efficiency of public funds. This estimate gives sensible results on the effect of subsidies, which in particular are very close in magnitude to the comparable subsidy effects on company financed expenditure reported in recent papers (see the detailed analysis of the next section).

On the other hand, the interpretation of the results obtained can be done as follows. Market power is confirmed as a determinant of effort, while it seems to have a non-significant effect on thresholds. The variables aimed at indicating a high quality-sensitivity of demand or expenditure-sensitivity of quality show more mixed results. They present significant positive effects on effort, but we are not able to pick up with some precision the expected negative effects on thresholds. However, this is compensated by the role that similar variables play in explaining thresholds (quality controls and technological sophistication). As expected, high set-up costs clearly appear to increase optimal effort and thresholds, but the scale effect associated with a concentrated market and a big size also lessens this impact. Finally other firm characteristics such as having foreign capital, a big market (domestic or by inclusion of markets abroad), or benefits steeming from geographical spillovers, help to reduce thresholds. In addition, after controlling for all these variables, it remains an important size effect by which big firms experience smaller thresholds. This points out the permanence of a problem of indivisibility of resources to set up R&D activities, independently of the industry or firm type, explaining a significant part of small firms' problems to undertake these activities.

6. Profitability gaps and subsidy effects

Model predictions and parameter estimates can be used to evaluate profitability gaps and the effects of subsidies in a number of ways, which we have explained in detail in section 3. In this section we firstly report the results of computing profitability gaps, or the differences between optimal efforts in the absence of subsidies and the firms' idiosyncratic threshold efforts. This is done using all the correctly predicted observations.Then we assess the potential and actual roles of subsidies in R&D decisions. We first report the results of computing the trigger subsidies, or the value of subsidies that would induce non-performing firms to undertake R&D activities, for all the (correctly predicted) non-expenditure observations. But we also evaluate the impact of actual subsidies on R&D decisions, by looking at the firms that would cease to perform R&D if subsidies were eliminated. The number of firms abandoning R&D in the absence of subsidies turns out to be very small, perhaps a bit surprisingly, and we check the robustness of this result. Next we focus on the effort effects of subsidies. We employ the β estimate, jointly with the ρ^e estimates and the observed ρ for the (correctly predicted) firms performing R&D that effectively receive subsidies, to assess the impact of subsidies in private expenditure. Finally, we compare our estimates with other recent results.

Table 9 reports the distribution of the estimated profitability gaps, and Figure 1 depicts 95% of their values (the graphic leaves 2.5% of observations unrepresented in each tail). Profitability gaps show a skew distribution, with a long tail of negative values, and some concentration of observations around the zero value that presents a greater frequency of positive gaps. Positive gaps represent 30% of total observations and their mean is about 1%, while negative values average an absolute value of 3.7%. More than 85% of positive values lie in the interval (0,1.5), while less than 75% of negative values lie in the broader interval (-5,0). Gaps hence show, on the one hand, that the excess of expenses on threshold expenditure has a somewhat skewed distribution but with an important mass of values concentrated at relatively uniform departures. On the other hand, an important number of optimal expenses fall short of threshold expenditure with a great heterogeneity, which includes a significant number of firms presenting relatively small gaps.

Table 10 further details this heterogeneity by reporting the distribution of trigger subsidies for the two non-performing firms (grouped in two sizes: firms with more than 200 workers and firms under this size). Both distributions are sensible, but differ openly in their means and degree of skewness. The distribution of trigger subsidies of the smallest firms tends to show the highest frequencies at high trigger subsidies. Subsidies required to induce firms to engage in R&D are accordingly smaller for the biggest firms and bigger for the smallest ones. With an expected funding of less than 20% of R&D expenditures, 25% of the non-performing big firms will switch performing innovative activities. On the contrary, inducing 10% of the small firms to perform R&D implies expected support accounting for up to 40% of the expenses, and inducing one firm out of three would require financing up to 60% of the expenses.

Table 11 reports the impact of subsidy withdrawal on performing firms and the statistics that characterise the profitability gaps of the presumably R&D abandoning firms. Rather surprisingly, subsidy withdrawal would induce stopping innovative activities only to a very small number of firms (17 observations, about a 1% of all observations) consisting of the same number of big and small firms (8 and 9). In addition, almost all the firms show very small negative pofitability gaps. All this strongly suggests that subsidies are effectively granted almost exclusively to firms with positive profitability gaps, and hence that would also perform R&D activities in the absence of public financing. That is, the sample of subsidised firms shows a strong form of selection that the model is able to uncover thanks to the separate consistent estimation of profitability gaps and expected grants.

To check the robustness of this result, we have performed some sensitivity analyses. The number of negative gaps of performing firms increases when we use alternative specifications which lead to a greater role of expected subsidies in explaining decisions and effort (a greater

β), but the increase is small and shows up at the cost of less statistical reliability of the estimation. For example, the decision equation may be specified in a way that admits the equality constraints at the limit (the likelihood ratio is 7.8), and constrained β equals 1.95, but the negative gap observations of performing firms only increase up to 63. We conclude that our estimation is robust.

Our point estimate for parameter β (1.58) implies that subsidies induce an increase in privately-financed effort. Let us assess the magnitude of this increase. Table 12 gives the bounds of private effort proportional increase as a result of subsidies, computed according to the methodology presented in section 3. The table shows, in the first place, that expected subsidies have an appreciable augmenting impact in privately-finaced effort (minimum effort increase), which in addition could be considerably enlarged as the result of their actual granting (maximum effort increase). On the other hand, the impact increases with the size of the subsidy, although the minimum effort bound increases more slowly than real subsidies because high subsidies are associated with a greater uncertainty about their perception.

How do these numbers compare with derivatives of private expenses with respect to subsidies in linear R&D expenditure explanatory models? Given a β estimate, we can compute these types of effects for each expected or real subsidy using the formula of section 3. Lach (2000) finds a value of the derivative of 0.41 in a sample of performing firms which show an average subsidy coverage of R&D expenditures of 30%. Our equivalent expression gives a value of 0.43 (!) when we take a subsidy of 30%, which is a subsidy not far from the averages of R&D expenditure coverage among subsidised firms (see Table 4). This is a really close effect.

6. Conclusions

This paper is aimed at exploring the effects of R&D commercial subsidies on firms' decisions about R&D expenditures. Despite the spread of these subsidies, the evidence on their impact on firms' behavior remains relatively modest and controversial. The paper contributes a series of findings about the potential and actual roles of subsidies, based on the estimation of an explicit and theoretically founded model about firms' decisions. In this model, firms' decisions on whether or not to spend on R&D emerge from the comparison of optimal effort and profitability threshold efforts, and the impact of the expected subsidy (or fraction of the effort that is expected to be publicly supported) on this comparison. At the same time, firms' decisions on the level of expenditure implement optimal effort taking into account the presence of subsidies. The model is estimated by a suitable censored variable econometric method, robust to the endogeneity of subsidies. Results indicate that taking into account discrete choices of firms matters.

The main findings, based on our representative panel sample of 1,800 Spanish manufacturing firms, are the following. Non-performance of innovative activities can effectively be traced back to the presence of optimal efforts under the profitability thresholds (that is, profitability gaps resulting from market failures). Small firms experiment the greatest profitability gaps, partly due to high set-up costs of R&D, but gaps also affect to a significant proportion of big firms. Subsidies are potentially effective in inducing firms to invest in R&D. We estimate that 25% of non-performing big firms could be induced to perform innovative activities financing less than 20% of their R&D expenditures, and one out of three non-performing small firms by financing up to 60% of their expenses. Actual subsidies, however, go almost exclusively to firms that would otherwise perform innovative activities. This fact, which can be seen as the result of a proper selection of applicants and risk-averse practices of agencies, neglects the inducing dimension of public support. In any case, subsidies change the level of expenditures chosen by the firms that perform innovative activities. Our parameter estimates imply that subsidies induce significant increases in the privately financed expenditures of firms. The model evaluates this increase in terms of effort, and we obtain a rich characterisation of the effects of both expected and actual subsidies, which imply effects very similar to other recent findings.

The employed framework has turned out to be useful in describing profitability gaps and the impact of subsidies. Further research should focus on developing dynamics to improve the ability to describe behavior of occasional performers and modelling the ex-post adjustments of firms.

Appendix 1: Econometric model and estimation strategy.

The model to be estimated is

$$e_i^* = -\beta \ln(1-\rho_i^e) + z_i\beta_1 + u_{1i}$$
$$\overline{e_i} = z_i\beta_2 + u_{2i}$$

$$e_i = \begin{cases} e_i^* & \text{if} \quad e_i^* > \overline{e_i} \\ 0 & \text{otherwise} \end{cases}$$

where we will consider $(u_{1i},\, u_{2i})$ i.i.d. drawings from a bivariate normal distribution with zero mean, variances σ_1^2, σ_2^2 and covariance σ_{12} . This has the form of a generalized Tobit (or Type 2 Tobit model in the Amemiya classification; Amemiya, 1985).

We can rewrite

$$e_i = \begin{cases} -\beta \ln(1-\rho_i^e) + z_i\beta_1 + u_{1i} & \text{if} \quad -\beta\ln(1-\rho_i^e) + z_i(\beta_1 - \beta_2) + u_i > 0 \\ 0 & \text{otherwise} \end{cases}$$

where $u_i = u_{1i} - u_{2i}$. Here (u_1, u) are i.i.d. drawings from a bivariate normal distribution with zero mean, variances σ_1^2, σ^2, and covariance σ_{u_1u}, where $\sigma^2 = \sigma_1^2 + \sigma_2^2 - 2\sigma_{12}$ and $\sigma_{u_1u} = \sigma_1^2 - \sigma_{12}$. We simplify the notation by writing

$$e_i = \begin{cases} w_i\delta_1 + u_{1i} & \text{if} \quad w_i\delta_2 + u_i > 0 \\ 0 & \text{otherwise.} \end{cases}$$

where $w_i = (\ln(1-\rho_i^e), z_i)$, $\delta_1 = (-\beta, \beta_1')'$, and $\delta_2 = (-\beta, (\beta_1 - \beta_2)')'$.

The likelihood function of the model is given by

$$L = \prod_0 P(\widetilde{e}_i \leq 0) \prod_1 f(e_i^* | \widetilde{e}_i > 0) P(\widetilde{e}_i > 0)$$

where $\widetilde{e}_i = e_i^* - \overline{e_i}$, $\prod_0$ and $\prod_1$ stand for the product over those i for which $e_i = 0$ and $e_i \neq 0$, respectively, and $f(e_i^*|\widetilde{e}_i > 0)$ stands for the conditional density of e_i^* given $\widetilde{e}_i > 0$. We can rewrite the previous expression as

$$L = \prod_0 P(\widetilde{e}_i \leq 0) \prod_1 \int_0^\infty f(\widetilde{e}_i | e_i^*) f(e_i^*) d\widetilde{e}_i = \prod_0 P(\widetilde{e}_i \leq 0) \prod_1 P(\widetilde{e}_i | e_i^*) f(e_i^*)$$

and it is possible to determine a specific form for $f(\widetilde{e}_i|e_i^*)$ from the fact that the conditional distribution of $\widetilde{e}_i$ given $e_i^* = e_i$ is normal with mean $w_i\delta_2 + \frac{\sigma_{u_1u}}{\sigma_1^2}(e_i - w_i\delta_1)$ and variance $\sigma^2 - \frac{\sigma_{u_1u}^2}{\sigma_1^2}$. Thus we can rewrite the likelihood as

$$\begin{aligned} L &= \prod_0 [1 - \Phi(w_i\delta_2\sigma^{-1})] \\ &\prod_1 \Phi\left\{[w_i\delta_2\sigma^{-1} + \sigma_{u_1u}\sigma^{-1}\sigma_1^{-2}(e_i - w_i\delta_1)]\left[1 - \frac{\sigma_{u_1u}^2}{\sigma^2\sigma_1^2}\right]^{-1/2}\right\} \\ &\sigma_1^{-1}\phi[\sigma_1^{-1}(e_i - w_i\delta_1)] \end{aligned}$$

Note that L depends on σ only through $\delta_2\sigma^{-1}$ and $\sigma_{u_1u}\sigma^{-1}$; this implies that σ can be normalized to 1 and the remaining parameters can be identified. If however, there is at least one common element between δ_1 and δ_2, all parameters are identified. In our case, the common parameter β allows us to identify σ and β_2.

Appendix 2: Variable definition 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 almost 8,000 observations (and the lagged observations needed for some variables). In what follows we briefly define the variables employed. Table A1 describes the sample and Table A2 gives some descriptive statistics.

Average industry patents: yearly average number of patents registered by the firms in the same industry (excluding the patents registered by the firm).

Advertising/sales ratio: advertising and promotional expenditures over sales.

Capital/sales ratio: capital over gross production.

Competition changes: dummy variable which takes the value one if the firm reports that a price variation has ocurred due to market changes.

Concentrated market: dummy variable which takes the value one if the firm reports that its main market consists of less than 10 competitors.

Differentiated product: dummy variable which takes the value one if the firm reports that its products are specifically designed for the customers and that rivals often change their products.

Expansive market: dummy variable which takes the value one if the firm reports that its demand is increasing.

Expected subsidy: computed as the product of the predicted probability times the predicted value.

Exporting firm: dummy variable which takes the value one if the firm has exported during the period.

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

Geographical opportunities: dummy variable which takes the value one if the firm has its main plant in the autonomous communities of Madrid, Cataluña or Pais Valenciano.

Industry dummies: set of 18 industry dummies.

Innovation intensity: product innovations per worker.

Market dimension: dummy variable which takes the value one if the firm reports that its main market is national and/or international, as opposed to local or regional.

Market share: market share reported by the firm in its main market. Firms are asked to split their total sales by markets and report their market shares. If a firm reports that its share is not significant, market share is set to zero.

Merger: dummy variable which takes the value one if the firm has merged or acquired another firm.

Occasional performer: dummy variable which takes the value one if the firm reports positive R&D expenditures only some of the observed years.

Quality controls: dummy variable which takes the value one if the firm reports that it carries out quality controls on a systematic basis.

Region dummies: set of 16 autonomous community (regions) dummies.

Relative age: age of the firm minus the firms' average age in the industry it belongs (in years).

R&D 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 employment: dummy variable which takes the value one if the firm has R&D employment.

Skilled labor: ratio of the number of highly qualified workers (engineers and graduates) to total personnel or dummy variable with value one if the firm reports skilled labour.

Size dummies: set of 6 dummy variables or a dummy variable which takes the value one if the firm has more than 200 workers.

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

Technological sophistication: dummy variable which takes the value one if the firm uses automatic machines, or robots, or CAD, and possesses higly qualified R&D personnel.

References

Amemiya, T. (1985), *Advanced Econometrics.* Basil Blackwell.

Arrow, K. (1962), "Economic welfare and the allocation of resources for inventions," in R. Nelson (ed.), *The Rate and Direction of Inventive Activity.* Princenton University Press.

Busom, I. (2000), "An empirical evaluation of the effects of R&D subsidies," *Economics of Innovation and New Technology*, forthcoming.

Cohen, W. (1995), "Empirical studies of innovative activity," in P. Stoneman (ed.), *Handbook of the Economics of Innovation and Technological Change.* Blackwell.

Cohen, W. and R. Levin (1989), "Empirical studies of innovation and market structure," in R. Shmalensee and R. Willing (eds.), *Handbook of Industrial Organization.* North Holland.

David, P., Hall, and Toole, A. (2000), "Is public R&D a complement or substitute for private R&D? A review of the Econometric Evidence." *Research Policy,* 29, pp. 497-529

Dorfman, R., and P. Steiner (1954), "Optimal advertising and optimal quality." *American Economic Review, 44,* pp. 826-836.

González, X. and Jaumandreu, J. (1998), "Threshold effects in product R&D decisiones: theoretical framework and empirical analysis." DT 9803, PIE-FEP.

Gronau, R. (1973), "The effect of children on the housewife's value of time." *Journal of Political Economy,* 81, pp. 168-199.

Hall, B. and J. Van Reenen (2000), "How effective are fiscal incentives for R&D? A review of the evidence." *Research Policy,* 29, pp. 449-469.

Klette, J., Moen, J. and Z. Griliches (2000), "Do subsidies to commercial R&D reduce market failures? Microeconometric evaluation studies." *Research Policy* (29)4-5, pp. 471-495.

Lach, S. (2000), "Do R&D subsidies stimulate or displace private R&D? Evidence from Israel." Working Paper 7943, NBER.

Leung, S. and S. Yu (1996), "On the choice between sample selection and two-part models." *Journal of Econometrics, 72, pp.* 197-229.

Maddala, G.S. (1983), *Limited-dependent and qualitative variables in econometrics,* Cambridge University Press.

Nelson, R. (1959), "The simple economics of basic scientific research." *Journal of Political Economy*, 76, pp. 297-306.

Nelson, F. (1977), "Censored regression models with unobserved stochastic censored thresholds." *Journal of Econometrics,* 6, pp. 309-327.

Parisi, M.L., and A.Sembenelli (2001), "Is private R&D spending sensitive to its price? Empirical evidence on panel data for Italy." mimeo, Boston College.

Toivanen, O. and P. Niininen (2000), "Investment, R&D, subsidies and credit constraints." Mimeo, Helsinki School of Economics.

Wallsten, S. (2000), "The effect of government-industry R&D programs on private R&D: the case of the small business innovation research program." *Rand Journal of Economics,* 1, pp. 82-100.

Table 1.- Firms with R&D activities
(percentages of fims)

Year	≤200 workers	> 200 workers
1990	17.8	73.0
1991	20.5	73.9
1992	19.8	74.4
1993	20.9	74.7
1994	21.1	75.6
1995	21.5	72.9
1996	21.7	75.4
1997	22.7	76.8

Table 2.- Firms with R&D activities during the period 1990-1997
(percentages of firms in the whole period)

Firm size	Stable performers[1]	Occasional performers[2]	Total
≤20 workers	5.5	15.7	21.2
21-50	10.4	18.3	28.7
51-100	19.5	24.4	43.9
101-200	36.0	27.0	63.0
201-500	46.7	35.5	82.2
>500	65.1	26.1	91.2

[1]Firms reporting R&D expenditures every observed year
[2]Firms reporting R&D expenditures some of the observed years

Table 3.- R&D performers granted at least one year during the period 1990-1997
(percentages of firms)

Firm size	All firms	Stable performers	Occasional performers
≤ 20 workers	15.5	16.7	15.1
21 y 50	19.0	10.3	26.8
51-100	32.7	31.1	33.9
101-200	31.3	31.2	31.6
201-500	40.8	49.6	29.0
>500	55.6	63.5	35.9

Table 4.- Average ratios of public funding to R&D expenditures
(subsidy/R&D expenditure, %, granted firms)

Firm size	All firms	Stable performers	Occasional performers
≤20 workers	36.8	23.6	42.7
21 - 50	42.9	39.0	43.9
51-100	25.6	28.2	23.5
101-200	38.5	34.8	43.2
201-500	25.0	23.4	28.8
>500	17.8	16.9	22.0

Table 5.- Total R&D effort with and without subsidies
(period averages of non-zero efforts)

Firm size	Without subsidies	With subsidies
$\leq$20 workers	2.8	4.3
21-50	2.4	2.6
51-100	1.4	3.8
101-200	2.0	3.3
201-500	1.7	2.5
$>$500	1.5	2.7

Table 6.- Total R&D effort with and without subsidies
(averages of non-zero efforts)

	$\leq$ 200 workers		$>$200 workers	
Year	Without subsidies	With subsidies	Without subsidies	With subsidies
1990	2.9	4.6	1.6	3.7
1991	2.4	5.2	1.7	3.1
1992	2.2	5.4	1.7	3.2
1993	2.2	5.3	1.9	3.4
1994	2.2	4.2	1.8	2.9
1995	1.9	4.0	1.5	3.7
1996	2.0	4.2	1.7	3.1
1997	2.0	3.7	1.6	3.5

Table 7.- Estimates of the equations $P(\rho > 0 \mid y)$ and $E(\ln \rho \mid \rho > 0, y)$
Dependent variable: (indicator function and log of) ρ

	Probability equation [1]	Subsidy equation[1]
Constant	-2.537 (-5.9)	-2.418 (-3.5)
Subsidy$_{t-1}$	1.077 (11.0)	0.670 (4.8)
R&D effort$_{t-1}$	9.928 (12.5)	-1.926 (1.9)
R&D employment[2]	0.811 (11.6)	-0.198 (-1.2)
Occasional performer[2]	-0.038 (-0.6)	0.362 (2.6)
Skilled labor[2]	0.140 (1.7)	-0.358 (-2.8)
Size >200 workers	0.386 (5.4)	-0.193 (-1.8)
Relative age	0.006 (3.3)	-0.008 (-2.8)
Foreign capital[2]	-0.285 (-4.2)	-0.551 (-5.3)
Exporting firm[2]	0.331 (4.2)	0.218 (1.8)
Industry dummies	included	included
Region dummies	included	included
Time dummies	included	included
σ		0.25
Estimation method:	Probit	OLS
N^o observations:	7,952	578
Correctly predicted observations[3]:		
zeroes	83,5%	
ones	82,4%	
R^2		0.85

[1] Coefficients and t-ratios.
[2] Dummy variable.
[3] Using a 0.1 critical value.

Table 8.- The effect of public funding on R&D decisions
Dependent variable: (indicator function and log of) R&D effort

	R&D decision[1]	R&D effort[1]	Threshold[1]
Constant[2]	-2.416 (-6.3)	-5.553 (-32.1)	-3.137 (-8.0)
Expected subsidy[3]	1.576 (8.4)	1.576 (8.4)	
Market share$_{t-1}$	0.188 (2.1)	0.188 (2.1)	
Differentiated product[4]	0.111 (2.9)	0.111 (2.9)	
Advertising/sales ratio$_{t-1}$	2.950 (6.1)	2.950 (6.1)	
Skilled labor	3.188 (5.0)	2.955 (5.3)	-0.233 (-0.3)
Innovation intensity$_{t-1}$	0.180 (2.9)	0.186 (1.8)	0.006 (0.1)
Expansive market[4]	0.147 (2.8)	0.092 (1.5)	-0.06 (-0.7)
Average industry patents	0.048 (0.9)	0.279 (6.8)	0.230 (3.7)
Capital/sales ratio	-0.155 (-1.6)	0.351 (3.0)	0.507 (3.3)
Occasional performer[4]	0.420 (5.5)	-0.652 (-11.1)	-1.073 (-11.6)
Merger[4]		-0.440 (-3.2)	-0.440(-3.2)
Concentrated market × firm size[5]		-0.201 (-2.0)	-0.201 (-2.0)
		0.049 (0.4)	0.049 (0.4)
		-0.131 (-1.2)	-0.131 (-1.2)
		-0.225 (-2.9)	-0.225 (-2.9)
		-0.297 (-3.2)	-0.297 (-3.2)
Foreign capital[4]	0.186 (3.0)		-0.186 (-3.0)
Market dimension[4]	0.150 (2.3)		-0.150 (-2.3)
Geographical opportunities[4]	0.278 (4.5)		-0.278 (-4.5)
Exporting firm[4]	0.317 (4.2)		-0.317 (-4.2)
Quality controls[4]	0.499 (5.6)		-0.499 (-5.6)
Technological sophistication[4]	1.323 (6.3)		-1.323 (-6.3)
Size dummies: 21-50 workers	0.207 (2.8)		-0.207 (-2.8)
51-100 workers	0.354 (3.4)		-0.354 (-3.4)
101-200 workers	0.557 (4.4)		-0.557 (-4.4)
201-500 workers	0.840 (5.7)		-0.840 (-5.7)
>500 workers	1.149 (5.6)		-1.149 (-5.6)

[1] Coefficients and t-ratios. Blank spaces mean constrained coeffs. First column equals $\beta_1 - \beta_2$.
[2] Coefficient of the first industry considered.
[3] Coefficient of the term $-\ln(1-\widehat{\rho^e})$.
[4] Dummy variable
[5] Dummy variables; see the size dummies for the sizes.

Table 8.- The effect of public funding on R&D decisions (continuation)
Dependent variable: (indicator function and log of) R&D effort

	R&D decision[1]	R&D effort[1]	Threshold[1]
Industry dummies[6]	included	included	included
Time dummies[7]		included	included
$\sigma, \sigma_1, \sigma_2$	1.05	1.32	1.57
$\sigma_{u_1 u}, \sigma_{12}$		0.18	1.56

Estimation method : ML
N^o observations: 7,947

Correctly predicted observations:

Non-performers	97.5%
Stable performers	85.4%
Occasional performers	
when R&D=0	71.4%
when R&D>0	53.8%

[6] 17 additional industry dummies.
[7] Years from 1992 to 1997.

Table 9.- The distribution of profitability gaps
(Number and percentage of observations by gap values)

Gaps in %	N^o observations	%
<-10	148	2.2
-10 to -9	111	1.6
-9 to -8	143	2.1
-8 to -7	203	3.0
-7 to -6	288	4.2
-6 to -5	390	5.7
-5 to -4	521	7.6
-4 to -3	653	9.5
-3 to -2	664	9.7
-2 to -1	718	10.5
-1 to 0	948	13.8
0 to 0.5	772	11.3
0.5 to 1	710	10.4
1 to 1.5	331	4.8
1.5 to 2	64	0.9
>2	192	2.8

N^{o}observations: 6,856
Mean of positive values: 0.9%
Mean of negative values: -3.7%

Table 10.- Subsidies required to engage in R&D
(Percentages of observations by subsidy values)

	≤ 200 workers		> 200 workers	
Trigger subsidy values in %	%	Cumulated %	%	Cumulated %
0-10	1.1	1.1	11.4	11.4
10-20	1.9	3.0	13.4	24.8
20-30	3.3	6.3	16.9	41.7
30-40	4.0	10.3	25.7	67.4
40-50	7.9	18.2	18.6	86.0
50-60	13.9	32.1	8.6	94.6
60-70	24.7	56.8	5.4	100.0
70-80	37.0	93.8	0.0	100.0
80-90	6.2	100.0	0.0	100.0
90-100	0.0	100.0	0.0	100.0

N^o observations ≤ 200 : 4,420
N^o observations > 200 : 350
Median trigger subsidy ≤ 200 : 67.6
Median trigger subsidy > 200 : 32.8

Table 11.- The impact of subsidy withdrawal

	Cease R&D	%	Profitability gaps Mean	Median	Min	Max
All observations	17	0.8	-0.1	-0.02	-1.0	-0.001
$\leq$ 200 workers	9	1.4	-0.2	-0.02	-1.0	-0.003
$>$ 200 workers	8	0.6	-0.05	-0.004	-0.3	-0.001

Table 12.- The impact of subsidies: bounds to increase of private effort
(N^o of observations and percentages)

Subsidy intervals in %	N^o observations	Mean ρ	Mean ρ^e	Minimum effort increase	Maximum effort increase
0-5	128	2.7	2.4	1.4	1.6
5-10	97	7.3	3.6	2.1	4.5
10-20	95	14.5	5.4	3.4	9.5
20-40	85	28.7	8.5	8.5	21.8
40-90	84	57.5	11.6	11.9	74.7

Table A1 : Number of firms by time spells and type of R&D performers.

Observed Years	Nº firms	Non-performers[1] Nº firms	Stable performers[2] Nº firms	Stable performers Mean effort ≤200	Stable performers Mean effort >200	Occasional performers[3] Nº firms	Occasional performers Mean effort ≤200	Occasional performers Mean effort >200
1	160	90	70	2.7	2.2			
2	279	153	99	3.3	2.8	27	1.4	0.5
3	249	124	71	4.0	2.7	54	1.1	0.7
4	256	137	61	3.1	1.8	58	1.6	0.9
5	224	106	63	2.8	2.5	55	2.0	1.1
6	242	131	50	2.4	2.6	61	2.4	1.2
7	413	211	79	3.6	2.9	123	2.0	0.8
Total	1823	952	493	3.2	2.6	378	1.9	0.9

[1] Firms reporting zero R&D expenditures every observed year

[2] Firms reporting positive R&D expenditures every observed year

[3] Firms reporting positive R&D expenditures some of the observed years

Table A2.- Variable descriptive statistics

	All observations				Observations with positive R&D			
	Mean	St. dev	Min	Max	Mean	St. dev	Min	Max
Dependent Variables								
R&D effort (×100)	0.82	2.3	0	41.9	2.36	3.5	0.0	41.9
R&D effort (dummy)	0.34	–	0	1				
Subsidy (×100)	1.67	8.7	0.0	100	4.79	14.2	0	100
Subsidy (dummy)	0.07	–	0	1	0.21	–	0	1
Explanatory Variables								
Adv./sales ratio$_{t-1}$(×100)	1.40	3.4	0	102.4	2.37	4.5	0	96.5
Avge. industry patents	0.42	0.7	0	4.3	0.63	1.0	0	4.3
Capital/sales ratio(× 100)	21.82	26.2	0.0	500.0	23.8	21.4	0.2	310.9
Concentrated market	0.55	–	0	1	0.69	–	0	1
Differentiated product	0.45	–	0	1	0.50	–	0	1
Expansive market	0.25	–	0	1	0.33	–	0	1
Expected subsidy (× 100)	1.23	3.5	0.0	93.2	2.72	5.1	0.0	93.2
Exporting firm	0.53	–	0	1	0.84	–	0	1
Foreign capital	0.20	–	0	1	0.40	–	0	1
Geog. opportunities	0.53	–	0	1	0.60	–	0	1
Innovation intensity$_{t-1}$	0.06	0.35	0	5.0	0.05	0.3	0	5.0
Market dimension	0.67	–	0	1	0.89	–	0	1
Market share$_{t-1}$	0.13	0.2	0	1	0.19	0.2	0	1
Merger	0.01	–	0	1	0.03	–	0	1
Occasional performer	0.25	–	0	1	0.32	–	0	1
Quality controls	0.53	–	0	1	0.84	–	0	1
R&D Employment	0.30	–	0	1	0.73	–	0	1
Relative age	10.5	18.6	−20.0	59.0	19.3	18.8	−19.0	59.0
Skilled labor (dummy)	0.51	–	0	1	0.82	–	0	1
Skilled labor (× 100)	2.97	5.2	0	69.2	5.20	6.3	0	46.0
Size dummies: <20 work.	0.35	–	0	1	0.08	–	0	1
21-50 workers	0.22	–	0	1	0.13	–	0	1
51-100 workers	0.07	–	0	1	0.07	–	0	1
101-200 workers	0.08	–	0	1	0.13	–	0	1
201-500 workers	0.20	–	0	1	0.39	–	0	1
>500 workers	0.08	–	0	1	0.20	–	0	1
Techn. sophistication	0.25	–	0	1	0.64	–	0	1

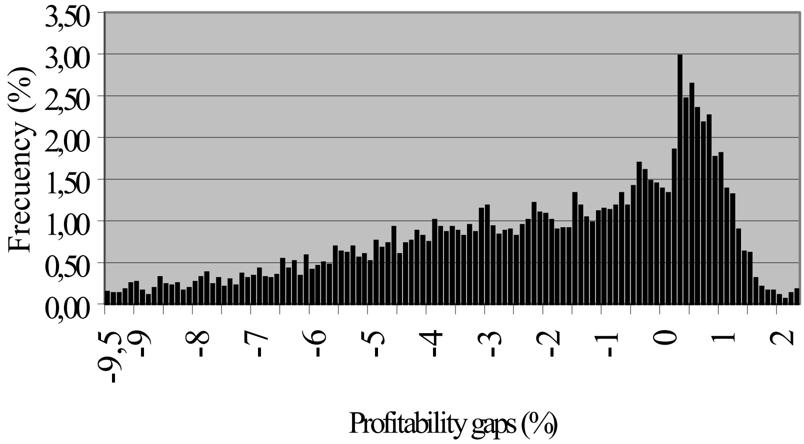

Figure 1: The distribution of profitability gaps