Which policies are effective at stimulating R&D?

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Abstract

Governments all around the globe have been setting R&D spending targets to promote economic growth. The systematic failure to meet such targets suggests that the fundamental drivers of R&D are not fully understood. A common characteristic of high R&D intensity countries is that they have a high proportion of R&D firms which, on average, make fairly large R&D investments. Which policies would allow low R&D intensity countries to achieve such high extensive and intensive margins? To answer this question we develop a structural model of firm R&D investment in which extensive and intensive margin choices (whether or not to invest and how much to invest) depend on three main determinants: marginal costs, fixed costs and firm profitability. We estimate the model on a panel dataset of Spanish manufacturing firms. Simulation over the estimated parameters reveals the following patterns: 1) lowering marginal costs through subsidies and tax credits generates improvements along the intensive margin; 2) lowering fixed costs generates improvements along the extensive margin; 3) increasing profitability generates improvements along both the intensive and extensive margins; 4) reasonable changes in marginal costs and fixed costs can explain movements along the intensive-extensive margin grid within clusters of countries, but not jumps from the low R&D intensity cluster to the high R&D intensity one. Shortening the R&D intensity gap between low and high R&D intensity countries requires implementing policies aimed at improving profitability.

Keywords: R&D; R&D targets; Intensive margin; Extensive margin; Subsidies; Tax credits.
JEL Codes: O31; O34

1 Introduction

Governments all around the globe have been setting R&D spending targets for some time in an attempt to promote sustained economic growth. Carvalho (2017) documents that, with only a few exceptions, none of the 112 targets set by more than 40 countries between 1990 and 2011 has been met. The best-known example is perhaps the EU target of increasing combined public and private investment in R&D to 3% of GDP by 2020, a deadline that will most likely be missed for the second time after the initial 2010 deadline was extended. Despite a consistent pattern of failure, R&D targets are not losing momentum. The 2030 United Nations Agenda for Sustainable Development encourages countries to propose aspirational goals for national public and private investment in R&D (see Colglazier, 2015). But there is no clear sign that the future results will be any different from the ones obtained so far. The goal of this paper is to inform on the type of policies that would help countries achieve their R&D targets.

The R&D position of a country essentially depends on multiple firm-level choices on whether or not to invest in R&D and how much to invest.[1] Figure 1 describes three important stylized facts about such intensive and extensive margin choices for a cross-section of European countries. First, there is substantial dispersion along both margins: there is variation along the extensive margin for countries with a similar intensive margin (e.g. Bulgaria, Poland, Hungary, Italy and Slovenia) and along the intensive margin for countries with similar extensive margins (e.g. Slovenia, Austria and Germany). Second, despite such dispersion there is a clear positive correlation between the extensive and intensive margins. Third, only countries with high extensive and intensive margins manage to achieve high ratios of business R&D over GDP. These three facts imply that high R&D intensities are attained through improvements along the horizontal axis, the vertical axis, and above all the

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[1]R&D targets are typically defined in terms of public and private investment in R&D over GDP. However, business R&D generally accounts for about two thirds of total R&D. See http://ec.europa.eu/eurostat/statistics-explained/index.php/R_%26_D_expenditure#
  R_.26_D_expenditure_by_sector_of_performance.

diagonal of the intensive-extensive margin grid.

In order to assess the intensive and extensive margin effects of R&D policies, we develop and estimate a structural model of firm R&D investment. Firms' intensive and extensive margin decisions (whether or not to invest and how much to invest in R&D) depend on three determinants: firm profitability, marginal costs of R&D, and fixed costs of investing in R&D. Policymakers can modify the marginal cost of R&D through channels explicitly laid out in our model (by offering more generous R&D subsidies and tax credits). Additionally, policymakers are assumed to be able to shift firm profitability and fixed costs through unspecified channels.[2] The main goal of the paper is to understand which determinants should be targeted by policymakers to generate improvements along the diagonal of the intensive-extensive margin grid.

Our modeling choices have their antecedents in several papers in the literature. On the profit side, we follow Takalo *et al.* (2013a), Takalo *et al.* (2017), Takalo *et al.* (2013b), González *et al.* (2005) and Arqué-Castells & Mohnen (2015) who assume a very stylized value function that yields a closed form optimal R&D investment equation. On the cost side, we follow Arqué-Castells & Mohnen (2015), Peters *et al.* (2017) and Vuong *et al.* (2016) who let the fixed cost of R&D depend on the firm's past R&D choice. We follow Peters *et al.* (2017) and Vuong *et al.* (2016) in assuming the fixed costs of R&D and the application costs for public funding to be exponentially distributed. Our model is close in spirit to the optimal R&D and subsidy application stages in the Takalo, Tanayama and Toivanen framework (see Takalo *et al.* , 2013a; Takalo *et al.* , 2017; Takalo *et al.* , 2013b). Our framework should be viewed as the microeconometric counterpart of the model in Arque-Castells (2018). The latter can be estimated on easily accessible country-level data, which

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[2]In practice, firm profitability and fixed costs can be shifted through a broad range of specific policies including policies on intellectual property rights, the promotion of basic research, education, competition policy, openess to trade or financial and labor market regulations. Such policies could be accomodated in our model if we had precise estimates on the effect of each one of them on firm profitability and fixed costs. Because we do not have such detailed information we simply experiment with broad changes in profitability and fixed costs.

allows obtaining comparable estimates of the profitability and fixed cost parameters for many countries, but neither incorporates the application decision nor does it let the fixed cost depend on past R&D choices.

We estimate the model on an unbalanced panel of Spanish manufacturing firms observed during the period 2001-2009. The dataset includes information on R&D discrete choices, R&D spending, application decisions for R&D subsidies and tax credits, and public funding received by firms. Our empirical strategy to recover the parameters of the model unfolds in three steps. In a first stage we estimate the optimal R&D equation to recover firm profitability. In a second stage we estimate the discrete R&D equation to recover the distribution of the fixed costs of R&D (continuation and entry fixed costs). In a third stage we estimate the subsidy and tax credit application decisions to recover the distribution of the application costs.

The most interesting parameter on the profit side, namely the elasticity of the expected discounted value with respect to R&D, is imposed from previous estimates in the literature (a necessary restriction for recovering structural parameters from the continuous R&D equation). Therefore, our most interesting estimates are on the cost side. In line with Peters *et al.* (2017) and Vuong *et al.* (2016) we find the fixed cost of R&D to depend on the firm's previous period R&D choice. The average fixed cost is €0.05-€0.1 million (small and large firms respectively) for firms with previous experience in R&D, but much larger at €5-€11 million (small and large firms respectively) for firms that have to start investing in R&D. In line with Takalo *et al.* (2013a) and Takalo *et al.* (2017) we find the fixed cost of applying for public funding to be fairly large. The mean application cost for R&D subsidies is €0.1-€0.3 million (small and large firms respectively). The average application cost for R&D tax credits is €208-€414 million (small and large firms respectively). Interestingly, the costs of applying for tax credits are larger than those of applying for R&D subsidies.

We use the parameter estimates to simulate firms' responses to policy changes affecting

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marginal costs, fixed costs and firm profitability. The simulations contribute four main findings. First, reductions in the marginal cost of R&D increase aggregate R&D mostly through improvements in the intensive margin. Interestingly, the generosity (amount of subsidy rate and tax credits offered) and accessibility (application costs) channels are both found to be important. Second, declines in the fixed costs generate increases in aggregate R&D through improvements in the extensive margin despite a deterioration of the intensive margin. Third, increases in firm profitability trigger increases in aggregate R&D through improvements in both the intensive and extensive margins. Four, reasonable changes in marginal costs and fixed costs can explain movements in the intensive-extensive margin grid within clusters of countries, but not jumps from the low R&D intensity cluster to the high R&D intensity one. Shortening the R&D intensity gap between low and high R&D intensity countries requires implementing policies aimed at improving profitability. These insights are consistent with the findings in Arque-Castells (2018).

Our findings would explain the consistent patterns of failure that governments have shown in the past to meet ambitious R&D targets. The prototipical policies used to stimulate business R&D heavily rely on R&D tax credits and R&D subsidies (see Bloom *et al.* , 2002 and Rao, 2016). Such policies are attractive because they are relatively well understood and generate effects in the short run, but have a limited scope. Increasing profitability is less appealing to policymakers because it requires implementing potentially costly structural reforms with effects in the long run. It shall be kept in mind that the costs of some of such reforms might exceed its benefits. It is beyond the scope of this paper to perform a welfare analysis. Our goal is more modest: to give clues on the targets that policymakers should aim at to increase aggregate R&D.

The paper is structured as follows. Section 2 presents the analytical model. Section 3 presents the empirical strategy. Section 4 describes the data. Section 5 presents the results. Section 6 presents simulations. Section 7 concludes.

2   Analytical framework

Firm i must choose whether or not to invest in R&D and how much to invest in year t. R&D decisions are made in the shadow of the R&D subsidy and tax credit policy in the country. In a first stage, the firm decides whether or not to apply for public support (just subsidies, just tax credits or both). Applying for public funding has positive fixed costs but lowers the marginal cost of the variable R&D investment. In a second stage, the firm chooses its optimal participation and investment decisions, which are characterized as a function of three determinants: the marginal cost resulting from the subsidy and tax credit application decisions, $mc_{it} \geq 0$; firm profitability, $\alpha_{it} \geq 0$; and the fixed cost of investing in R&D, C_{it}. The main goal of the paper is to compare firms' responses to shocks in mc_{it}, α_{it} and C_{it} to establish which are the targets that policymakers should aim at to stimulate business R&D.

2.1   The R&D decision

We specify the firm's expected discounted value (gross of fixed costs) as

$$
V_{it} = \begin{cases} \alpha_{it} R_{it}^{\phi} - mc_{it} R_{it} & if \quad R_{it} > 0 \\ \alpha_i & if \quad R_{it} = 0 \end{cases} \tag{1}
$$

where $R_{it} > 0$ is the variable investment in R&D, α_{it} is a constant shifting the expected profitability of R&D and $\phi \in (0, 1)$ is the elasticity of the expected discounted value (gross of the R&D investment) with respect to R&D.

Optimal level of R&D.   The first-order condition with respect to R_{it} leads to the optimal R&D investment, which is increasing in α_{it} and decreasing in mc_{it}:

$$
R_{it}^* = \left(\frac{\phi \alpha_{it}}{mc_{it}} \right)^{\frac{1}{1-\phi}} \tag{2}
$$

Optimal investment decision. Combining equations (1) and (2) we define the expected marginal benefit of investing in R&D as

$$\Delta V_{it} = V(R_{it} = R_{it}^*) - V(R_{it} = 0) = (1 - \phi)(\phi/mc_{it})^{\frac{\phi}{1-\phi}}(\alpha_{it})^{\frac{1}{1-\phi}} - \alpha_{it}. \tag{3}$$

The firm chooses to invest in R&D if the expected marginal benefit of investing in R&D is greater than the fixed cost. This implies that the R&D selection equation is given by:

$$y_{it} = 1\left\{\Delta V_{it} > C_{it}\right\}, \tag{4}$$

where y_{it} is a binary variable with value one if the firm invests in R&D in year t and value zero otherwise, $C_{it} = y_{it-1}F_{it} - (1 - y_{it-1})E_{it}$ is the fixed cost of the firm which is allowed to depend on the firm's prior period R&D choice and $1\{\}$ is the indicator function.

2.2 Marginal cost and the application decision

The firm can apply for R&D subsidies, tax credits or both. Applying for subsidies or tax credits gives access to lower marginal costs, but entails positive application costs.

The marginal cost of R&D. The public funding policy of the country is defined by a triplet $(s_t, \tau_t, \widetilde{\tau}_t)$, with $s_t \in [0, 1]$ being the average R&D subsidy rate received by subsidy applicants in year t, $\tau_t \in [0, 1]$ the R&D tax credit in year t and $\widetilde{\tau}_t \in [0, 1]$ the corporate tax rate in year t. Tax credits are exempt from corporate taxation. Moreover, for firms benefiting from both R&D subsidies and tax credits, tax credits are rewarded on the non-subsidized $(1 - s_t)$ and subsidized but taxed $(\widetilde{\tau}_t s_t)$ parts of the R&D investment. This implies that the marginal cost of R&D is given by (see Appendix A for more details):

$$mc_{it}(ds_{it}, d\tau_{it}) = 1 - s_t ds_{it} - \tau_t d\tau_{it}\frac{1 - (1 - \widetilde{\tau}_t)s_t ds_{it}}{1 - \widetilde{\tau}_t}. \tag{5}$$

where ds_{it} and $d\tau_{it}$ are binary variables with value one if the firm applies for R&D subsidies and tax credits respectively and value zero otherwise. The effective marginal cost of the firm depends on the policy mix of the country and on whether the firm applies for public support. The marginal cost varies as the application dummy variables switch on and off: $mc_{it}(0,0) = 1$ if the firm neither applies for subsidies nor for tax credits, $mc_{it}(1,0) = 1 - s_t$ if it just applies for R&D subsidies, $mc_{it}(0,1) = 1 - \frac{\tau_t}{1-\widetilde{\tau}_t}$ if it just applies for tax credits, and $mc_{it}(1,1) = 1 - s_t - \tau_t \frac{1-(1-\widetilde{\tau}_t)s_t}{1-\widetilde{\tau}_t}$ if it applies for both. Reductions in the marginal cost of R&D translate into increases in the optimal R&D investment (see equation (2)) and the expected marginal benefit of investing in R&D (see equation (3)). Therefore, lower marginal costs potentially affect both the intensive and extensive margins of R&D.

The application decision. Because of the positive costs of applying for R&D subsidies and tax credits, access to lower marginal costs is not immediate. Firms only apply for public support if the expected benefit of having lower marginal costs outweighs the application cost. In the empirical section we estimate separate application equations for both R&D subsidies and tax credits. However, here we just focus on the application decision for subsidies holding the tax credit application decision constant. The analogous application decision for tax credits holding the subsidy application decision constant looks exactly the same. Let π_{it}^1 and π_{it}^0 be the expected discounted value of applying and not applying respectively. The application equation is then given by

$$ds_{it} = 1\left\{\pi_{it}^1 - \pi_{it}^0 > K_{it}^s \mid d\tau_{it}\right\}. \tag{6}$$

Upper indices indicate whether the firm does (1) or does not (0) apply for subsidies. If it does, $mc_{it}(1, d\tau_{it}) = 1 - s_t - \tau_t d\tau_{it}\frac{1-(1-\widetilde{\tau}_t)s_t}{1-\widetilde{\tau}_t}$. If it does not, $mc_{it}(0, d\tau_{it}) = 1 - \frac{\tau_t d\tau_{it}}{1-\widetilde{\tau}_t}$.

3 Empirical strategy

The goal of the empirical section is to estimate the profitability of R&D α_{it}, the distribution of the fixed costs of R&D F_{it} and E_{it}, and the distribution of the fixed costs of applying for public support K_{it}^s and K_{it}^τ. In order to estimate these parameters we proceed in three steps. In a first stage we estimate the optimal R&D equation and obtain estimates of the parameters needed to calculate ΔV_{it}. In a second stage we estimate the discrete R&D equation and recover the distribution of the fixed costs F_{it} and E_{it}. In a third stage we estimate the subsidy and tax credit application decisions to recover the distribution of the application costs K_{it}^s and K_{it}^τ.

3.1 The optimal R&D equation

Taking logs of equation (2) and letting $\alpha_{it} = \exp(X_{it}\theta + v_{it})$ we obtain

$$\ln(R_{it}^*) = \frac{1}{1-\phi}\left[-\ln(mc_{it}) + \ln(\phi) + X_{it}\theta + v_{it}\right], \tag{7}$$

where X_{it} is a vector of observable firm characteristics (including capital stock, number of employees, age, a dummy variable with value one for high-tech sectors and a full set of year dummy variables), θ is a vector of parameters to be estimated and $v_{it} \sim N(0, \sigma_v)$ is a random R&D productivity shock known to the firm but not to the econometrician. Notice that variation in mc_{it} gives identification of ϕ and, consequently, of θ and σ_v. In this paper we do not attempt to estimate ϕ. Based on previous estimates in the literature we impose $\phi = 0.2$ (see Appendix B for a detailed survey of the literature).

3.2 The R&D participation equation

We assume F_{it} and E_{it} to be exponentially distributed with rate parameters λ_F and λ_E. We estimate λ_F and λ_E as the values that maximize the likelihood of observing y_{it} given y_{it-1},

ΔV_{it} and the participation rule in equation (4):

$$L^y = \prod_{i=1}^{N} \prod_{t=1}^{T} L_{it}^y(y_{it}|y_{it-1}, \Delta V_{it}). \tag{8}$$

We take expectations over v_{it} using the information obtained in the previous stage. We simulate over v_{it} using a Gauss-Hermite approximation. The exact form of $L_{it}()$ is given in Appendix C.

3.3 The application equation

We assume K_{it}^j to be exponentially distributed with rate parameter λ_{K^j}. Regarding R&D subsidies, we estimate λ_{K^s} as the value that maximizes the likelihood of observing ds_{it} given ΔV_{it}, C_{it} and the participation rule in equation (6):

$$L^{ds} = \prod_{i=1}^{N} \prod_{t=1}^{T} L_{it}^{ds}(ds_{it}|\Delta V_{it}, C_{it}). \tag{9}$$

We take expectations over v_{it} and C_{it} using the distributions estimated in the previous two stages. Again, we simulate over v_{it} using a Gauss-Hermite approximation. The details of $L_{it}^d()$ are provided in Appendix D.

4 Data

The dataset used to estimate the model is drawn from the "Encuesta Sobre Estrategias Empresariales" (from now on ESEE).[3] This survey gathers information on manufacturing firms operating in Spain employing more than nine workers. It is conducted on a yearly basis since the early nineties across twenty different sectors. The initial sampling undertaken in conducting the survey differentiated firms according to their size. While all firms employing

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[3]The ESEE (Survey on Firm Strategies) has been conducted since 1990 by the Fundación SEPI under the sponsorship of the Spanish Ministry of Industry.

more than 200 employees were required to participate, firms between 10 and 200 employees were selected by stratified sampling (stratification across the twenty sectors of activity and four size intervals). Subsequently, all newly created firms with more than 200 employees together with a randomly selected sample of firms between 10 and 200 employees have been gradually incorporated.

The survey keeps track of the firms' technological activity and reports information on several measures of R&D performance including intramural expenditure, R&D contracted out with external laboratories or research entities and technological imports. For our purposes, a firm is classified as an R&D performer whenever it reports having incurred expenditure in any of these categories excluding technological imports. The survey also provides information on R&D subsidy and tax credit application decisions as well as on the actual subsidies and tax credits enjoyed by the firm. Information on these variables is used to construct the marginal cost of R&D. Moreover, the survey provides information on many variables some of which we use as explanatory variables in the continuous R&D equation. These variables are capital stock, the number of employees, firm age, technological content of the industry in which the firm operates (high vs. low) and year. Precise variable definitions are provided in Appendix E.

In this study, we use survey data from 2001 to 2009 (information on R&D tax credits is only provided since 2001). For the empirical analysis, firms are grouped by size groups according to the sampling threshold used to elaborate the survey. Small firms are defined as firms with fewer than 200 employees while large firms are defined as firms with at least 200 employees. We retain all firms with at least two consecutive years of non-missing information on the variables used in the regressions. The final sample of small firms comprises 1,268 firms and 5,181 observations while the sample of large firms comprises 697 firms and 3,300 observations. Notice that firms can switch samples over time if their number of employees fluctuates above or below the threshold.

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Descriptive statistics are reported in Table 1 for each subsample. Starting with the sub-sample of small firms, about 30% invest in R&D. There is an important degree of persistence in the R&D investment decision with 85% of the firms investing at t-1 also investing at t. The percentage of firms that start investing R&D is much lower at round 6%. The average R&D investment by firms that invest in R&D is €265 thousand. Slightly more than 10% of the firms in the sample, and 33% of the firms that invest in R&D, apply for R&D subsidies. Similar figures hold for R&D tax credits. The marginal cost of R&D is 0.916 for the whole sample and 0.776 for the subsample of firms that invest in R&D. The average number of employees is 68, with most firms being between 20 and 49 years old, and only 30% operating in high-tech industrial sectors.

For the subsample of large firms, the percentage of firms that invest in R&D is 70%, considerably higher than the percentage observed for small firms. Out of the firms that invest in R&D at t-1, 94.5% also choose to do so at t. The percentage of firms that start investing R&D is 13.6%. The average R&D investment by firms that invest in R&D is above €1 million. About 28% of the firms in the sample, and 39% of the firms that invest in R&D, apply for R&D subsidies. The numbers are slightly larger for R&D tax credits, with 34% of the firms and 45% of the R&D performing firms applying for R&D tax credits. The marginal cost of R&D for large firms is 0.789 for the whole sample and 0.714 for the subsample of firms that invest in R&D. The average number of employees is 521, with most firms being between 20 and 49 years old, and 35% operating in high-tech industrial sectors.

5 Results

Profitability of R&D (α). Table 2 reports estimates of the continuous R&D equation. The dependent variable is defined as $(1-\phi)\ln(R_{it}^*)+\ln(mc_{it})-\ln(\phi)$ so the estimates identify indeed θ and σ_v. The estimates of the R&D investment equation allow us to recover firm profitability, $\alpha_{it} = \exp(X_{it}\theta + v_{it})$. The optimal R&D investment is increasing in the capital

stock and the number of employees. A one percent change in the capital stock is associated with a 0.136 percent increase in R&D expenses. Similarly, a one percent change in the number of employees is associated with a 0.478 percent increase in R&D expenses. Age seems to matter for the subsample of large firms only. For large firms, the R&D investments of firms older than 10 years are on average 30 percent larger. Firms in high-tech industries invest more heavily in R&D, with their investments being on average around 70 percent larger than those of firms in low-tech industries. The intercept is an important component of the profitability of R&D that captures a country-specific profitability fixed effect after controlling for firm-specific attributes. Finally, the standard deviation of the error term is around 1.05 for both samples, in line with the estimates in Takalo *et al.* (2013a), González *et al.* (2005) or Arqué-Castells & Mohnen (2015).

Fixed cost of R&D (C). Panel A in Table 3 reports the estimates of the fixed cost of R&D. We find the fixed cost of R&D to depend on the firm's previous period R&D choice in line with previous results in the literature. The mean of the maintenance cost (F) is substantially lower than the mean of the entry cost (E). The average maintenance cost is at around €55 and €102 thousand for small and large firms respectively. The average entry cost is much higher at almost €5 and €11 million for small and large firms respectively. The results on the fixed costs are consistent with the estimates in Peters *et al.* (2017) and Vuong *et al.* (2016).

Application costs $(K^s$ **and** $K^\tau)$. Panel B in Table 3 reports estimates of the application costs for R&D subsidies. The mean cost is €133 and €326 thousand for small and large firms respectively. Panel C in Table 3 reports estimates of the application cost for R&D tax credits. The mean cost is €208 thousand for small firms and €414 thousand for large firms. Interestingly, the costs of applying for tax credits are larger than those of applying for R&D subsidies. Overall, the magnitude of the application costs is large, but in line with estimates

in related papers (see Takalo *et al.* , 2017). Application costs include administrative costs, opportunity costs and also the costs of closer scrutiny by the tax authorities. The latter are potentially high in Spain according to recent research by Almunia & Lopez-Rodriguez (n.d.).

Fit of the model.   Table 4 compares predicted and observed values to assess the accuracy of the model. Predicted outcomes are calculated with equations (2), (4) and (6), using values of v, C, K^s and K^τ drawn from the estimated distributions. The predictions are very accurate in terms of the percentage of R&D firms, and subsidy and tax credit applicants. The predicted average R&D investment is slightly larger than the observed R&D investment for small firms, but very close to the observed value for large firms.

6   Simulations

We simulate firms' response to policy changes affecting the marginal cost, the fixed cost and the profitability of R&D. Firms' behavior is simulated over a 30 year period with the policy change taking place in $t = 15$. To carry out the simulation we proceed as follows. First, we preserve the last observation for each firm and weight the sample to obtain representative figures for the whole of manufacturing. Second, we draw values of v, K^s, K^τ, F and E using the estimated distributions. Third, we use equations (6), (5), (2) and (4) (in this order) to predict subsidy and tax credit application decisions, marginal costs, optimal R&D investments and extensive margin decisions on whether or not to invest. Finally, we aggregate the results and report figures for the extensive margin (i.e. percentage of firms investing in R&D), the intensive margin (i.e. average investment by firms that invest in R&D) and aggregate R&D. Intensive and extensive margins characterize the R&D position of a country pretty well, with countries managing to achieve R&D intensities of up to 3% of the GDP typically having more than 30% of firms investing in R&D with an average investment above one million (see Arque-Castells, 2018). These are the effects of each policy:

Increase in marginal costs through a complete withdrawal of R&D subsidies and tax credits.
Spain's tax incentives and subsidy programs are rather generous.[4] How much of the current
level of R&D investment would be lost without such generous programs? Figure 2 shows that
completely eliminating R&D subsidies and tax credits has almost no effect on the extensive
margin (Chart A), with the percentage of firms investing in R&D remaining fairly stable
at around 30%. However, the effect on the intensive margin is notable, with the average
investment by R&D active firms declining by €0.5 million (Chart B). As a result of the
combined effects on the extensive and intensive margins aggregate R&D declines by nearly
20%, or what is the same, €0.5 billion (Chart C).

Decline in marginal costs through a reduction in application costs. Innovation agencies and
tax authorities can lower application costs by offering guidance throughout the application
process. Figure 3 shows that reducing application costs by 20% has little effect on the
extensive margin, with the percentage of firms investing in R&D remaining largely unchanged
(Chart A). However, it has a substantial effect on the intensive margin, with average R&D
investments increasing by €0.5 million (Chart B). The combined effects generate an increase
in overall R&D of €0.3 billion approximately (Chart C). Therefore, reducing application
costs by 20% has a similar effect as eliminating R&D tax credits and subsidies, but in the
opposite direction.

Decline in fixed costs. Figure 4 displays the effects of a 20% decline in the continuation and
entry fixed costs F and E. Notice that we cannot simulate changes in just one or the other
because we have assumed both to be proportional ($\delta F_{it} = E_{it}$, see Appendix (C) for details).
Reducing the fixed cost of R&D has a considerable positive effect on the extensive margin
with the percentage of firms increasing from 30% to just below 40% (Chart A). However,
it has a negative effect on the intensive margin because lower profitability firms with lower
optimal R&D investments now find it profitable to invest in R&D (Chart B). The overall

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[4]See http://www.oecd.org/sti/rd-tax-incentive-indicators.htm.

effect on aggregate R&D is positive but moderate (Chart C).

Increase in profitability. Increases in profitability can be simulated through increases in parameters or variables in $X_{it}\theta$. We simulate a 10% increase in the intercept of the R&D equation. The intercept partly captures firm-level characteristics not included among the set of controls and a country-specific fixed effect. Therefore, an increase in the intercept can be interpreted broadly as a change in country-specific policies (ranging from intellectual property to antitrust) which shift firm profitability.[5] Of course, even if the intercept can be given a structural interpretation, an increase in the intercept of the R&D equation will by construction translate into higher optimal R&D investments. The truly non-trivial outcome of the simulation is whether higher profitability generates improvements along the extensive margin. Fixed entry costs are high so extensive margin effects cannot be taken for granted. Figure 5 shows that increasing the profitability fixed-effect by 10% results in substantial intensive and extensive margin effects. The percentage of firms investing in R&D increases in 20 percentage points from just above 30% to just above 50% (Chart A). This effect manifests gradually over time as an increasing number of firms is hit by a positive profitability shock (i.e. high v_{it}). The average R&D investment increases by about €1 million with a slight overshooting soon after the policy change (Chart B). The overshooting is an entry selection effect: firms only start investing in R&D if they are hit by a high enough profitability shock that sets the expected marginal benefit above the high entry costs, but can continue carrying out R&D as long as the expected marginal benefit stays above the lower continuation cost even as they go through lower profitability (lower R&D) stages. The combination of extensive and extensive margin effects generates a €2 billion increase in aggregate R&D (Chart C).

Multiple combinations of marginal costs, fixed costs and profitability values. Now that the

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[5]Our point estimates for the intercept are 5.8 and 6.4 for small and large firms respectively, but Takalo *et al.* (2013a) obtain a much larger point estimate of 12.8 for Finland using a similar specification. While this comparison should be taken with a grain of salt it suggests that profitability is higher in Finland than in Spain.

effects of changes in each one of the variables of interest are well understood, we simulate multiple intensive-extensive margin pairs for different combinations of profitability, marginal costs and fixed costs values. Figure 6 displays the resulting intensive and extensive margin pairs for the last period of the simulation.[6] Declines in marginal costs produce vertical movements along the intensive margin (from triangles to circles). Declines in fixed costs produce horizontal movements along the extensive margin (from larger to smaller markers). Increases in profitability produce diagonal improvements along the intensive-extensive margin grid (from the cluster of light blue markers to the cluster of black markers). Combined variation in marginal and fixed costs produce diagonal movements within a relatively confined area of the grid for a given profitability value. However, increases in profitability generate much more pronounced jumps along the diagonal of the grid even for varying combinations of marginal cost and fixed cost values. According to these results, it would seem that profitability is the one force that can rationalize the strong positive relationship observed in the intensive and extensive margins of R&D across countries in Figure 1. Reasonable changes in marginal costs and fixed costs can explain movements within clusters of countries, but hardly big enough jumps from the group of low R&D intensity to the group of high R&D intensity countries. Shortening the R&D intensity gap between low and high R&D intensity countries requires implementing policies aimed at improving firm profitability. However, such policies are structural in nature, potentially costly and likely to generate results in the long run. Policymakers tend to rely more heavily on policies aimed ar reducing the marginal costs of R&D such as subsidies and tax credits. Such results would explain the consistent patterns of failure of a large number of countries in achieving their objectives.

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[6]There are differences in Spain's baseline position in Figure 6 and its position in Figure 1 due to differences in sampling and cleaning. First, Figure 6 restricts to manufacturing firms while Figure 1 includes both manufacturing and services. Second, the extensive margin is higher in Figure 6 where we use a broader definition of R&D comprising not just intramural expenditure but also R&D contracted out with external laboratories or research entities and technological imports. Third, the intensive margin is higher in Figure 1 which includes all R&D observations including the upper tail ones which have been winzorized in our simulations. Despite these differences, the two figures are conceptually similar.

7   Conclusion

Governments systematically fail to meet strategic R&D targets. This paper develops an empirical model to identify which factors drive firms' decisions on whether or not to invest and how much to invest in R&D. The ultimate purpose of our framework is to shed light on the targets that policymakers should aim at to increase aggregate investments and meet their R&D targets. In our two stage-model, the firm first decides whether or not to apply for public funding (just subsidies, just tax credits or both). Next, it decides whether or not to invest and how much to invest in R&D as a function of three determinants: the marginal cost resulting from the application decision, firm profitability and fixed costs.

We estimate the model on a panel of Spanish manufacturing firms to recover the underlying primitives. Our estimates reveal that the fixed costs required to start investing in R&D are high, but decline substantially upon entry. The costs of applying for public support are also found to be fairly large, difficulting access to the available R&D subsidy and tax credit programs. Simulation over the estimated parameters contribute three main findings. First, reductions in the marginal cost of R&D increase aggregate R&D mostly through improvements in the intensive margin. Second, declines in the fixed cost of R&D generate increases in aggregate R&D through improvements in the extensive margin despite a deterioration of the intensive margin. Finally, increases in firm profitability trigger increases in aggregate R&D through improvements in both the intensive and extensive margins.

According to our findings, profitability is the only determinant that can rationalize the strong positive relationship between the intensive and extensive margins of R&D across countries. This finding would explain the difficulty in achieving R&D spending targets. Increasing profitability may demand significant structural and regulatory changes.

References

AGRAWAL, AJAY, ROSELL, CARLOS, & SIMCOE, TIMOTHY S. 2014 (October). *Do Tax Credits Affect R&D Expenditures by Small Firms? Evidence from Canada.* Working Paper 20615. National Bureau of Economic Research.

ALMUNIA, MIGUEL, & LOPEZ-RODRIGUEZ, DAVID. Under the Radar: The Effects of Monitoring Firms on Tax Compliance. *American Economic Journal: Economic Policy.*

ARQUE-CASTELLS, PERE. 2018. *What Drives Differences in R&D Across Countries? Insights from the Intensive and Extensive Margins.* Available at SSRN: https://ssrn.com/abstract=3202894 or http://dx.doi.org/10.2139/ssrn.3202894.

ARQUÉ-CASTELLS, PERE, & MOHNEN, PIERRE. 2015. Sunk Costs, Extensive R&D Subsidies and Permanent Inducement Effects. *The Journal of Industrial Economics*, **63**(3), 458–494.

BLOOM, NICK, GRIFFITH, RACHEL, & VAN REENEN, JOHN. 2002. Do R&D tax credits work? Evidence from a panel of countries 1979–1997. *Journal of Public Economics*, **85**(1), 1–31.

CARVALHO, ADÃO. 2017. Wishful thinking about R&D policy targets: what governments promise and what they actually deliver. *Science and Public Policy*, **45**(3), 373–391.

COLGLAZIER, WILLIAM. 2015. Sustainable development agenda: 2030. *Science*, **349**(6252), 1048–1050.

DAVID, PAUL A, HALL, BRONWYN H, & TOOLE, ANDREW A. 2000. Is public R&D a complement or substitute for private R&D? A review of the econometric evidence. *Research policy*, **29**(4), 497–529.

DECHEZLEPRÊTRE, ANTOINE, EINIÖ, ELIAS, MARTIN, RALF, NGUYEN, KIEU-TRANG, & REENEN, JOHN VAN. 2016 (July). *Do tax Incentives for Research Increase Firm Innovation? An RD Design for R&D.* Working Paper 22405. National Bureau of Economic Research.

EINIÖ, ELIAS. 2014. R&D subsidies and company performance: Evidence from geographic variation in government funding based on the ERDF population-density rule. *Review of Economics and Statistics*, **96**(4), 710–728.

GONZÁLEZ, XULIA, JAUMANDREU, JORDI, & PAZÓ, CONSUELO. 2005. Barriers to Innovation and Subsidy Effectiveness. *The RAND Journal of Economics*, **36**(4), 930–950.

GUCERI, IREM, & LIU, LI. 2015. *Effectiveness of fiscal incentives for R&D: Quasi-experimental evidence.* Tech. rept.

HALL, BRONWYN, & VAN REENEN, JOHN. 2000. How effective are fiscal incentives for R&D? A review of the evidence. *Research Policy*, **29**(4), 449–469.

LACH, SAUL. 2002. Do R&D subsidies stimulate or displace private R&D? Evidence from Israel. *The Journal of Industrial Economics*, **50**(4), 369–390.

PETERS, BETTINA, ROBERTS, MARK J., VUONG, VAN ANH, & FRYGES, HELMUT. 2017. Estimating dynamic R&D choice: an analysis of costs and long-run benefits. *The RAND Journal of Economics*, **48**(2), 409–437.

RAO, NIRUPAMA. 2016. Do tax credits stimulate R&D spending? The effect of the R&D tax credit in its first decade. *Journal of Public Economics*, **140**, 1 – 12.

TAKALO, TUOMAS, TANAYAMA, TANJA, & TOIVANEN, OTTO. 2013a. Estimating the benefits of targeted R&D subsidies. *Review of Economics and Statistics*, **95**(1), 255–272.

TAKALO, TUOMAS, TANAYAMA, TANJA, & TOIVANEN, OTTO. 2013b. Market failures and the additionality effects of public support to private R&D: Theory and empirical implications. *International Journal of Industrial Organization*, **31**(5), 634 – 642.

TAKALO, TUOMAS, TANAYAMA, TANJA, & TOIVANEN, OTTO. 2017. *Welfare Effects of R&D Support Policies.* CEPR Discussion Papers 12155. C.E.P.R. Discussion Papers.

VUONG, VAN ANH, MAICAN, FLORIN, ORTH, MATILDA, & ROBERTS, MARK. 2016. *R&D Dynamics and Its Impact on Productivity and Export Demand in Swedish Manufacturing.* Tech. rept.

WALLSTEN, SCOTT J. 2000. The effects of government-industry R&D programs on private R&D: the case of the Small Business Innovation Research program. *The RAND Journal of Economics*, 82–100.

WILSON, DANIEL J. 2009. Beggar thy neighbor? The in-state, out-of-state, and aggregate effects of R&D tax credits. *The Review of Economics and Statistics*, **91**(2), 431–436.

Tables

Table 1.Descriptive statistics

Notes: R&D expenditures and capital stock are in thousands of euros.

	Small			Large		
	Count	Mean	S.d.	Count	Mean	S.d.
	(1)	(2)	(3)	(4)	(5)	(6)
R&D dummy variable, y	5,181	0.330	0.470	3,300	0.709	0.454
R&D dummy variable, $y = 1\|y_{t-1} = 1$	1,757	0.853	0.354	2,339	0.945	0.228
R&D dummy variable, $y = 1\|y_{t-1} = 0$	3,424	0.061	0.239	961	0.136	0.343
R&D dummy variable t-1, y_{t-1}	5,181	0.339	0.473	3,300	0.709	0.454
R&D expenditures, $R\|y = 1$	1,708	265	409	2,341	1,046	1,344
Subsidy applicant, ds	5,181	0.120	0.325	3,300	0.284	0.451
Tax credit applicant, dt	5,181	0.127	0.333	3,300	0.340	0.474
Marginal costs, mc	5,181	0.916	0.180	3,300	0.789	0.246
Subsidy applicant, $ds\|y = 1$	1,708	0.331	0.471	2,341	0.393	0.488
Tax credit applicant, $dt\|y = 1$	1,708	0.336	0.472	2,341	0.458	0.498
Marginal costs, $mc\|y = 1$	1,708	0.776	0.238	2,341	0.714	0.248
Capital stock t-1	5,181	4,164	7,580	3,300	43,998	58,510
Number of employees t-1	5,181	68	59	3,300	521	498
Age, 0-9	5,181	0.137	0.344	3,300	0.085	0.278
Age, 10-19	5,181	0.293	0.455	3,300	0.175	0.380
Age, 20-49	5,181	0.486	0.500	3,300	0.548	0.498
Age, > 49	5,181	0.084	0.278	3,300	0.192	0.394
High-tech industry	5,181	0.299	0.458	3,300	0.356	0.479

Table 2. Profitability of R&D

Notes: This table reports the results of estimating the R&D continuous equation by OLS. ***, ** and * indicate significance at a 1%, 5% and 10% level respectively. The dependent variable is defined as $(1 - \phi) * ln(R) - ln(\phi) + ln(mc)$, so the estimates identify θ and σ_v or, what is the same, α. All the regressions include year fixed effects.

	Small	Large
	(1)	(2)
Intercept	5.855***	6.435***
	(0.312)	(0.357)
ln(Capital stock t-1)	0.136***	0.153***
	(0.028)	(0.026)
ln(Number of employees t-1)	0.478***	0.347***
	(0.047)	(0.046)
Age 10-19	0.078	0.345***
	(0.094)	(0.094)
Age 20-49	0.025	0.274***
	(0.087)	(0.084)
Age > 49	0.158	0.347***
	(0.110)	(0.093)
High-tech industry	0.719***	0.647***
	(0.052)	(0.044)
R^2	.29	.17
σ_v	1.05	1.04
Firms	416	485
Observations	1,708	2,341

Table 3. Cost structure

Notes: This table reports the results of estimating the R&D selection equation, and the subsidy and tax credit application equations. The coefficients are estimated by simulated maximum likelihood. ***, ** and * indicate significance at a 1%, 5% and 10% level respectively. The dependent variables are y in Panel A, ds in Panel B, and $d\tau$ in Panel C.

	Small (1)	Large (2)
A. R&D participation equation		
Mean F: $1/\lambda^{fc}$	54,855***	102,300***
	(3,590)	(7,297)
Mean E: $1/\lambda^{sc}$	4,899,325***	10,993,000***
	(386,993)	(1,161,712)
B. Subsidy application equation		
Mean K^s: $1/\lambda^{Ks}$	133,436***	326,041***
	(7,548)	(15,569)
C. Tax credit application equation		
Mean tax credits K^τ: $1/\lambda^{K\tau}$	208,218***	414,006***
	(11,529)	(18,924)
Firms	1,268	697
Observations	5,181	3,300

Table 4. Fit of the model

Notes: This table reports the mean and standard deviation of observed and simulated values for the R&D dummy variable y, the R&D investment R^*, the subsidy applicant dummy variable ds and the tax credit applicant dummy variable $d\tau$. Simulations are obtained by generating the profitability shock v and the cost shocks F, E, K^s and K^τ and calculating the respective outcomes according to the model's equations. The statistics of the simulated R^* are calculated for the subset of simulated values that are lower than the maximum value of the observed R^*.

	Small (1)	Large (2)
A. R&D participation equation		
Observed $y_t = 1 \mid y_{t-1} = 0$	0.061	0.136
	(0.239)	(0.343)
Predicted $y_t = 1 \mid y_{t-1} = 0$	0.064	0.136
	(0.245)	(0.343)
Observed $y_t = 1 \mid y_{t-1} = 1$	0.853	0.945
	(0.354)	(0.228)
Predicted $y_t = 1 \mid y_{t-1} = 1$	0.857	0.950
	(0.350)	(0.219)
B. Optimal R&D investment, for $y = 1$		
Observed R^*	264,514	1,045,978
	(409,131)	(1,344,460)
Predicted R^*	386,405	1,051,295
	(683,775)	(1,410,316)
C. Subsidy application decision		
Observed ds	0.120	0.284
	(0.325)	(0.451)
Predicted ds	0.115	0.271
	(0.319)	(0.444)
D. Tax credit application decision		
Observed dt	0.127	0.340
	(0.333)	(0.474)
Predicted dt	0.119	0.339
	(0.323)	(0.474)

Figures

Figure 1. Intensive and extensive margins

This figure provides a twoway scatterplot of the intensive and extensive margins of R&D for several countries. The intensive margin is defined as the average R&D investment by firms that invest in R&D in the country. The extensive margin is defined as the percentage of firms that invest in R&D in the country. The size of the markers is proportional to the ratio of aggregate business R&D over GDP. The labels indicate the name of the respective country and the percentage of business R&D over GDP. The variables used to produce the graph (expenditure in in-house R&D, number of firms engaged in in-house R&D and number of firms in the population) are Community Innovation Survey statistics available as part of the EU Science and Technology Statistics in Eurostat at: http://ec.europa.eu/eurostat/data/database.
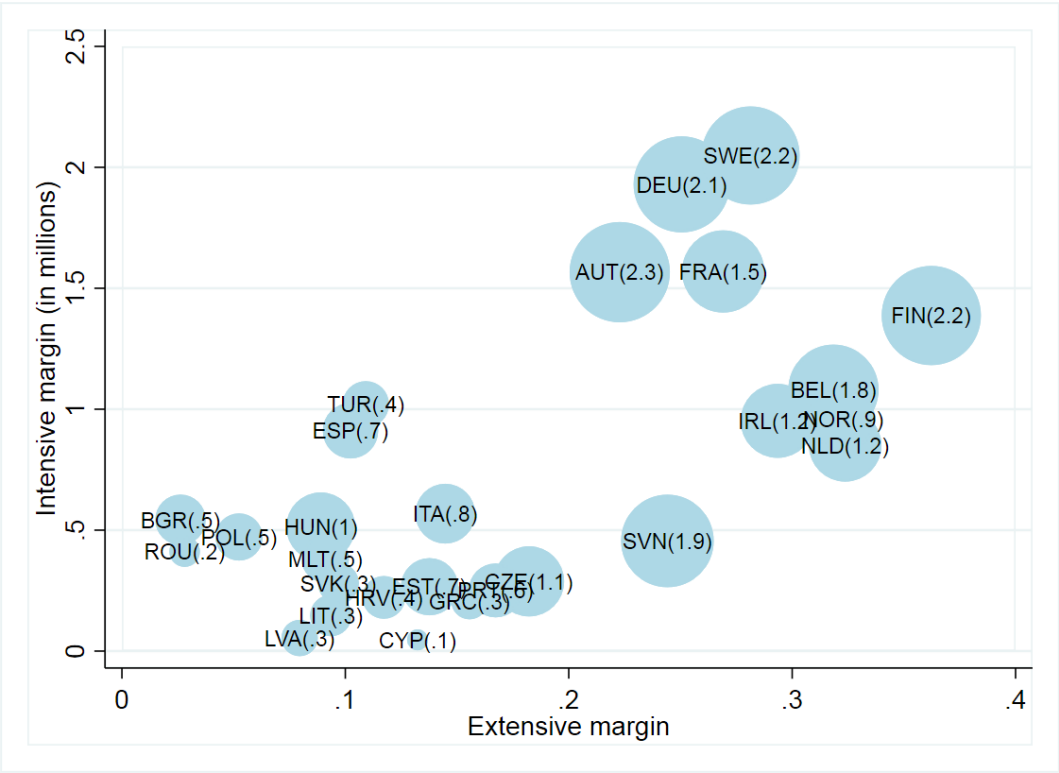
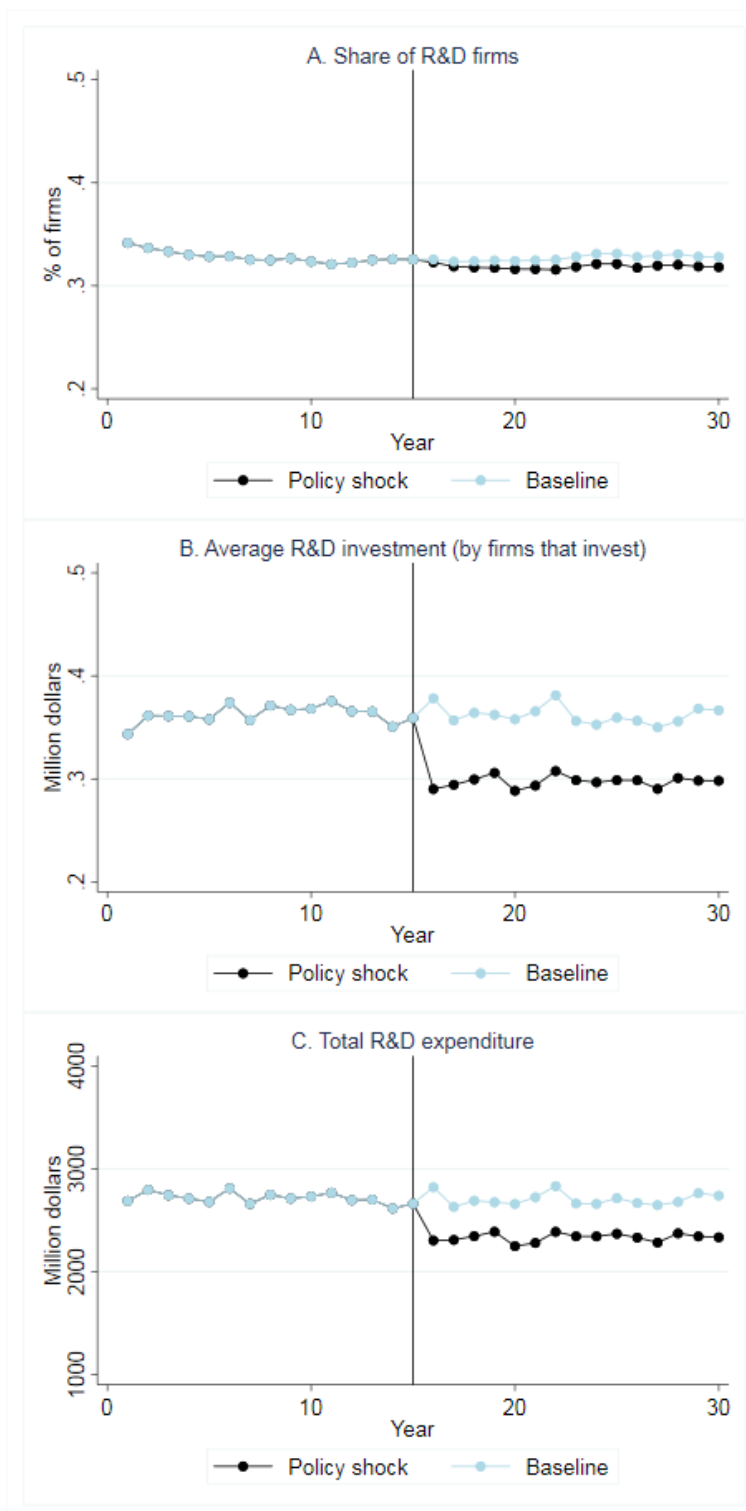# Figure 2. Withdrawal of subsidies and tax credits
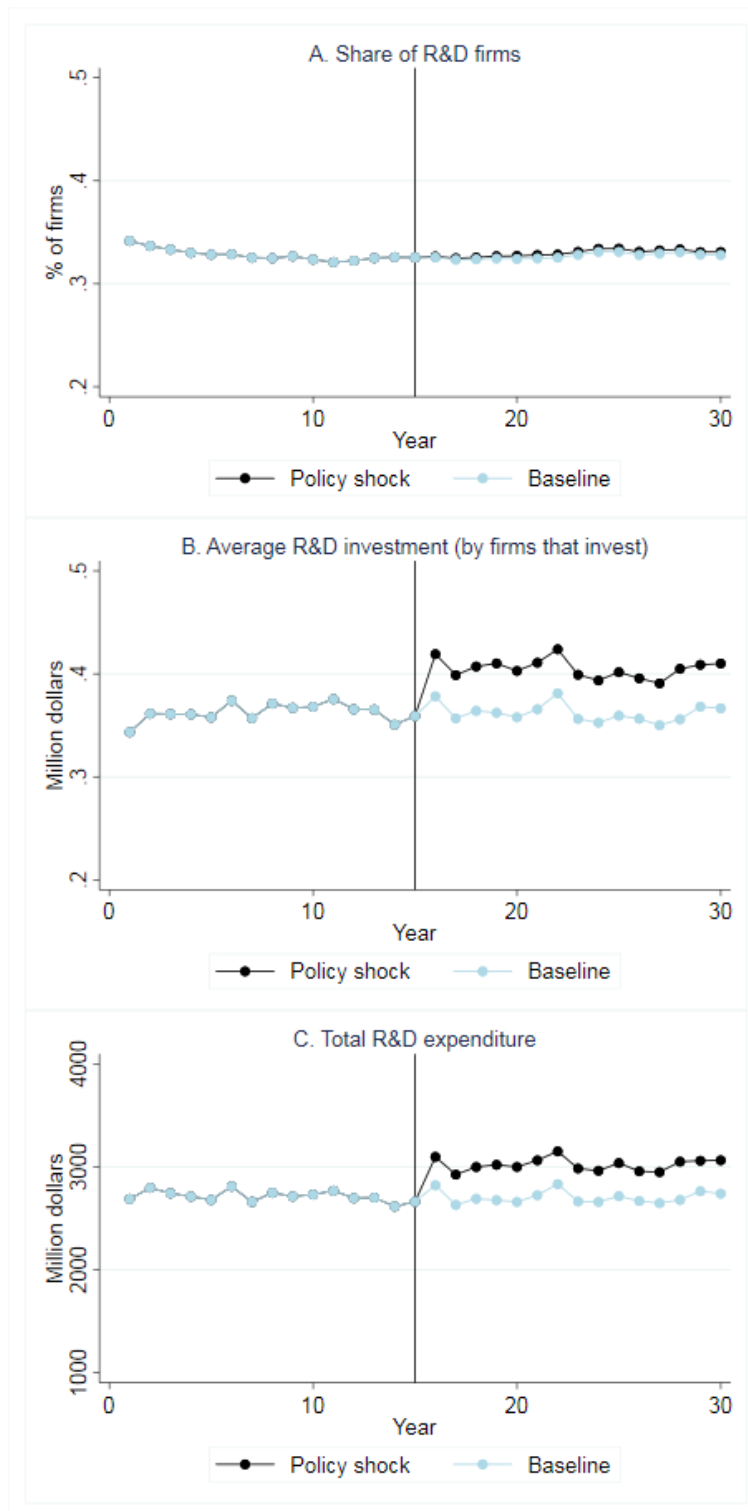
Figure 3. 20% reduction in application costs

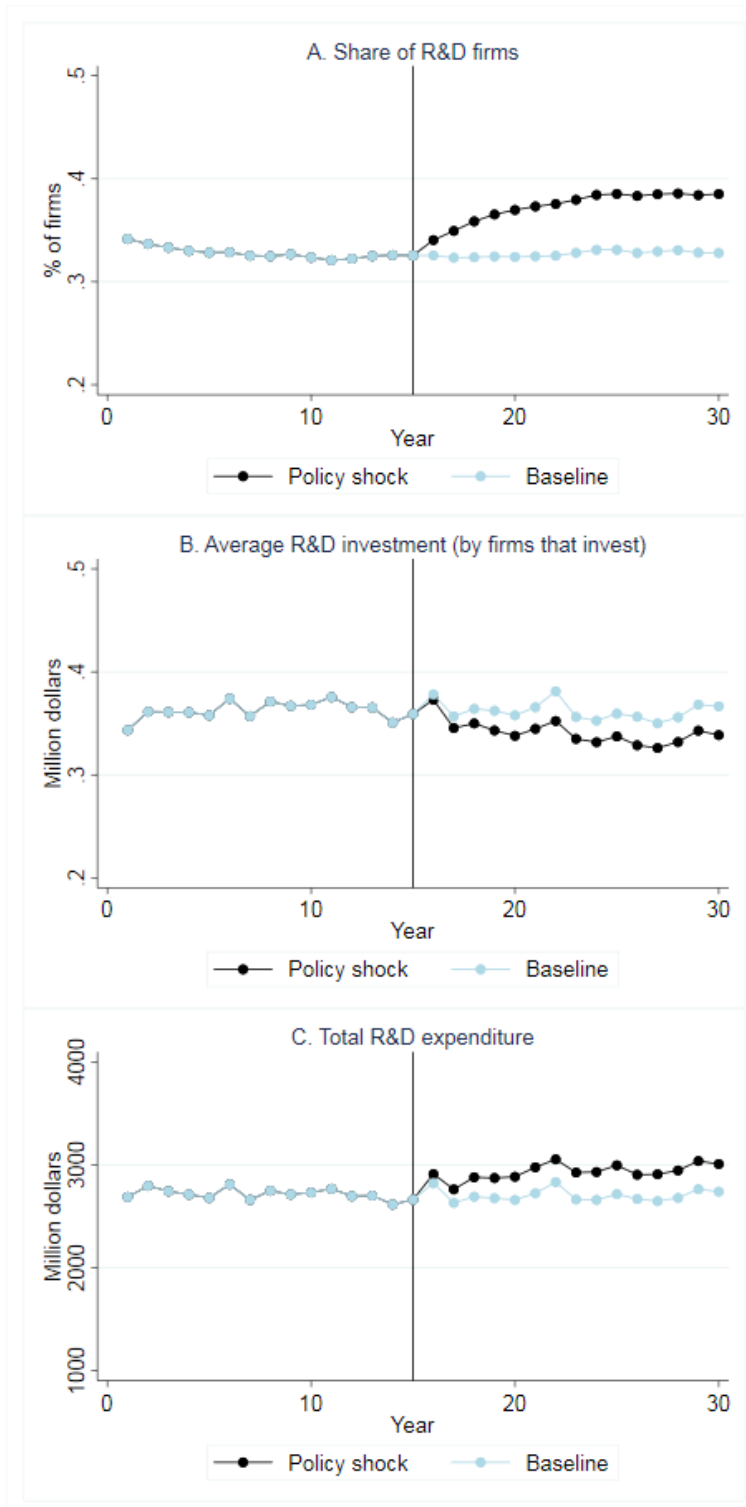Figure 4. 20% reduction in fixed costs
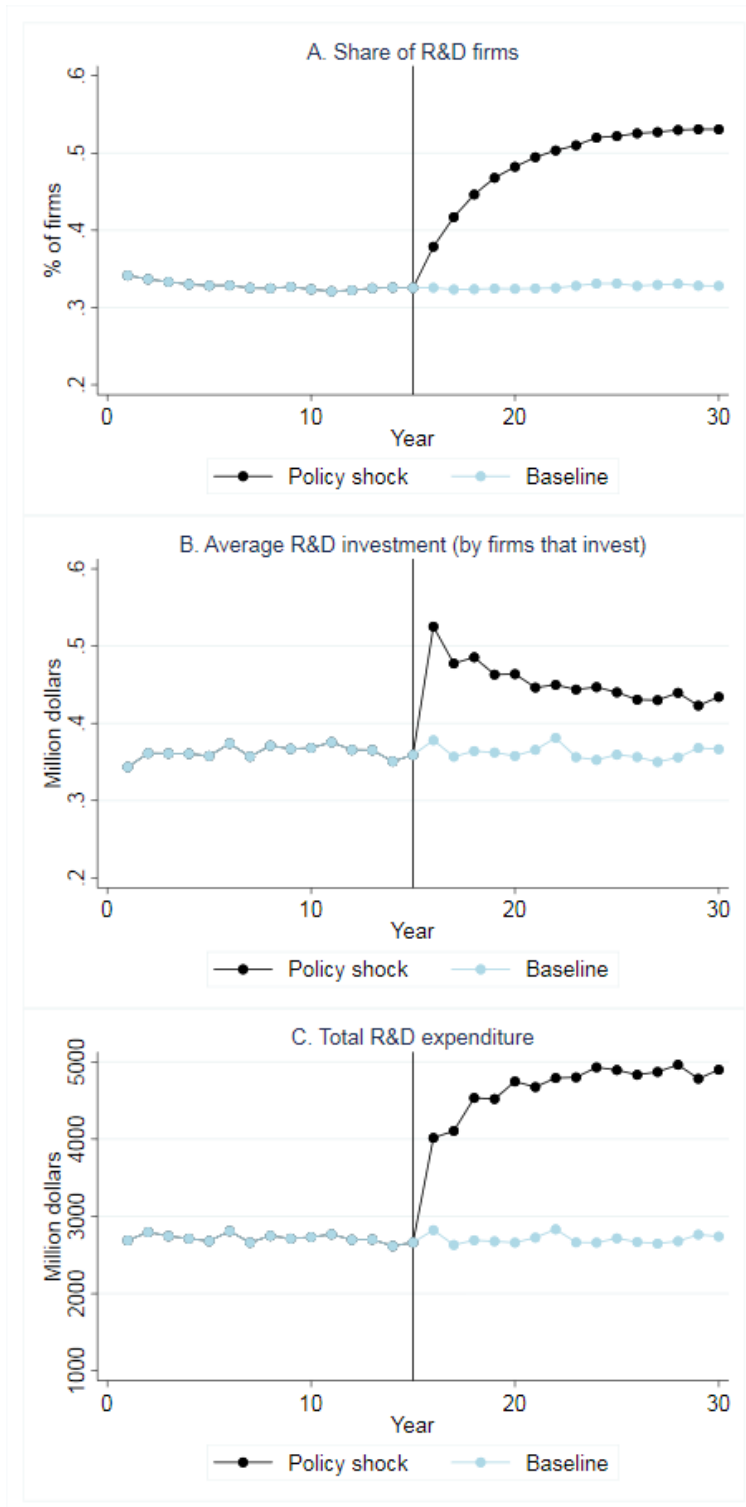
Figure 5. 10% increase in profitability

Figure 6. Intensive and extensive margins

This figure plots the intensive and extensive margins in the final period of the simulation for several combinations of profitability, marginal costs and fixed costs values. Light blue denotes low profitability (a 10% decline in the constant of the R&D equation), blue denotes original profitability, and black denotes high profitability (a 10% increase in the constant of the R&D equation). Large markers indicate large fixed costs (a 20% increase in fixed costs), medium sized markers indicate original fixed costs, and small markers indicate low fixed costs (a 20% decline in fixed costs). Triangles denote high marginal costs (complete elimination of subsidies and tax credits), squares denote original marginal costs, and circles denote low marginal costs (a 30% increase in marginal costs). The horizontal and vertical lines indicate the simulation results with the original values. R&D expenditures are winzorized at the 95% in all the simulations.
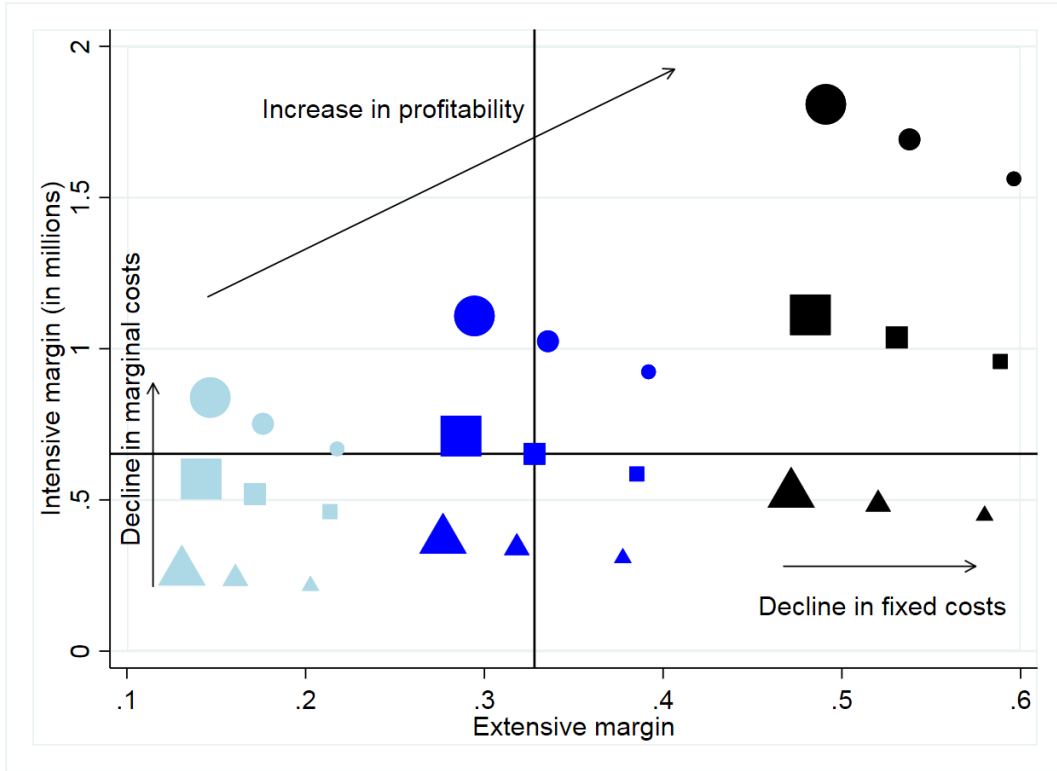
Appendix

A   Marginal cost of R&D

Let $s_t \in [0,1]$ denote the R&D subsidy rate (i.e. R&D subsidy over R&D investment), $\widetilde{\tau}_t \in [0,1]$ the corporate tax rate and $\tau_t \in [0,1]$ the R&D tax credit rate. Tax credits are exempt from corporate taxation. Moreover, for firms benefiting from both R&D subsidies and tax credits, tax credits are rewarded on the non-subsidized $(1 - s_t)$ and subsidized but taxed $(\widetilde{\tau}_t s_t)$ parts of the R&D investment. Let $V_{it}^{\widetilde{\tau}} = (1 - \widetilde{\tau}_t)V_{it}$ be the firm's expected discounted value (gross of year t fixed and entry costs), net of corporate taxes. For a firm applying for both R&D subsidies and tax credits, the expression for $V_{it}^{\widetilde{\tau}}$ is:

$$
\begin{aligned}
V_{it}^{\widetilde{\tau}} &= (1 - \widetilde{\tau}_t)\left[\alpha_{it}\max\{1, R_{it}\}^{\phi} - (1 - s_t)R_{it}\right] + \tau_t(1 - (1 - \widetilde{\tau}_t)s_t)R_{it} \\
&= (1 - \widetilde{\tau}_t)\left[\alpha_{it}\max\{1, R_{it}\}^{\phi} - \left(1 - s_t - \tau_t\frac{1 - (1 - \widetilde{\tau}_t)s_t}{1 - \widetilde{\tau}_t}\right)R_{it}\right] \\
&= (1 - \widetilde{\tau}_t)\left[\alpha_{it}\max\{1, R_{it}\}^{\phi} - mc_{it}R_{it}\right].
\end{aligned}
$$

The marginal cost of R&D is therefore given by $mc_{it} = 1 - s_t - \tau_t\frac{1-(1-\widetilde{\tau}_t)s_t}{1-\widetilde{\tau}_t}$. Notice that corporate taxes only enter the optimal R&D investment and selection equations through mc_{it} regardless of whether the problem is cast in terms of $V_{it}^{\widetilde{\tau}}$ or V_{it}. In the alternative formulation with $V_{it}^{\widetilde{\tau}}$, $(1 - \widetilde{\tau}_t)$ cancels out both in the first order condition for optimal R&D and in the R&D selection equation, leaving equations (2) and (4) unchanged.

B   Estimates of ϕ

Equation (7) can be rewritten as $\ln(R_{it}^*) = -\gamma\ln(mc_{it}) + X_{it}\beta + \varepsilon_{ij}$, where $\gamma = \frac{1}{1-\phi}$ and $X_{it}\beta + \varepsilon_{ij} = \frac{1}{1-\phi}\left[\ln(\phi) + X_{it}\theta + v_{it}\right]$. This implies that ϕ can be obtained from estimates of the user cost elasticity of optimal R&D as $\phi = 1 - \frac{1}{\gamma}$ (notice that $\gamma > 1$ is a necessary condition for ϕ to be positive). These insights are already pointed out in Arqué-Castells & Mohnen (2015) or Takalo *et al.* (2013b).

There is an abundant empirical literature providing estimates of γ from variation in R&D subsidies or tax credits (see the surveys by David *et al.* , 2000; Hall & Van Reenen, 2000). Two conditions must hold for such estimates to deliver satisfactory approximations of the structural parameter ϕ. First, estimates must be based on samples including positive R&D investments only. Samples including zeros provide upward biased estimates as they capture not only marginal effects on R_{it}^* but also discrete jumps from the corner solution $R_{it} = 0$

to $R_{it} = R_{it}^*$.[7] Second, the potential endogeneity of mc_{it} must be addressed. Most papers meet either condition one or condition two, but seldomly both. In what follows we review available estimates of γ and ϕ based on specifications and identification strategies that meet condition one, condition two and both.

Meet condition one. Papers based on R&D subsidies provide estimates for samples with positive R&D investments (i.e. meet condition one) but fail to satisfactorily address the endogeneity of mc_{ij} due to the lack of valid instruments (i.e. fail to meet condition two). It is common to define the user cost as $mc_{it} = 1 - s_{it}$ whith s_{it} being the share of subsidized R&D expenditures.[8] This definition of the user cost by construction generates downward biased estimates of γ.[9] González *et al.* (2005) and Arqué-Castells & Mohnen (2015) use predicted (rather than actual) user costs to deal with this bias. Predicted user costs are a suboptimal solution because predictors (predetermined firm-level attributes) are still potentially endogenous. Moreover, measurement error in the predicted user cost is likely to result in attenuated estimates. This approach generates estimates of γ that range between 1.07 (Table 5 in González *et al.* , 2005) and 1.08 (Table VII in Arqué-Castells & Mohnen, 2015). The implied values of ϕ are 0.065 and 0.075 respectively, which are rather low.

Meet condition two. Some recent papers provide estimates based on plausibly exogenous variation in R&D tax credits (i.e. meet condition two), but use observations with zero R&D investments (i.e. fail to meet condition one). This is the case of Dechezleprêtre *et al.* (2016), Rao (2016), Agrawal *et al.* (2014) and Guceri & Liu (2015).[10] The estimates of γ in these papers range between 1.05 and 4.04 with the mean estimate centered around 2.5.[11] This implies that ϕ ranges between 0.05 and 0.75 with a rather large mean value of 0.6.

Meet conditions one and two. Rao (2016) and Agrawal *et al.* (2014) provide estimates for firms with positive R&D investments by way of robustness check. The estimates of γ for

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[7]This excludes studies at the country or state level (e.g. Bloom *et al.* , 2002 and Wilson, 2009) which capture intensive and extensive margin effects. The estimates we are interested in must be at the firm level and capture intensive margin effects solely (i.e. exclude observations with zero R&D).

[8]Related papers enter the subsidy variable differntly in specifications that do not allow for direct estimates of γ (e.g. Wallsten, 2000; Lach, 2002).

[9]Because $-\ln(1 - \rho_{ij})$ is negatively correlated with the error term (see the discussion in Arqué-Castells & Mohnen, 2015).

[10]While the specifications in these papers are in general not equivalent to (??), they do provide estimates of γ or back of the envelope calculations of γ.

[11]The estimates of γ range between 2.56 and 3.97 in Dechezleprêtre *et al.* (2016) (see Table A12 in the cited paper); between 1.175 and 4.044 in Rao (2016) (see Table 4 in the cited paper); between 1.05 and 3 in Agrawal *et al.* (2014) (see Table 5 in the cited paper); and between 1.74 and 2.39 in Guceri & Liu (2015) (see Table 9 in the cited paper). The mean estimate among the reported minimum and maximum estimates in each paper (not among all the estimates in each paper) is 2.5.

these subsamples are 1.175 (Table 4 in Rao, 2016) and 1.45 (Table A-6 in Agrawal *et al.* , 2014) which imply that ϕ is 0.15 and 0.31 respectively. Einiö (2014) uses exogenous variation in the allocation of R&D subsidies in Finland obtaining a preferred estimate of 1.380 (see the IV results in Column (5), Table 3 of the cited paper), which implies a value of ϕ of 0.27.[12] Therefore, the mean value of ϕ for papers relying on exogenous variation and using positive R&D expenditures is 0.24. As expected, this value is between the estimates of papers that only meet condition one an the estimates of papers that only meet condition two.

C   Likelihood function of the R&D decision

According to equation (4) the firm invests in R&D if

$$y_{it-1}F_{it} + (1 - y_{it-1})E_{it} < \Delta V_{it}, \tag{A}$$

where $\Delta V_{it} = (1 - \phi)(\phi/mc_{it})^{\frac{\phi}{1-\phi}} \exp(X_{it}\theta + v_{it})^{\frac{1}{1-\phi}} - \exp(X_{it}\theta + v_{it})$. Letting $\delta F_{it} = E_{it}$, equation (A) can be rewritten as

$$F_{it} < \frac{\Delta V_{it}}{(1 - \delta)y_{it-1} + \delta}. \tag{B}$$

Assuming F_{it} to be exponentially distributed with rate parameter λ_F, the likelihood function for firm i and year t can be written as follows:

$$L_{it}^y = \int_{-\infty}^{\infty} \left[1 - \exp\left(\frac{-\lambda_F \Delta V_{it}}{(1 - \delta)y_{it-1} + \delta} \right) \right]^{y_{it}} \left[\exp\left(\frac{-\lambda_F \Delta V_{it}}{(1 - \delta)y_{it-1} + \delta} \right) \right]^{1-y_{it}} g(v_{it})dv_{it}, \tag{C}$$

where $g(v_{it}) = (\sigma_v\sqrt{2\pi})^{-1} \exp(\frac{-v_{it}^2}{2\sigma_v^2})$ stands for the normal density function. Using the variable change $z_{it} = \frac{v_{it}}{\sigma_v\sqrt{2}}$ (i.e. $dv_{it} = dz_{it}\sigma_v\sqrt{2}$) the likelihood funciton can be written as follows:

$$L_{it}^y = \int_{-\infty}^{\infty} \exp(-z_{it}^2) \left[1 - \exp\left(\frac{-\lambda_F \overline{\Delta V}_{it}}{(1 - \delta)y_{it-1} + \delta} \right) \right]^{y_{it}} \left[\exp\left(\frac{-\lambda_F \overline{\Delta V}_{it}}{(1 - \delta)y_{it-1} + \delta} \right) \right]^{1-y_{it}} dz_{it}, \tag{D}$$

---

[12] The explanatory variable is not the (log of the) user cost of R&D but a dummy variable indicating whether the firm is a subsidy grantee or not. So in purity this is not an estimate of the user cost elasticity of R&D but an average partial effect of a reduction in the user cost. On average, subsidy grantees received subsidies covering about 0.25 of their R&D investment so the R&D subsidy grantee dummy variable captures declines in the user cost from 1 to 0.75.

where $\overline{\Delta V}_{it} = (1-\phi)(\phi/mc_{it})^{\frac{\phi}{1-\phi}} \exp(X_{it}\theta + z_{it}\sigma_v\sqrt{2})^{\frac{1}{1-\phi}} - \exp(X_{it}\theta + z_{it}\sigma_v\sqrt{2})$. The integral in (D) can be approximated using Gauss-Hermite quadrature, which satates that

$$\int_{-\infty}^{\infty} \exp(-z^2)f(z)dz \simeq \sum_{m}^{M} w_m f(a_m), \tag{E}$$

where w_m and a_m are the weights and abscissas of the Gauss-Hermite quadrature and M is the total number of integration points. Using the Gauss-Hermite approximation, the likelihood function becomes:

$$L_{it}^{y} \simeq \frac{1}{\sqrt{\pi}} \sum_{m}^{M} w_m \left[1 - \exp\left(\frac{-\lambda_F \overline{\overline{\Delta V}}_{it}}{(1-\delta)y_{it-1} + \delta} \right) \right]^{y_{it}} \left[\exp\left(\frac{-\lambda_F \overline{\overline{\Delta V}}_{it}}{(1-\delta)y_{it-1} + \delta} \right) \right]^{1-y_{it}}, \tag{F}$$

where $\overline{\overline{\Delta V}}_{it} = (1-\phi)(\phi/mc_{it})^{\frac{\phi}{1-\phi}} \exp(X_{it}\theta + a_m\sigma_v\sqrt{2})^{\frac{1}{1-\phi}} - \exp(X_{it}\theta + a_m\sigma_v\sqrt{2})$.

D Likelihood function of the application decision

According to equation (6) the firm applies for R&D subsidies if

$$K_{it} < \pi_{it}^1 - \pi_{it}^0. \tag{G}$$

Neither the profitability shock nor the fixed costs are observed. Therefore, we need to take expectations over both. Taking expectations over the fixed costs, we can define the expected discounted value of applying and not applying for a given value of the profitability shock as follows:

$$\Pi_{it}^1 = p_{it}^1 \left[V_{it}(R_{it} = R_{it}^{1*}) - E(C_{it}|\Delta V_{it}^1 > C_{it}) \right] + (1 - p_{it}^1) \left[V_{it}(R_{it} = 0) \right], \tag{10}$$

$$\Pi_{it}^0 = p_{it}^0 \left[V_{it}(R_{it} = R_{it}^{0*}) - E(C_{it}|\Delta V_{it}^0 > C_{it}) \right] + (1 - p_{it}^0) \left[V_{it}(R_{it} = 0) \right], \tag{11}$$

where $p_{it} = \Pr(\Delta V_{it} > C_{it})$ denotes the probability that the firm invests in R&D. Expectations with repect to the profitability shock are obtained by integrating out the profitability shock in the likelihood function.

Assuming K_{it}^s to be exponentially distributed with rate parameter λ_{K^j}, the likelihood function of the application equation for firm i and year t can be written as follows:

$$L_{it}^{ds} = \int_{-\infty}^{\infty} \left[1 - \exp\left(-\lambda_{K^s} \left[\Pi_{it}^1 - \Pi_{it}^0 \right] \right) \right]^{y_{it}} \left[\exp\left(-\lambda_{K^s} \left[\Pi_{it}^1 - \Pi_{it}^0 \right] \right) \right]^{1-y_{it}} g(v_{it})dv_{it}. \tag{J}$$

Applying the same variable change used above and using the Gauss-Hermite approximation for the integral, the likelihood function can be rewritten as

$$L_{it}^{ds} \simeq \frac{1}{\sqrt{\pi}} \sum_m^M w_m \left[1 - \exp\left(-\lambda_{K^s} \left[\overline{\overline{\Pi}}_{it}^1 - \overline{\overline{\Pi}}_{it}^0 \right] \right) \right]^{y_{it}} \left[\exp\left(-\lambda_{K^s} \left[\overline{\overline{\Pi}}_{it}^1 - \overline{\overline{\Pi}}_{it}^0 \right] \right) \right]^{1-y_{it}}, \quad (K)$$

where

$$\overline{\overline{\Pi}}_{it}^1 = \overline{\overline{p}}_{it}^1 \left[\overline{\overline{V}}_{it}(R_{it} = R_{it}^{1*}) - E(C_{it}|\overline{\overline{\Delta V}}_{it}^1 > C_{it}) \right] + (1 - \overline{\overline{p}}_{it}^1) \left[\overline{\overline{V}}_{it}(R_{it} = 0) \right], \quad (L)$$

$$\overline{\overline{\Pi}}_{it}^0 = \overline{\overline{p}}_{it}^0 \left[\overline{\overline{V}}_{it}(R_{it} = R_{it}^{j0*}) - E(C_{it}|\overline{\overline{\Delta V}}_{it}^0 > C_{it}) \right] + (1 - \overline{\overline{p}}_{it}^0) \left[\overline{\overline{V}}_{it}(R_{it} = 0) \right]. \quad (M)$$

Where all the components with upper bars contain abscissas of the Gauss-Hermite quadrature:

$$\overline{\overline{\Delta V}}_{it}^1 = (1 - \phi)(\phi/mc_{it}(1, d\tau_{it}))^{\frac{\phi}{1-\phi}} \exp(X_{it}\theta + a_m\sigma_v\sqrt{2})^{\frac{1}{1-\phi}} - \exp(X_{it}\theta + a_m\sigma_v\sqrt{2}),$$

$$\overline{\overline{\Delta V}}_{it}^0 = (1 - \phi)(\phi/mc_{it}(0, d\tau_{it}))^{\frac{\phi}{1-\phi}} \exp(X_{it}\theta + a_m\sigma_v\sqrt{2})^{\frac{1}{1-\phi}} - \exp(X_{it}\theta + a_m\sigma_v\sqrt{2}),$$

$$\overline{\overline{V}}_{it}(R_{it} = R_{it}^{1*}) = (1 - \phi)(\phi/mc_{it}(1, d\tau_{it}))^{\frac{\phi}{1-\phi}} \exp(X_{it}\theta + a_m\sigma_v\sqrt{2})^{\frac{1}{1-\phi}},$$

$$\overline{\overline{V}}_{it}(R_{it} = R_{it}^{0*}) = (1 - \phi)(\phi/mc_{it}(0, d\tau_{it}))^{\frac{\phi}{1-\phi}} \exp(X_{it}\theta + a_m\sigma_v\sqrt{2})^{\frac{1}{1-\phi}},$$

$$\overline{\overline{V}}_{it}(R_{it} = 0) = \exp(X_{it}\theta + a_m\sigma_v\sqrt{2}),$$

$$\overline{\overline{p}}_{it}^1 = 1 - \exp\left(\frac{-\lambda_F \overline{\overline{\Delta V}}_{it}^1}{(1-\delta)y_{it-1} + \delta} \right),$$

$$\overline{\overline{p}}_{it}^0 = 1 - \exp\left(\frac{-\lambda_F \overline{\overline{\Delta V}}_{it}^0}{(1-\delta)y_{it-1} + \delta} \right),$$

$$E(C_{it}|\overline{\overline{\Delta V}}_{it}^1 > C_{it}) = \frac{(1-\delta)y_{it-1} + \delta}{\lambda_F} - \overline{\overline{\Delta V}}_{it}^1 \left[\frac{\exp\left(\frac{-\lambda_F \overline{\overline{\Delta V}}_{it}^1}{(1-\delta)y_{it-1}+\delta} \right)}{1 - \exp\left(\frac{-\lambda_F \overline{\overline{\Delta V}}_{it}^1}{(1-\delta)y_{it-1}+\delta} \right)} \right],$$

$$E(C_{it}|\overline{\overline{\Delta V}}_{it}^0 > C_{it}) = \frac{(1-\delta)y_{it-1} + \delta}{\lambda_F} - \overline{\overline{\Delta V}}_{it}^0 \left[\frac{\exp\left(\frac{-\lambda_F \overline{\overline{\Delta V}}_{it}^0}{(1-\delta)y_{it-1}+\delta} \right)}{1 - \exp\left(\frac{-\lambda_F \overline{\overline{\Delta V}}_{it}^0}{(1-\delta)y_{it-1}+\delta} \right)} \right].$$

E   Variables definitions

R&D expenditure (R):   Cost of intramural R&D activities and R&D contracted with external laboratories or research entities (this definition is consistent with the Frascati Manual).

R&D dummy variable (y):   Dummy variable with value one if R&D expenditure is positive and value zero otherwise.

R&D subsidy rate (s):   The R&D subsidy rate is defined as the R&D subsidies received by the firm over total R&D expenditures. The subsidies received by the firm include the total quantity of public aid granted by the various public agencies (primarily the national agency, CDTI, but also regional and European agencies). It must remain clear that this measure essentially includes subsidies but also other forms of public support such as low-interest and capital credits.

Subsidy applicant dummy variable (ds):   The survey does not provide direct information on subsidy applicants. It does provide information on the public R&D funding received by successful subsidy applicants as well as on whether firms sought external financing without success. Since the public sector is by far the main available source of external financing for R&D in Spain we can safely view firms claiming to have sought external R&D funding without success as rejected subsidy applicants. We consider a firm to be a subsidy applicants either if it claims to have sought external financing without success or if it receives subsidies.

Corporate tax rate $(\widetilde{\tau})$:   The corporate tax rate in Spain was 0.35 from 1990 to 2006, 0.325 in 2007 and 0.30 from 2008 on.

R&D tax credit (τ):   The R&D tax credit in Spain was 0.30 between 2000-2006, 0.27 in 2007 and 0.25 from 2008 on.

Tax credit applicant dummy variable $(d\tau)$:   Dummy variable with value one if the firm applies the tax deductions for R&D and technological innovation.

Capital stock: Capital at current replacement values $\widetilde{K}_{it}$ is computed recursively from an initial estimate and the data on current investments in equipment goods $\widetilde{I}_{it}$. We update the value of the past stock of capital by means of the price index of investment P_{it} as $\widetilde{K}_{it} = (1 - \delta_k)(P_{it}/P_{it-1})\widetilde{K}_{it-1} + \widetilde{I}_{it}$, where δ_k is an industry-specific estimate of the rate

of depreciation of capital. Capital in real terms is obtained by deflating capital at current replacement values by the price index of investment as $K_{it} = \widetilde{K}_{it}/P_{it}$.

Labor: Total number of employees of the firm.

Age of the firm: Years elapsed between incorporation and the current year.

High-tech dummy variable: Dummy variable with value one if the industrial sector of the firm is high-tech. The high-tech group consists of firms in chemicals, machinery, electronics and instruments, and vehicles. The low-tech group consists of firms in basic metals, mineral, food, textiles, timber and furniture, paper, and miscellaneous.