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# Suppliers R&D Subsidies Policies for Product Innovation in Indian Context: An Analysis

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**Abstract:** This paper attempts to examine the product innovation by R&D subsidies policies in a supply chain by supplier. This study derives a model for a supplier's product innovation R&D subsidies policy. The product innovation of supplier can contribute to the long-term competitiveness for the supply chain. For many supply chains, product innovation is a major factor, and it should be considered in the development of strategies for a supplier. In this paper, we study whether there is scope for using R&D subsidies to smooth out obstacles to R&D performance for product innovation and expand the share of R&D to suppliers. To this end we consider a dynamic model with sunken entry costs in which supplier optimal participation strategy is defined in terms of two subsidy thresholds that characterise entry and continuation. A survey result in India is studied whether there is scope for using R&D subsidies to smooth out obstacles to R&D performance for product innovation and expand the share of R&D to suppliers. We are able to compute the subsidy thresholds from the estimates of a dynamic panel data type-2 to bit model for an unbalanced panel of about 3,000 Indian suppliers. The results suggest that extensive R&D subsidies (i.e., subsidies on the extensive margin) are a feasible and efficient tool for expanding the share of R&D for product innovation by suppliers.

**Keywords:** Indian Suppliers, R&D subsidies policies, product innovation, sunk cost, dynamic models

## 1 INTRODUCTION

The development of new products and improvement of existing products, are considered to be critical to the survival of a supply chain facing tough competition and globalization. Due to an increase in competition and rapid advancement of technology, product innovation and new product development are becoming the essential strategies for the management of the suppliers to survive in the world [15]. Product innovation is an effective tool that a supplier can utilize to maintain its competitive position in the market. The position of the supplier in the market can be influenced by the frequency of releasing new or improved products [16].

As a result of increased buyer communications in many markets, buyers are flooded with many product choices, resulting in shorter product life cycles and rapid changes in buyer preferences. Product dynamism refers to the continuous change in the product which is characterized by speed and magnitude of technological change in the product. To cope up with competition and dynamic change in market demand many suppliers are adopting open product innovation which involves collaboration with external entities, like suppliers, universities, research organizations and competitors [23]. Many suppliers are switching towards open product innovation models, from traditional closed product innovation models, to increase their level of product innovation and retain competitive position in the supply chain. All suppliers have R&D policies and product innovation support programs to spur growth by overcoming market failures. Such programs comprise a wide range of tools including subsidies for performing R&D activities, the creation of technological laboratories

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or product innovative clusters. Of all these forms of support, an R&D subsidy policy is the principal tool of involvement for product innovation. R&D subsidy policies aimed at enhancing the overall R&D expenditure of a given supplier can follow two different courses of action. On the one hand, they can act on the intensive margin, seeking to promote the R&D effort of regular R&D performers. On the other hand, they can act on the extensive margin, seeking to expand the base of R&D performers. This lack of interest in extensive R&D subsidies policies for product innovation is hard to understand for one main reason. It is only those suppliers with a substantial share of R&D subsidies that achieve high R&D intensities. Hence even if the final goal is to increase R&D intensity it must necessarily be achieved through R&D subsidies. Our goal is to study whether there is scope for using extensive R&D subsidies to expand the share of R&D activities of a supplier. At the limit all suppliers could be subsidized but this would be costly and not necessarily benefit enhancing. So a first step is to define which circumstances if any justify the use of extensive R&D subsidies. Our justification is related with the existence of sunk entry costs in R&D activities. Becoming R&D-performing activities is costly as it often requires setting up a new department, hiring and training researchers and investing in machinery. These outlays are generally non-recoverable and can be considered as sunk costs. As a result of the existence of sunk entry costs, some suppliers are likely to need R&D subsidies to start but not to continue performing R&D. We defend that extensive subsidies should essentially be used to smooth out the sunk entry costs of these suppliers. We set out to detect whether such a group of suppliers exists in India, a low R&D-intensity country with a small share of R&D suppliers. We also aim to quantify the costs (total amount of subsidies) and benefits (total R&D stock generated) derived from inducing this group of suppliers into R&D. In short, we ask ourselves how far India can progress along with a policy based on extensive subsidies. To this end, we consider a dynamic model with sunk entry costs in which suppliers decide whether to start, continue or stop performing R&D on the grounds of the subsidy coverage (share of to-be-made R&D expenditures) they expect to receive. Suppliers' optimal participation strategy is defined in terms of two subsidy (or R&D) thresholds that characterise entry and continuation. The entry threshold is larger than the continuation threshold owing to the fact that suppliers are in greater need of aid when they lack experience in R&D and sunk costs still need to be paid. Whenever the expected subsidy coverage is above the entry (respective continuation) threshold, suppliers find it optimal to enter (respective continue doing) R&D. Temporary subsidies above the entry threshold can lead to permanent R&D activity as long as the level of subsidies remains above the continuation threshold. Suppliers with positive entry thresholds and zero or negative continuation thresholds can be permanently induced into R&D by means of one-shot trigger subsidies. Suppliers' optimal participation policy can be cast in terms of a type-2 to bit specification with dynamics in the selection equation where suppliers find it optimal to enter (respective continue doing) R&D if optimal R&D expenditure is above the R&D entry (respective continuation) threshold. We estimate the model using an unbalanced panel of more than 3,000 Indian suppliers observed during the period 2000-2013. The dataset includes numerous entries into, and exits from, R&D and reports information on R&D spending. Somewhat unusually the dataset also contains information on both successful and rejected subsidy applicants, the latter information being crucial for identifying subsidies' inducement effects. However, we construct a measure of expected subsidies drawing on the information we have on subsidy applicants. This will enable us to control for fixed effects, which will ultimately result in a better identification of the R&D subsidy parameters. The paper leads to a series of interesting findings. First of all, expected R&D subsidies significantly affect both R&D expenditure and the decision to perform R&D. In addition, there is true state dependence in the sense that suppliers that perform R&D in a given period are 51% more likely than those that do not to perform R&D in the next period. This result implies that there are two R&D subsidy thresholds rather than one, which allows for permanent inducement effects. The R&D subsidy thresholds are used to classify suppliers according to their dependence on R&D subsidies for making the performance of R&D activities profitable. Interestingly, 21% of Indian manufacturing suppliers are found to need subsidies when they lack any previous experience, but they can persist in R&D without them. In our dynamic framework with sunk entry costs a supplier's optimal participation strategy can be defined in terms of two (rather than one) subsidy thresholds characterising entry and continuation. This enhancement proves crucial as it allows us to detect the permanent inducement effects (which go unnoticed in a static setting) that make "extensive" R&D subsidies a feasible and efficient tool to induce entry. Open product innovation involves interaction of suppliers with several external entities to generate new ideas to improve existing products and develop new products. In recent years, the literature on product innovation has made some important issues of discussion. Of all the different types of methodologies adopted for innovation of the product, suppliers' product innovation has the most significant impact on the performance and success of the supply chain [14]. Supplier increases the technology knowledge available to a supply chain, which helps it reduce the product development time by identifying the potential problems beforehand [6]. Ragatz *et al.* [18]found that involvement of suppliers in product innovation process result in benefits such cost reduction, improved quality and sales increase. Peterson *et al.* [15] argued that the integration of suppliers into new product development activities can reduce the risk involved with technology which is at its formative stage. Supplier product innovation reduces potential problems during the early stages of development [29]. Although significant benefits can be achieved through the use of supplier, for a company seeking to leverage the product innovation by R&D subsidies policies of its supplier through collaboration, it is necessary that the correct attributes are considered in the design of supplier collaboration relationships. This paper is regarded as the benchmark in this area. The objective of our research is to gain a better understanding of the factors that a supplier must consider in product innovation by R&D subsidies policies. Therefore it is very helpful to see how a supplier, who is the most important contributor to the technological progress for product development, behaves in the different situations. What determines their effort decisions and their product innovation achievements? How supplier's knowledge for product innovation is per se produced? If we have a thorough understanding in these questions, then we will be more confident to provide some suggestions as to how to enhance a supplier's product innovation achievement and ultimately boost the technical progress of the new product development. Surprisingly, however, this important issue has by far received inadequate attention. Yet most of the above literatures only treat the product innovation within a macro context with little effort by far devoted to the analysis of supplier's performance to discover how product innovation is produced. Actually in most cases, the R&D and other product innovation activities are just implicitly assumed to take place automatically so long as supplier is input into the "product innovation generator". There are several reasons that might explain why this problem has not been studied sufficiently. First, the product innovation is conducted mainly in the institutions affiliated with profit-maximizing firms, which tends to induce the economists to treat product innovation process in the same way as physical production. But actually these two kinds of processes are fundamentally different in many aspects. First of all, the knowledge and innovation are partially non-excludable and non-competitive, which is dissimilar to the common products, therefore the accumulation of knowledge is essentially different from accumulation of physical capital; Secondly, the product innovation process is intrinsically more independent, harder to monitor, more risky and vulnerable to failure, and with a more obvious accumulating nature which means today's product innovation relies heavily on yesterday's achievement. Thirdly, the profits for the suppliers is greatly different from that for the traditional production activities, the former is based on the non-market priority right or the market-oriented patent system, and it is more common that knowledge is undersupplied because the supplier is often not fully compensated duo to externality of knowledge. Fourthly, these two kinds of processes also take place in the different institutions. Another reason why a supplier's performance hasn't been intensively examined is possibly that it is quite difficult to make the analysis beyond the existent frameworks such as game-theoretic teamwork theory, principle-agent theory, and other topics on mechanism design etc. Admittedly, these frameworks of analysis could be important in dealing with this problem, but clearly they are not proper in some essential aspects. For instance, the analysis should be compatible in a dynamic general equilibrium setting, which means that the horizon should be the same with other agents such as a buyer; the supplier's time preference is endogenously determined.

The remainder of this paper is arranged as follows: In the next section we review some relevant papers on this topic that have different contributions. Models are developed in section 3, a general dynamic model, supplier's utility, product innovation function, the steady state analysis, dynamics of the product innovation achievement and the supplier, supply chain cooperation in product innovation. Where we find that the optimal effort level adjusts dynamically in a diversifying way and the research achievement also undergoes variation accordingly, in some circumstances following a saddle-point stable equilibrium path while in others showing a cyclical change. The frequency of the fluctuation is usually determined by the nature of the research process or the supplier's own characteristics such as supplier's product innovative ability. The short-run analysis of the effect of the supply chain cooperation is also conducted in the product innovation activity. The concluding remarks are in the last section.

## 2 LITERATURE REVIEW

The first paper that tries to model this phenomenon was carried out by Krugman [7]. He developed an exogenous product innovation rate of new product, g, and an exogenous rate of technology migration. This exogenous process ensures that the share of the supplier product measure in the whole measurement is constant. In his analysis, he got that the technological lag gives rise to exporting new products and importing old products. This one is really suggestive for product innovation effect, but also suffers from the causes for this technology transfer. Also, the assumptions are simple enough and lose some kind of generality. The level of supplier integration in product development ranges from simple consultation in the design of products, to the independent development of entire modules by suppliers [25]. Research shows that supplier involvement in new product development enhances the customer firm's performance along various dimensions. Supplier involvement in the product development reduces development cost, development time, and cost of the product to the customer firm [25]. Supplier involvement in product innovation by R&D subsidies policies helps firms penetrate at a faster rate into the new markets, share risks among suppliers and increase the competency level. Park and Oduntan [14] identified the following key attributes for innovative suppliers.

- Innovative suppliers are responsible for improving the attributes related to the module they innovate.
- The modules supplied by innovative supplier have unique attributes which can be perceived by the buyer.
- Innovative suppliers identify the features and attributes of the module as desired by the buyers and work for improving the attributes.
- Innovations in the modules supplied by innovative suppliers can influence the buying decision of the buyer.

Clark and Fujimoto [3] classified the parts related to auto industry into three types based on the extent of involvement of suppliers in their development:

- "Detailed control parts" in which development is performed entirely by the buer i.e., the auto manufacturer
- "Black-box" parts in which specifications and interface requirements are given by buyer. "Supplier proprietary" parts whose development is performed entirely by the supplier [3].

Fredrik *et al.* [4] identified nine factors which are crucial for the success of new product development based on the case study of an auto manufacturer. Proactive role of the supplier, role of auto manufacturer as coordinator, linkage between production and development, supplier's support to other auto manufacturers are the four key factors which need to be investigated before making the decision to involve suppliers in new product development [4]. Liker *et al.* [8] identified several variables, including tier structure, degree of responsibility, inter-company communication, intellectual property agreements and supplier membership which play key role in supplier integration and the success of new product development projects. Primo *et al.* [17] found that factors such as current technological capabilities and product innovation level required by the customer firm are critical for analyzing the level of involvement of suppliers in the product innovation. Wagner *et al.* [26] categorized the critical factors for the success of new product innovation projects with the involvement of suppliers into two domains such as factors related to organizational level and management of suppliers in the project. The architecture of the product design and interaction with suppliers during product innovation process must be in coherence [2]. Modular architecture of the product allows one-to-one mapping of the functional requirements to the physical components and allows standardized interfaces between modules [22]. Modular product architecture enables easy upgrade and substitution of components allowing the customer firm to divide the design and development activities to the suppliers efficiently [19] [24]. With the integral product architecture there is more than one physical component which performs a single functional requirement [22], which makes the task of dividing the design and development of components complex because a change in one functional requirement necessitates changes in more than one physical components [19] [24]. Supplier involvement strategies depend on product architecture, design and interfaces with suppliers ranging from "none" and "white box" to "grey box" and "black box" supplier integration [13]. Henderson and Clark [5] distinguished the R &D capabilities of the suppliers as architectural and component knowledge. Component knowledge refers to the capability of the supplier to design and manufacture the component for the final product, but not the final product itself. Architectural knowledge refers to the ability of the supplier to integrate and coordinate the knowledge between other suppliers and customer firm. Supplier assessment based on their manufacturing, assembly and logistic expertise is vital for supplier selection in the new product development process [13]. Mabert *et al.* [11] found that early involvement of suppliers in the innovation process reduces the development time. [26] categorized the variables influencing supplier selection into "hard" and "soft" criteria categories. "Hard" criteria involve supplier potential to innovate new products for the customer, and a "soft" criterion involves openness, mutual support and reliability between the supplier and the customer firms. Although much research supports the theory that supplier product innovation is beneficial to the new product development performance of a firm, there is some research that suggests supplier product innovation might not have a significant positive influence on a firm's product development performance. Littler *et al*. [10] through their study of UK firms in communication sector concluded that the involvement of suppliers increases the cost of product as the complexity involved in the management of collaborative projects increases. As the differentiation among the firms involved in new product development increases, challenges to achieving common goals also increase [20]. A major obstacle for supplier integration comes from unwillingness to share the internal design information and not invented here culture which prevents engineers from relinquishing product development responsibilities to suppliers [18]. Johnson (1999) emphasizes the need for the implementation of standard procedures to involve suppliers in new product development processes by R&D subsidies policies. Rapid generation of new technology creates technology turbulence in the business environment in which the firms operate. Technology turbulence reduces the life cycle of the product as new products with new technology emerge at faster rate [21]. The firms should increase research and development activities and create advanced products from the new technologies to capture market and to retain competitive position by R&D subsidies policies [12]. To cope with challenges created by the technology turbulence, the firms must continuously strive to introduce new products at faster rate to sustain competitive advantage [16]. Adopting supplier product innovation by R&D subsidies policies strategy can reduce the development time of the product as the suppliers are more knowledgeable about their products which enable the manufacturer to release new products to sustain competitive advantage. By utilizing supplier product innovation by R&D subsidies policies strategy, manufacturers can invest more resources in developing the core competency while outsourcing the product innovation activities related to non-core competency. Following our review of literature we categorized the variables influencing supplier product innovation into the following categories (Table 1): environmental characteristics; supplier attributes; product characteristics; quality and management of relationship; and duration of partnership.

Table 1: Classification of characteristics for the supplier involvement in the new product development by R&D subsidies

| **Category** | **Variable Investigated in Prior Studies** |
|---|---|
| Firm Characteristics | • Willingness to accept external ideas |
| Nature of Enterprise Supplier Relationship | • Role of the supplier (Clark,1991 ) and enterprise<br>• Supplier's responsibility<br>• Frequency of communications (Wasti and Liker, 1999)<br>• Nature of relationship (what aspect?) Birou and Fawcett (1994)<br>• Newness of partnership - Gerwin and Ferrari (2004)<br>• Distribution skills - Gerwin and Ferrari (2004)<br>• Degree of differentiation (Sushman and Ray, 1999)<br>• Coordination (Gerwin, 2004)<br>• Timing for the involvement of suppliers (Wasti and Liker 1997) |
| Supplier Characteristics | • Uniqueness (Park *et al.* 2010)<br>• Technical expertise<br>• Innovativeness (Wagner and Hoegl, 2006)<br>• Component and architectural knowledge (Henderson,1990)<br>• Supplier support to competitors<br>• Downstream customer orientation( Wagner, 2010)<br>• Trust and reliability (Wagner and Hoegl, 2006)<br>• Supplier Innovation rate |
| Business Environment | • Technology Turbulence (Tushman *et al.* 1986)<br>• Number of suppliers (Swan *et al.* 2003) |
| Product Characteristics | • Integral product<br>• Modular design (Schrader and Göpfert, 1997)<br>• Number of modules<br>• Product Dynamism (Swan *et al.* 2003) |

Models that seek to answer the questions of why and what kinds of suppliers seek to perform joint research activities are grounded in several theoretical strands. The industrial organization literature emphasizes competitive motives for engaging in R&D subsidies among competitors (horizontal cooperation), concentrating on spillovers and appropriability issues. When anticipated, voluntary or involuntary transfers of know-how complicate R&D subsidies strategies in a non-trivial way. De Bondt provides an overview of the impact of spillovers on non-cooperative R&D subsidies levels. A similar focus on the effects of spillovers on R&D subsidies is omni-present in reviewing the literature on R&D subsidies. A first finding in these models is that investment in R&D when suppliers cooperate is increasing in the level of the spillover. A second finding across the various models is that when spillovers are high enough, i.e. above a critical level, R&D subsidies will result in higher R&D investment compared to non-cooperating suppliers. Cooperation allows the suppliers to overcome the disincentive effect from the positive externality that outgoing spillovers create on rival suppliers. This suggests that R&D subsidies are most beneficial for technological progress when technology is difficult to keep proprietary. Although spillovers will increase the stock of effective knowledge and hence have a market expansion or cost reduction effect, large spillovers typically have a disincentive effect on the supplier's levels of non-cooperative R&D subsidies.

This disincentive effect is demonstrated most clearly in strategic two-stage models where suppliers take into account that whenever knowledge leaks out to competing suppliers, this will have a negative impact on their own profitability, thus reducing the attractiveness of R&D subsidies. The nature of product market competition critically shapes this disincentive effect, with the critical spillover level depending on whether firms are producing substitutes or complements. When goods are substitutes the level of product differentiation and the number of rivals are important parameters that determine the critical spillover level [16]. Similarly, inter-industry cooperation is more likely to boost R&D subsidies as compared to intra-industry co-operation. Given the assumption of coordination through joint profit maximization, while ignoring any explicit costs to R&D subsidies, these models find that cooperation always increases the suppliers' profitability. Spillovers increase the profitability of R&D subsidies and once spillovers are sufficiently high, i.e. above the critical spillover level, higher spillovers make R&D subsidies increasingly more attractive as compared to independent R&D subsidies. On the other hand, higher spillover levels also increase the potential profits from cheating by a partner and from free-riding by an outsider to the cooperative agreement. Hence R&D subsidies become more profitable the more suppliers are able to restrict outgoing spillovers and selectively share information with cooperation partners. This result emphasizes a dual role of spillovers: outgoing spillovers may jeopardize the cooperative agreement and incoming spillovers increase the attractiveness of cooperation. Recent literature models take into account that suppliers can attempt to manage spillovers, trying to minimize outgoing spillovers while at the same time maximizing the incoming spillovers. Minimizing outgoing spillovers can be accomplished through the use of effective legal and strategic protection measures. Suppliers can maximize incoming spillovers by voluntarily increasing the spillovers among cooperating partners, as in the research joint venture scenario of Kamien *et al*. and Katsoulacos and Ulph. Such information sharing, which increases the incoming spillover for partners, is found to further increase the profitability of R&D subsidies. In addition, firms can increase the effectiveness of incoming spillovers by investing in "absorptive capacity".

Cohen and Levinthal argue that external knowledge is more effective for the product innovation process when the supplier engages in R&D subsidies. The direct effect of higher absorptive capacity is thus to increase the effectiveness of incoming information. Finally, the choice of research approach by the firm influences the appropriability conditions it faces and the extent of incoming spillovers it enjoys. Kamien and Zang show that firms that cooperatively choose their R&D subsidies, maximize information flows -their incoming spillovers through the choice of very broad research directions for the research joint venture. If the suppliers cannot coordinate their R&D subsidies, they are more concerned about managing their outgoing spillovers by choosing a more narrow research approach. The development of new products and improvement of existing products through R&D subsidies, are considered to be critical to the survival of a supply chain facing tough competition in globalization. Due to an increase in competition and rapid advancement of technology, product innovation and new product development through R&D subsidies are becoming the essential strategies for the management of the suppliers to survive in the world [15].

Product innovation through R&D subsidies is an effective tool that a supplier can utilize to maintain its competitive position in the market. The position of the supplier in the market can be influenced by the frequency of releasing new or improved products [16]. Product dynamism refers to the continuous change in the product which is characterized by speed and magnitude of technological change in the product. To cope up with competition and dynamic change in market demand many suppliers are adopting open innovation through R&D subsidies which involves collaboration with external entities, like customers, suppliers, universities, research organizations and competitors [23]. Many suppliers are switching towards open innovation models, from traditional closed innovation models, to increase their level of innovation through R&D subsidies and retain competitive position in the supply chain. Open innovation involves interaction of suppliers with several external entities such as customers and suppliers to generate new ideas to improve existing products and develop new products through R&D subsidies. Of all the different types of external sources of collaboration adopted for innovation of the product, suppliers' innovation through R&D subsidies has the most significant impact on the performance and success of the supply chain [14].

Supplier collaboration increases the technology knowledge available to a supply chain, which helps it reduce the product development through R&D subsidies time by identifying the potential problems beforehand [6]. Ragatz *et al.* [18] found that involvement of suppliers in product innovation process through R&D subsidies result in benefits such cost reduction, improved quality and sales increase. The successful development of supplier collaboration involves shared training, mutual trust and commitment, rewards and agreed performance measures [18]. Peterson *et al.* [15] argued that the integration of suppliers into new product development through R&D subsidies activities can reduce the risk involved with technology which is at its formative stage. Supplier's product innovation through R&D subsidies reduces potential problems during the early stages of development [29]. Although significant benefits can be achieved through the use of supplier collaboration, for a company seeking to leverage the product innovation through R&D subsidies of its supplier through collaboration, it is necessary that the correct attributes are considered in the design of supplier collaboration relationships. In their paper, these are supposed to be a quality in the product, it will be improved level by level and will be charged with quality adjust price.

The model is built upon their previous work on product development and featured product innovation through R&D subsidies and technology transfer. The probability for successful innovation or imitate is random but the aggregate (or average) rate is constant. The equilibrium is then characterized by constant aggregate rates of product innovation and imitation. Even this paper is regarded as the benchmark in this area. The objective of our research is to gain a better understanding of the factors that a supplier must consider for product innovation through R&D subsidies with sunk cost.

## 3 INDIAN SUPPLIERS' DATA

This survey gathers information from suppliers operating in India employing more than nine workers. It is conducted on a yearly basis across twenty different sectors. The initial sampling undertaken in conducting the survey differentiated suppliers according to their size. While all suppliers employing more than 200 employees were required to participate, suppliers with 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 suppliers with more than 200 employees together with a randomly selected sample of new suppliers with between 10 and 200 employees have been gradually incorporated.

Table 2: Composition of the panel

| | number of Indian suppliers |
|---|---|
| 2 | 415 |
| 3 | 460 |
| 4 | 450 |
| 5 | 240 |
| 6 | 275 |
| 7 | 120 |
| 8 | 160 |
| 9 | 180 |
| 10 | 210 |
| 11 | 110 |
| 12 | 180 |
| 13 | 200 |
| Number of suppliers | 3,000 |

Notes: this table shows the number of Indian suppliers that are observed for each spell length.

The survey keeps track of the suppliers' technological activity and reports information on several measures of R&D performance including intramural expenditure, R&D contracted with external laboratories or research entities and technological imports. For our purposes, a supplier is classified as an R&D performer whenever it reports having incurred expenditure in any of these categories excluding technological imports. In addition, the survey provides information on the R&D subsidies received by successful subsidy applicants. The subsidy variable we use considers the total quantity of aid granted by the various agencies. We can also identify rejected subsidy applicants from a question available in the since 2000 that asks suppliers whether they sought external financing without success. In this study, we refer to survey data obtained between 2002 and 2013 (both years inclusive). The cleaned panel data sample comprises 15,450 observations corresponding to 3,000 firms observed over a varying number of years (see Table 2), 5,126 R&D observations, 1,585 R&D funding applications and 1,151 successful applications. Approximately 2/3 of applications were accepted. Remarkably only 7% of the subsidies are granted to supplier that did not perform R&D in the previous period. This suggests that subsidies are mainly targeted at active R&D suppliers and very rarely used to encourage entry into R&D.

Table 3 shows the importance of having data on funding applications to study the subsidies inducement effects. While all successful applicants perform R&D, only 63% (55% of firms that continue plus 8% of entrants) of rejected applicants do so. Interestingly, 22% of rejected applicants fail to enter into R&D and 6% are forced to abandon R&D presumably due to the lack of financing. This group of rejected applicants would have performed R&D had it received subsidies. This suggests that subsidies do have some inducement effects. Notice that the group of non applicants is not good to study inducement effects because it does not allow distinguishing whether firms want to enter into R&D but fail to do so due to the lack of subsidies or simply are not interested in R&D.

Table 3: Successful applicants, rejected applicants and non applicants

| | | Number of suppliers | % |
|---|---|---|---|
| Successful applicants | | | |
| | Continue in R&D | 1,058 | 92 |
| | Enter into R&D | 81 | 8 |
| | Fail to enter into R&D | 0 | 0 |
| | Exit from R&D | 0 | 0 |
| | Total | 1,151 | 100 |
| Rejected applicants | | | |
| | Continue in R&D | 330 | 55 |
| | Enter into R&D | 54 | 8 |
| | Fail to enter into R&D | 132 | 22 |
| | Exit from R&D | 34 | 6 |
| | Total | 610 | 100 |
| Non applicants | | | |
| | Continue in R&D | 2,810 | 18 |
| | Enter into R&D | 590 | 3 |
| | Fail to/do not want to enter into R&D | 9,300 | 61 |
| | Exit from R&D | 620 | 4 |
| | Total | 15,450 | 100 |

Table 4 provides an initial insight of the extent to which firms engage in R&D activities as well as of the stylised facts governing the assignment of subsidies to R&D performers. A marked stylised fact is that the proportion of R&D performers increases greatly with size. Whereas, in most years, only around 21% of firms with fewer than 200 workers perform R&D, this percentage rises to 72% when we consider firms with more than 200 workers. Similarly, the proportion of subsidized firms among R&D performers increases with firm size. Whereas only 14% to 24% of R&D performers with fewer than 200 workers enjoy subsidies, 26% to 21% of R&D firms with more than 200 workers receive subsidies. As for the subsidy coverage (ratio of subsidy to R&D expenditure), this adopts a mean value of 35% for firms with fewer than 200 workers, falling to 26% in the case of firms with more than 200 workers. Hence, the proportion of subsidized R&D expenditure declines with firm size. Interestingly, there is a sharp increase in the percentage of subsidized R&D performers from 2004 onwards. However, the average number of R&D firms and the average subsidy coverage remain unaltered. This confirms that the Indian suppliers sought to increase R&D expenditures by focusing on the intensive margin (i.e., subsidizing active R&D firms).

Table 5 differentiates between stable and occasional R&D performers and provides more detail on the probability of a firm undertaking R&D and being granted a subsidy. It appears that stable R&D performance, understood as performing R&D during the whole sample period is mainly observed in large firms and that it is quite uncommon among small firms. By contrast, occasional performance is more evenly distributed among firms of different sizes, being most common among medium-sized firms. If we focus solely on R&D performers, the probability of being granted a subsidy increases markedly with firm size and stable performance.

Table 4: Percentage of R&D and subsidized suppliers by supplier size

| | Fewer than 200 workers | | | More than 200 workers | | |
|---|---|---|---|---|---|---|
| | Suppliers with R&D (%) | Subsidized R&D suppliers (%) | Average subsidy share (%) | Suppliers with R&D (%) | Subsidized R&D suppliers (%) | Average subsidy share (%) |
| 2002 | 21 | 14 | 24 | 72 | 26 | 21 |
| 2003 | 24 | 17 | 25 | 75 | 28 | 20 |
| 2004 | 22 | 16 | 33 | 76 | 28 | 26 |
| 2005 | 21 | 15 | 21 | 74 | 25 | 26 |
| 2006 | 18 | 16 | 36 | 74 | 23 | 24 |
| 2007 | 23 | 15 | 24 | 71 | 25 | 23 |
| 2008 | 21 | 17 | 30 | 70 | 25 | 26 |
| 2009 | 22 | 19 | 30 | 72 | 25 | 24 |
| 2010 | 21 | 18 | 31 | 71 | 32 | 26 |
| 2011 | 20 | 22 | 33 | 73 | 35 | 33 |
| 2012 | 21 | 21 | 34 | 72 | 33 | 28 |
| 2013 | 23 | 27 | 36 | 74 | 34 | 25 |

Notes: this table reports the percentage of R&D performers, the percentage of subsidized suppliers among R&D performers and average subsidies for subsidized suppliers in each year of the sample in a breakdown by size.

Table 5: R&D and subsidies by supplier size and frequency of R&D performance

| | Suppliers with R&D (%) | | Suppliers granted at least one year (%) | |
|---|---|---|---|---|
| | Stable performers | Occasional performers | Stable performers | Occasional performers |
| <20 workers | 4 | 12 | 35 | 23 |
| 21-50 | 11 | 21 | 36 | 22 |
| 51-100 | 26 | 28 | 42 | 26 |
| 101-200 | 36 | 26 | 42 | 35 |
| 201-500 | 55 | 29 | 55 | 29 |
| >500 | 72 | 21 | 59 | 44 |

## 4 THE MODEL

In this section we present a stylized analytical setting that illustrates how R&D subsidies modify suppliers' optimal R&D decisions (whether to perform R&D and how much to invest). We will then draw on this set up to build our empirical specification.

## 5 BUYERS DEMAND

We consider a product-differentiated market with monopolistic competition in which suppliers produce a single type of each variety of good. These varieties are symmetrically differentiated, with common elasticity of substitution $\sigma > 1$ between any two of them. The demand for buyer i's output, $q_{it}$, is generated by a representative buyer that spends a fixed amount of income $Y$ on the products of the supplier. The utility function is to accommodate the buyer's valuation:

$$U(\Lambda_{it}q_{it}) = \left(\sum_i (\Lambda_{it}q_{it})^{\frac{\sigma-1}{\sigma}}\right)^{\frac{\sigma}{\sigma-1}} \tag{1}$$

where $U(\bullet)$ is assumed to be differentiable and quasi-concave and $\Lambda_{it}$ represents the buyer's valuation of firm $i$ product. Utility maximization gives demands of the form:

$$q_{it}(p_{it},\Lambda_{it}) = z_t\, p_{it}^{-\sigma}\Lambda_{it}^{\sigma-1} \tag{2}$$

where $p_{it} = \bar{p}_{it}/\tilde{p}_{it}$ is the deflated price, $\bar{p}_{it}$ is the nominal price, $\tilde{p}_{it} = \left[\sum(\bar{p}_{it}/\Lambda_{it})^{(1-\sigma)}\right]^{1/1-\sigma}$ is a quality-adjusted price index (a price deflator) and

$z_{it} = Y_t / \widetilde{p}_{it}$ captures exogenous demand shifters. Suppliers are considered too small to influence the aggregate $p$ -index and so competitive interaction among suppliers can be ignored thereby keeping the analysis relatively straightforward. We assumed that the buyers' valuation of a given product depends on its quality, which can be improved through R&D expenditure. Consequently, the buyers' valuation is allowed to take the following functional form: $\Lambda_{it} = [s_{it}(x_{it-\tau})]^{\delta}$ in which $s_{it}$ stands for product quality, $x_{it-\tau}$ denotes R&D expenditure and $\delta$ is the elasticity of the buyers' valuation with respect to quality. R&D investments affect product quality according to the relation $s_{it}(x_{it-\tau}) = x_{it-\tau}^{\phi}$ where $\phi < 1$ is the elasticity of quality with respect to R&D. Notice that we are assuming that R&D does not immediately improve product quality but rather takes $\tau$ periods to become effective. Product quality is assumed to be constant at $s = 1$ if no R&D investments are made. Hence, buyer $i$ demand is $q_{it}(p_{it}, \Lambda_{it}) = z_{it} p_{it}^{-\sigma} x_{it-\tau}^{\phi\varepsilon}$ if it performs R&D and $q_{it}(p_{it}, \Lambda_{it}) = z_{it} p_{it}^{-\sigma}$ if it does not, where $\varepsilon = (\sigma - 1)\delta$ is the elasticity of demand with respect to product quality. Buyers' demand can also be expressed in a more compact way as follows:

$$q_{it}(p_{it}, \Lambda_{it}) = z_t p_{it}^{-\sigma}(1\{x_{it-\tau} = 0\} + 1\{x_{it-\tau} > 0\} x_{it-\tau})^{\phi\varepsilon}. \qquad (3)$$

## 6 SUPPLIERS' R&D SUBSIDIES WITHOUT SUNK COSTS

Before presenting the dynamic problem with sunk costs we first consider a simpler two-period setting that will serve to introduce many of the concepts we will use throughout. In this two-period setting supplier *i* might choose to invest in R&D at *t*. If it does, then it reaps the benefits at $t + \tau$ . Alternatively it might prefer not to invest in R&D. In such a case it gets standard non-R&D profits at $t + \tau$ . We assume that for subsidies spent on R&D each supplier can expect to get a rebate $\rho_{it}^{e} \in [0,1]$. Hence, $\rho_{it}^{e}$ is the expected share of subsidized R&D expenditure, something we shall later refer to as the subsidy coverage. Also, let $E_{it}$ be the expectations operator, parameter $\beta$ stand for the discount factor and $c_{it}$ represent marginal cost. Then, the expected gross operating profits of R&D performers suppliers are obtained by simultaneously choosing the price and the level of R&D expenditure that solve the following problem:

$$\max_{p_{it+\tau}, x_{it}} E_t[\pi_{it}(p_{it+\tau}, x_{it})] = \beta^{\tau} E_t[(p_{it+\tau} - c_{it+\tau}) z_{it+\tau} p_{it+\tau}^{-\sigma} x_{it}^{\phi\varepsilon}] - (1 - \rho_{it}^{e}) x_{it} - f_{it} \qquad (4)$$

The first order conditions lead to optimal price and R&D expenditure

$$p_{it+\tau}^{*}(c_{it+\tau}) = \frac{\sigma}{\sigma - 1} c_{it+\tau}$$

$$x_{it}^{*}(\rho_{it}^{e}, c_{it+\tau}, z_{it+\tau}) = \left[ \frac{\phi\varepsilon\beta^{\tau} E_t[A_{it+\tau}]}{(1 - \rho_{it}^{e})} \right]^{1/1-\phi\varepsilon} \qquad (5)$$

where $A_{it+\tau} = c_{it+\tau}^{1-\sigma}(\sigma - 1)^{\sigma-1}\sigma^{-\sigma} z_{it+\tau}$ . Plugging expressions (4) and (5) into the profit function gives raise to optimal current period profits, which turn out to be increasing in expected subsidies $\rho_{it}^{e}$ and demand conditions $z_{it+\tau}$ , and decreasing in marginal costs $c_{it+\tau}$ and fixed costs $f_{it}$ :

$$E_t[\pi_{it}^{R\&D}(\rho_{it}^{e}, c_{it+\tau} z_{it+\tau}, f_{it})] = (1 - \phi\varepsilon)\left( \frac{\phi\varepsilon}{(1 - \rho_{it}^{e})} \right)^{\phi\varepsilon/1-\phi\varepsilon} \qquad (6)$$

$$\left(\beta^{\tau} E_t[A_{it+\tau}]\right)^{1/1-\phi\varepsilon} - f_{it}$$

Proceeding analogously for the situation in which no R&D expenditures are incurred, it is immediate to obtain:

$$E_t[\pi_{it}^{NoR\&D}(c_{it+\tau}, z_{it+\tau})] = \beta^{\tau} E_t[A_{it+\tau}] \qquad (7)$$

The optimal participation rule is that the supplier is R&D active only if the profits generated by R&D are greater than the profits earned when not doing R&D. Because only equation (6) depends on subsidies, an optimal participation policy of this type can be characterized in terms of a threshold defined as the value of the subsidy for which the supplier remains indifferent between performing R&D or not, that is, for which $(6) = (7)$:

$$\widetilde{\rho}_{it}(c_{it+\tau}, z_{it+\tau}, f_{it}) = 1 - \phi\varepsilon\left( \frac{1 - \phi\varepsilon}{\beta^{\tau} E_t[A_{it+\tau}] + f_{it}} \right)^{1-\phi\varepsilon/\phi\varepsilon} \beta^{\tau} E_t[A_{it+\tau}] \qquad (8)$$

All suppliers with $\rho_{it}^{e} \geq \widetilde{\rho}_{it}$ will self-select into R&D activities. Note that while $\rho_{it}^{e}$ can only take values between 0 and 1 (as it is defined as the expected fraction of R&D expenditure covered by the subsidy), the threshold subsidy is fixed between minus infinity and one, $\widetilde{\rho}_{it} \in (-\infty, 1]$ , depending on the parameter values. Notice that the threshold subsidy is a negative function of $z_{it+\tau}$ , $\varepsilon$ and $\phi$ , while it is a positive function of $c_{it+\tau}$ , $f_{it}$ , $\sigma$ and $\tau$ . Hence, suppliers with favourable demand shifters, high elasticity of product quality with respect to R&D, high elasticity of demand with respect to product quality, low marginal costs, a low elasticity of demand with respect to price (large market power) and short lags between R&D

and profits should be less dependent on R&D subsidies. Zero or negative thresholds denote that suppliers find it profitable to perform R&D no matter what their expected subsidies. By contrast, positive thresholds denote suppliers that rely on sufficiently large expected subsidies to engage in R&D. Given our assumptions and our modeling of subsidies as a share of to-be-made R&D expenditures all suppliers can be induced into R&D with a sufficiently large $\rho_{it}^{e}$ . This is reasonable because even suppliers operating in very unfavourable conditions (with $\tilde{\rho}_{it} = 1$ ) will find it profitable to perform R&D if expenditures are subsidized ( $\rho_{it}^{e} = 1$ ). Since R&D expenditure increases monotonically in the expected subsidies (see equation (5)), for any subsidy threshold $\tilde{\rho}_{it}$ there will exist a unique R&D threshold $\tilde{x}_{it} = x_{it}^{*}\ (\tilde{\rho}_{it})$ . This implies that the optimal policy can be recast in terms of R&D expenditures. Plugging (8) into (5) we get the R&D threshold:

$$\tilde{x}_{it}(c_{it+\tau}, z_{it+\tau}, f_{it}) = \left( \frac{\beta^{\tau} E_t[A_{it+\tau}] + f_{it}}{1 - \phi\varepsilon} \right)^{1/\phi\varepsilon} \qquad (9)$$

The optimal decision is to perform R&D when $x_{it} \geq \tilde{x}_{it}$ . Notably, $\rho_{it}^{e}$ enters the optimal R&D equation (5) but not the R&D threshold (9). This will prove crucial for identification of the thresholds in the empirical exercise.

## 7 SUPPLIERS’ R&D SUBSIDIES WITH SUNK COSTS

Now, let us suppose that a sunk cost of $K_{it}$ units is to be incurred every time a supplier starts engaging in R&D activities. In such a case it is clearly more costly to enter into R&D than it is to persist in R&D. Sunk costs imply that it is easier for suppliers to stay “in” than it is to get “in”. This circumstance can favour cases in which suppliers find it optimal to persist in R&D activities even when profit levels are lower than those that could be obtained by abandoning product innovative activities, since, by doing so, suppliers avoid future re-entry costs. Thus, suppliers face a dynamic optimisation problem in which they must decide, in each period, whether to perform R&D activities or not on the grounds of their expectations over $\rho^{e}$ , $c$ , $z$ and $f$ . Therefore, the supplier will plan its participation in R&D activities in order to maximize its present discounted profits (since our interest lies on subsidies in what follows we abstract from $c$ , $z$ and $f$ and simplify notation by writing $\pi_{it}^{R\&D}(\rho_{it}^{e}) = E_t[\pi_{it}^{R\&D}(\rho_{it}^{e}, c_{it+\tau} z_{it+\tau}, f_{it})]$ and

$$\pi_{it}^{NoR\&D} = E_t[\pi_{it}^{NoR\&D}(c_{it+\tau}, z_{it+\tau})]$$

$$V_{it} = \max_{\{y_{it+s}\}_0^{\infty}} E_{it} \sum_{s=0}^{\infty} \beta^{s} \begin{bmatrix} y_{it+s} \begin{pmatrix} \pi_{it}^{R\&D}(\rho_{it+s}^{e}) - \\ (1 - y_{it+s-1}) K_{it} \end{pmatrix} + \\ (1 - y_{it+s}) \pi_{it}^{NoR\&D} \end{bmatrix} \qquad (10)$$

where $y_{it}$ is a binary variable with value one if the supplier performs R&D activities at period $t$ and value zero otherwise. It amounts to the same thing, and at the same time it is much simpler, to characterise the optimal participation policy by choosing the $y_t$ that satisfies the following equation corresponding to the above expression:

$$V_{it} = \max_{y_{it}} \begin{bmatrix} \mathrm{y}_{\mathrm{it}} \left( \pi_{it}^{R\&D}(\rho_{it}^{e}) - (1 - y_{it-1}) K_{it} \right) + \\ (1 - y_{it}) \pi_{it}^{NoR\&D} + \beta E_{it} \left( V_{it+1} \mid y_{it} \right) \end{bmatrix} \qquad (11)$$

The profit-maximizing supplier will calculate the value function for both $y_{it} = 1$ and $y_{it} = 0$ will choose the option yielding the highest value. In this kind of infinite horizon problem with entry costs it is well known that the optimal participation strategy can be characterised in terms of two threshold values defined as the realization of expected subsidies for which the supplier is indifferent to being active and inactive. This is due to the fact that the indifference condition depends on whether suppliers have previous experience in R&D activities. The indifference condition is given by:

$$\pi_{it}^{R\&D}(\tilde{\rho}_{it}) - \pi_{it}^{R\&D} + \beta \psi_{it+1}[\tilde{\rho}_{it}] = (1 - y_{it-1}) K_{it} \qquad (12)$$

Where $\psi_{it+1}[\tilde{\rho}_{it}] = [E_t(V_{it+1} \mid \tilde{\rho}_{it}, y_{it} = 1) - E_t(V_{it+1} \mid \tilde{\rho}_{it}, y_{it} = 0)]$ is the discounted expected value of the advantage that can be enjoyed at period $t+1$ by a supplier that is already R&D-performing at period $t$ . Note that while the thresholds are implicitly defined by equation (12), there is no analytical expression for them. Nevertheless, provided that certain conditions hold, the period $t$ optimal entry-exit strategy can be depicted as in Figure 1. We will refer to the threshold values as $\tilde{\rho}_{it}^{E}$ when $y_{it-1} = 0$ and $\tilde{\rho}_{it}^{C}$ when $y_{it-1} = 1$ with $\tilde{\rho}_{it}^{E} \geq \tilde{\rho}_{it}^{C}$ . The superscripts E and C have been chosen to reflect the fact that one threshold characterises “Entry” while the other characterizes “Continuation” of R&D. Accordingly, supplier’s optimal entry-exit strategy will be to perform R&D only if $\rho_{it} \geq \tilde{\rho}_{it}^{E}$ when $y_{it-1} = 0$ or if $\rho_{it} \geq \tilde{\rho}_{it}^{C}$ when $y_{it-1} = 1$.

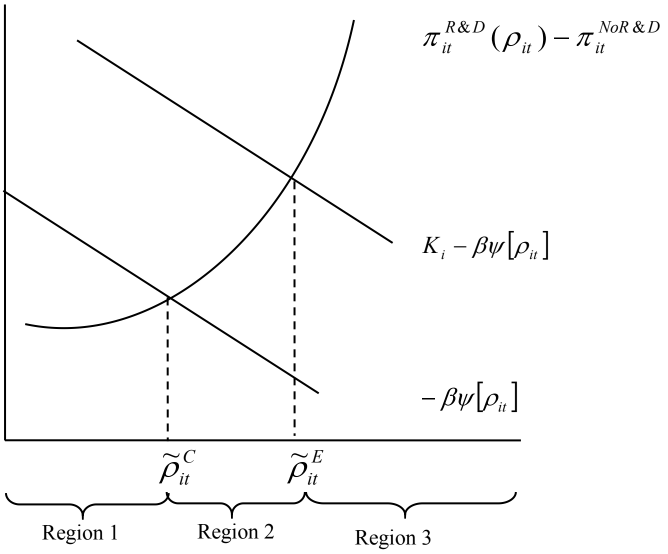

Figure 1: Representation of the indifference condition that defines the thresholds

Figure 1 provided that the following condition is satisfied $\partial\left(\pi^{R\&D}(\tilde{\rho}_{it}) - \pi^{NoR\&D} + \beta\psi_{it+1}[\tilde{\rho}_{it}]\right)/\partial\rho_{it} > 0$

The period $t$ optimal entry-exit strategy can be depicted as in Figure 1. This Figure 1 shows that the thresholds define three regions into which subsidies can be differentiated. Region 1 contains all those subsidies for which a supplier will not perform R&D regardless of its history. At the opposite end of the spectrum, region 3 contains all those subsidies for which the supplier will perform R&D regardless of its history. Finally, region 2 identifies all those values of a subsidy for which a supplier's previous status does matter. More specifically, a supplier expecting to receive a subsidy that falls between the boundaries defined by region 2 will only perform R&D if it was already performing R&D in the previous period. As shown in the two-period setting without sunk costs, suppliers' optimal policy can likewise be stated in terms of optimal R&D expenditure. Since R&D expenditure increases monotonically in the expected subsidies (see equation (5)), for any pair of subsidy thresholds $\tilde{\rho}_{it}^{E}$ and $\tilde{\rho}_{it}^{C}$ there will exist a unique pair of R&D thresholds $\tilde{x}_{it}^{E} = x^{*}(\tilde{\rho}_{it}^{E})$ and $\tilde{x}_{it}^{C} = x^{*}(\tilde{\rho}_{it}^{C})$. Thus, the optimal decision is to perform R&D when $x_{it}^{*} > \tilde{x}_{it}^{E}$ and $y_{it-1} = 0$ or when $x_{it}^{*} > \tilde{x}_{it}^{C}$ and $y_{it-1} = 1$, and to refrain from R&D otherwise.

## 8 ECONOMETRIC MODELLING

Econometrically, suppliers' optimal participation policy can be cast in terms of a type-2 tobit specification in which R&D expenditure $x_{it}^{*}$ is observed only when $x_{it}^{*} - \tilde{x}_{it}^{E} > 0$ for first-time R&D performers and when $x_{it}^{*} - \tilde{x}_{it}^{C} > 0$ for continuing R&D performers. Assuming that the logs of $x_{it}^{*}$ and $\tilde{x}_{it}^{E}$ or $\tilde{x}_{it}^{C}$ can be linearly approximated by a set of reduced form determinants, the tobit model is defined by the following equations:

$$\ln x_{it}^{*} = \gamma sub_{it} + w_{1it}\beta_1 + \alpha_{1i} + \varepsilon_{1it} \quad (13)$$

$$\ln \tilde{x}_{it} = -\eta y_{it-1} + w_{0it}\beta_0 + \alpha_{0i} + \varepsilon_{0it} \quad (14)$$

where $\tilde{x}_{it} = \tilde{x}_{it}^{E}$ when $y_{t-1} = 0$ and $\tilde{x}_{it} = \tilde{x}_{it}^{C}$ when $y_{t-1} = 1$. As for the optimal R&D equation (equation (13)), $sub_{it} = -\ln(1 - \rho_{it}^{e})$ , which implies that expected subsidies are expressed in the way they appear in equation (5). The remaining determinants of optimal R&D, namely the elasticities $\varepsilon$, $\phi$ and $\sigma$, the marginal costs $c$, and the demand shifters $z$ are unobservable and need to be approximated by a set of exogenous or predetermined variables $w_{1it}$ (this will be explained in section 5.1). Similarly, the thresholds are assumed to be a function of the same variables contained in $w_{1it}$ plus a number of other variables that account for fixed costs $f$ in a way that $w_{0it}$ contains at least all the variables that appear in $w_{1it}$. In addition, as suggested by the analytical framework, we suspect that the threshold might take two different values depending on a supplier's past R&D. For this reason, we allow it to be a function of $y_{it-1}$, a dummy variable that takes value one if the supplier performed R&D at $t-1$ and zero otherwise. In this way, the continuation threshold is lower than the entry threshold by $\eta$, a parameter to be estimated. We assume that the two thresholds differ only by the parameter η. By examining the significance and the magnitude of $\eta$ it is possible to conclude whether there are two thresholds rather than one and to measure the distance between them. Finally, both the optimal R&D and the threshold equations include time-invariant individual effects, $\alpha_{1i}$ and $\alpha_{0i}$, and idiosyncratic error terms, $\varepsilon_{1it}$ and $\varepsilon_{0it}$.

## 9 THRESHOLDS WITH A DYNAMIC PANEL DATA TYPE-2 TOBIT MODEL

Clearly, the thresholds are not observable in practice, which implies that the parameters of equation (14) cannot be estimated directly. Fortunately, we can observe a supplier's decision to perform R&D, which contains information about the relationship between optimal and threshold R&D. Specifically, R&D performance takes place when $x_{it}^{*}-\tilde{x}_{it}^{E}>0$ for new R&D performers and when $x_{it}^{*}-\tilde{x}_{it}^{C}>0$ for ongoing R&D performers. More formally, this can be expressed in the classical type-2 tobit formulation with the following selection and level equations:

$$y_{it}=1[\eta y_{it-1}+\gamma sub_{it}+w_{0it}\beta_2+\alpha_{2i}+\varepsilon_{2it}>0] \quad (15)$$

$$y_{1it}=\begin{cases}\ln x_{it}^{*} & if\ y_{it}=1\\ 0 & if\ y_{it}=0\end{cases} \quad (16)$$

where $\beta_2=\beta_1-\beta_0$, $\alpha_{2i}=\alpha_{1i}-\alpha_{0i}$, $\varepsilon_{2it}=\varepsilon_{1it}-\varepsilon_{0it}$ and $x_{it}^{*}$ is given by equation (13). Under certain conditions, in a maximum likelihood estimation framework, the parameters of the threshold equation ($\eta$ and $\beta_0$) can be recovered through the relationship between the parameters of the selection and the level equations. In our case the absence on theoretical grounds of the subsidy variable in the threshold equation, is a sufficient condition for the identification of all parameters of the model.

## 10 THE RELATIONSHIP BETWEEN TRUE STATE DEPENDENCE AND THE THRESHOLDS

The main feature of selection equation (15) is that it includes the lag of the dependent variable among the set of regressors. Algebraically, this is a very obvious derivation of the fact that the threshold equation includes dynamics. Conceptually, however, the mechanism by which the existence of the two thresholds results in a dynamic selection equation is very interesting and merits careful consideration. Dynamic selection equations enable us to identify whether R&D performance exhibits persistence, and whether this persistence is attributable to true state dependence as opposed to spurious state dependence. True state dependence implies that a causal behavioural effect exists in the sense that the decision to undertake R&D in one period enhances the probability of R&D being undertaken in the subsequent period. In the presence of sunk costs two thresholds must exist if true state dependence is prevalent. To understand why, note that for any optimal R&D that lies between the entry and the continuation threshold, $\tilde{x}_{it}^{C}<x_{it}^{*}<\tilde{x}_{it}^{E}$, present R&D performance occurs thanks to the past performance of R&D. The wider the gap between the two thresholds, i.e. the higher the sunk costs, the higher is the chance of having true state dependence.

Figure 2 illustrates the relationship between the thresholds and true state dependence. It considers two optimal R&D paths that take different values in the initial period but are identical thereafter. The deviation in the initial period is not trivial, though, and leads to different R&D decisions: path 1 entails

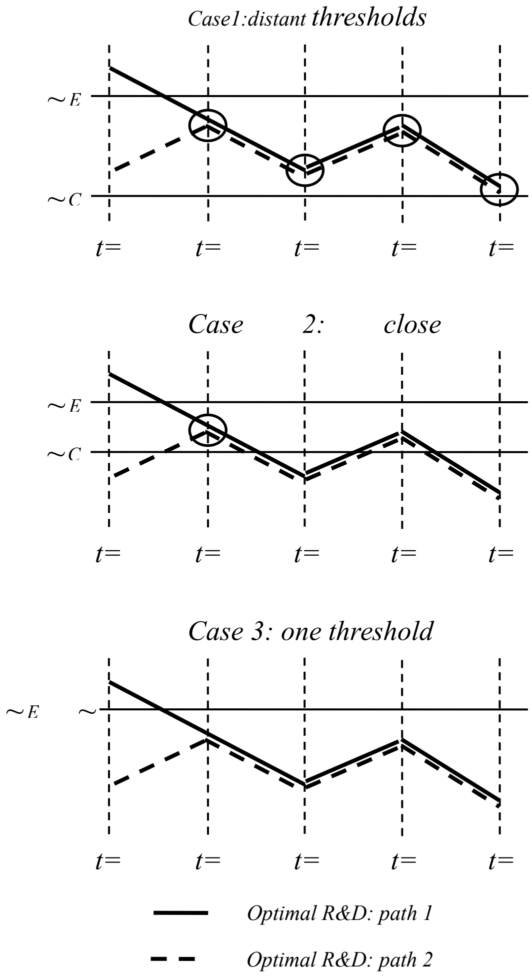

Figure 2: Relationship between the thresholds and true state dependence

Note: the circles identify the periods in which, under path 1, firms perform R&D because they were already performing R&D in the previous period.

R&D performance at *t=0* while path 2 does not. This initial departure allows us to evaluate, for periods *t=1* to *t=4*, the relevance of previous experience in explaining present R&D performance. This evaluation is conducted for three different scenarios that consider varying distances between the thresholds reflecting the magnitude of R&D sunk costs. As the continuation threshold gradually approaches that of entry and the gap between the thresholds shrinks, the importance of past experience in accounting for present R&D performance decreases and true state dependence vanishes. For instance, in case 1 where the distance between the thresholds is substantial, experience is found to have considerable impact: path 1 leads to R&D performance from *t=1* onwards while path 2 never results in R&D performance. The effect of previous experience declines in case 2, where the distance between the thresholds is smaller. Here, previous experience only explains R&D performance at *t=1*. Finally, when there is a single threshold, as in case 3, previous experience is irrelevant for explaining R&D performance. In the estimation framework of equation (15), case 1 should lead to significant and sizeable estimates of $\eta$ while case 2 should lead to significant but modest estimates and case 3 to values insignificantly different from zero.

## 11 MAXIMUM LIKELIHOOD ESTIMATION

The estimation of dynamic panel data sample selection models poses two main problems: the treatment of unobserved individual effects and the so-called problem of the initial conditions. The modeling of the former through fixed effects leads to the “incidental parameters” problem, which results in inconsistent maximum likelihood estimators when the number of periods is small. The latter arises because of the fact that, for variables generated by stochastic dynamic processes, the first observation (that which initialises the process) is correlated both with future realizations of the variable (due to state dependence) and with the unobservable individual term (given that the unobservable term is part of the process that generates the variable). Consequently, unless the first observation in the process (i.e., the initial condition) is accounted for, the lagged dependent variable will be correlated with the unobservable term and the estimates will be inconsistent. Wooldridge's (2005) provides simple, satisfactory solutions to both of these problems: in light of the shortcomings of the fixed effects approach, they assume the individual effects $\alpha_{1i}$ and $\alpha_{2i}$ to follow a joint distribution and opt for a random effects approach. Moreover, we adopt solution to the initial conditions problem, which involves modeling the individual term as a linear function in the explanatory variables and the initial conditions

$$\alpha_{1i} = \alpha_1^0 + \alpha_1^1 y_{i0} + \overline{w}_{1i}\alpha_1^2 + a_{1i} \qquad (17)$$

$$\alpha_{2i} = \alpha_2^0 + \alpha_2^1 y_{i0} + \overline{w}_{0i}\alpha_2^2 + a_{2i} \qquad (18)$$

where $\alpha_1^0$ and $\alpha_2^0$ are constants, $\overline{w}_{1i}$ and $\overline{w}_{0i}$ are the within-means of the explanatory variables and $y_{i0}$ is the initial condition, which takes a value of one if the supplier performs R&D in the first year of the sample used for conducting the estimates and 0 otherwise. The vectors $(\varepsilon_{1it}, \varepsilon_{2it})'$ and $(a_{1i}, a_{2i})'$ are assumed to be independently and identically (over time and across individuals) normally distributed with means zero and covariance matrices:

$$\Omega_{\varepsilon 1\varepsilon 2} = \begin{pmatrix} \sigma_{\varepsilon 1}^2 & \rho_{\varepsilon 1\varepsilon 2}\sigma_{\varepsilon 1}\sigma_{\varepsilon 2} \\ \rho_{\varepsilon 1\varepsilon 2}\sigma_{\varepsilon 1}\sigma_{\varepsilon 2} & \sigma_{\varepsilon 2}^2 \end{pmatrix} \quad \text{and}$$

$$\Omega_{a1a2} = \begin{pmatrix} \sigma_{a1}^2 & \rho_{a1a2}\sigma_{a1}\sigma_{a2} \\ \rho_{a1a2}\sigma_{a1}\sigma_{a2} & \sigma_{a2}^2 \end{pmatrix}$$

With the above assumptions, the likelihood function of one individual, starting from *t=1* and conditional on the means of the regressors and the initial conditions, is written as

$$L_i = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty}\prod_{t=1}^{T} L_{it}(y_{1it} \mid y_{i0}, y_{it-1}, \overline{w}_i, a_{1i}, a_{2i})\, g(a_{1i}, a_{2i})\, da_{1i}\, da_{2i} \qquad (19)$$

where $\prod_{t=1}^{T} L_{it}(y_{1it} \mid y_{i0}, y_{it-1}, \overline{w}_{it}, a_{1i}, a_{2i})$ denotes the likelihood function once the individual effects have been integrated out and can be treated as fixed, and $g(a_{1i}, a_{2i})$ stands for the bivariate normal density function of $(a_{1i}, a_{2i})'$. The double integral in equation (19) will be approximated by a "two-step" Gauss-Hermite quadrature Wooldridge's (2005) for a derivation of the "two-step" Gauss-Hermite quadrature expression). Next, treating the individual effects as fixed and using the standard properties of the bivariate normal distribution, the partial conditional likelihood function for firm *i* at period *t* can be written as follows

$$L_{it} = \Phi[-(\delta_0 sub_{it} + A_{it} + \widetilde{a}_{2i})]^{(1-y_{it})} \times \left[\frac{1}{\sigma_{\varepsilon 1}}\phi\left(\frac{y_{1it} - \gamma sub_{it} - B_{it} - a_{1i}}{\sigma_{\varepsilon 1}}\right) \times \Phi\left(\frac{\delta_0 sub_{it} + A_{it} + \widetilde{a}_{2i} + \rho_{\varepsilon 1\varepsilon 2}(y_{1it} - \gamma sub_{it} - B_{it} - a_{1i})/\sigma_{\varepsilon 1}}{\sqrt{1-\rho_{\varepsilon 1\varepsilon 2}^2}}\right)\right]^{y_{it}} \qquad (20)$$

where

$$\delta_0 = \frac{\gamma}{\sigma_{\varepsilon 2}} \qquad (21)$$

$$A_{it} = [\eta y_{it-1} + w_{0it}\beta_2 + \alpha_2^0 + \alpha_2^1 y_{i0} + \overline{w}_i\alpha_2^2]/\sigma_{\varepsilon 2} \qquad (22)$$

$$\widetilde{a}_{2i} = \frac{a_{2i}}{\sigma_{\varepsilon 2}} \qquad (23)$$

$$B_{it} = w_{1it}\beta_1 + \alpha_1^0 + \alpha_1^1 y_{i0} + \overline{w}_{1i}\alpha_1^2 \qquad (24)$$

The presence of γ in both the optimal R&D equation [equation (13)] and the selection equation [equation (15)] together with the exclusion of the subsidy coverage from the threshold equation [equation (14)], allows us to identify the standard error of $\varepsilon_{2it}$ : $\sigma_{\varepsilon 2} = \gamma / \delta_0$ . Knowing $\sigma_{\varepsilon 2}$ , it is possible to recover all the parameters of the threshold equation via (22). So correct identification of the parameters of the threshold equation critically depends on parameters $\delta_0$ and $\gamma$ . We will in turn discuss how to correctly identify these two parameters.

## 12 IDENTIFICATION OF $\gamma$ & $\delta_0$ .

Agencies may be encouraged to support research projects with the best technical merits and the highest potential for commercial success. As these projects typically have high private returns they are likely to be undertaken even in the absence of the support. In other words, R&D subsidies are granted by agencies according to the contemporary effort and performance of suppliers, and hence are presumably endogenous. This implies that the compound error terms of the levels and the selection equations $a_{1i} + \varepsilon_{1it}$ and $a_{2i} + \varepsilon_{2it}$ are likely to be positively correlated with $\rho_{it}^e$ which would lead to upward biased estimates of $\gamma$ and $\delta_0$ . To solve this problem we assume that suppliers react to R&D subsidies. The expected R&D subsidies coverage as follows:

$$\rho_{it}^e = E(\rho_{it} \mid z_{it}^\rho) = P(\rho_{it} > 0 \mid z_{it}^\rho)E(\rho_{it} \mid z_{it}^\rho, \rho_{it} > 0) \qquad (25)$$

where $P(\rho_{it} > 0 \mid z_{it}^\rho)$ is the probability of receiving a subsidy (joint probability of applying for a subsidy and receiving the subsidy) and $E(\rho_{it} \mid z_{it}^{p}, \rho_{it} > 0)$ is the expected value of the subsidy for successful applicants. The expected R&D subsidies coverage will not be positive for all suppliers but just for R&D subsidies applicants. This will give more within variation to the expected R&D subsidies shares and will enable us to control for fixed effects via the inclusion of means which will ultimately result in a better identification of of $\gamma$ and $\delta_0$ . We calculate the expected R&D subsidies coverage as follows:

$$\rho_{it}^{e} = \begin{cases} P(\rho_{it} > 0 \mid z_{it}^{\rho}, ap_{it} = 1) E(\rho_{it} \mid z_{it}^{\rho}, \rho_{it} > 0) & \text{if } ap_{it} = 1 \\ 0 & \text{if } ap_{it} = 0 \end{cases} \qquad (26)$$

where $ap_{it}$ is a dummy with value one if supplier *i* applies for a subsidy in year *t*, $P(\rho_{it} > 0 \mid z_{it}^{\rho}, ap_{it} = 1)$ is now the probability of receiving a subsidy among applicants and $E(\rho_{it} \mid z_{it}^{p}, \rho_{it} > 0)$ is the expected value of the subsidy for successful applicants. We estimate $P(\rho_{it} > 0 \mid z_{it}^{\rho}, ap_{it} = 1)$ by means of a probit of parameters $\lambda_1$ and assume $\ln(\rho_{it} \mid z_{it}^{\rho}, \rho_{it} > 0) \sim N(z_{it}^{\rho}\lambda, \sigma^2)$ to estimate $E(\rho_{it} \mid z_{it}^{p}, \rho_{it} > 0)$ by means of a regression of parameters $\lambda_2$ . The parameters $\hat{\lambda}_1$ and $\hat{\lambda}_2$ are used to construct $\hat{\rho}_{it}^{e}$ . We also calculate two alternative measures of the expected subsidy coverage for comparison purposes. The first one ( $\hat{\rho}_{it}^{e}\_1$ ) is calculated via expression (26). The second one ( $\hat{\rho}_{it}^{e}\_2$ ) is calculated via expression (25). In the main regressions we will always use $\hat{\rho}_{it}^{e}$ , but we will show that our results do not change if we use f $\hat{\rho}_{it}^{e}\_1$ . We will also show that $\hat{\rho}_{it}^{e}\_2$ is not resistant to the inclusion of means. All the details of the calculation of $\hat{\rho}_{it}^{e}$ , $\hat{\rho}_{it}^{e}\_1$ and $\hat{\rho}_{it}^{e}\_2$ are provided . Columns (1) and (2) of Table 6 report estimates of the parameter vectors $\lambda_1$ and $\lambda_2$ . The dependent variable of the probit regression is a dummy with value one for successful subsidy applicants and value zero for rejected applicants (successful applicant dummy). The dependent variable of the regression is the natural logarithm of the R&D subsidies share for successful applicants. Regarding the explanatory variables, the lagged endogenous variables of the probit and the equations are included to capture persistence in the probability of getting R&D subsidies and in the R&D subsidies coverage. There are some cases in which suppliers that received a R&D subsidies at time t did not receive a R&D subsidies at t-1. For this reason we complement the log of the R&D subsidies in the equation with a dummy variable with a value of one if the supplier did not receive a R&D subsidies at t-1. Apart from the variables that seek to account for dynamics we consider some additional regressors. We include a lagged R&D dummy both in the probit and the regressions to reflect the fact that regular R&D suppliers are more likely to get R&D subsidies while R&D entrants are likely to be awarded larger R&D subsidies shares. We also include the initial value of the lagged dependent variables, the R&D dummy and the "no subsidy dummy" to capture suppliers' unobservable heterogeneity. We also include the standard explanatory variables. These are mainly features that may be seen as critical when making their decisions: supplier size, age, degree of technological sophistication, a dummy indicating whether the supplier is a domestic exporter. Some of these explanatory variables are considered predetermined and are thus included with a lag, while others are assumed to be strictly exogenous. The definitions and descriptive statistics of the variables used in the regressions are reported in Table 6. The results are reported in Table 7. Regarding the probit regressions, the probability of receiving R&D subsidies is higher for applicants who received R&D subsidies in the past, have experience in R&D, and are large and technologically sophisticated. As for the regressions, present coverage depends on the past coverage and agencies appear to be more inclined to award larger R&D subsidies to entrants into R&D, to small suppliers and to suppliers with market power. All the parameters of the initial conditions are significant. The goodness of fit is acceptable (the pseudo R-squared is 0.33 and the adjusted R-squared 0.19). Using the estimated $\hat{\lambda}_1$ and $\hat{\lambda}_2$ we calculate the expected subsidy coverage $\hat{\rho}_{it}^{e}$ as follows:

$$\hat{\rho}_{it}^{e} = \begin{cases} \Phi(z_{it}^{\rho}\hat{\lambda}_1)\exp(z_{it}^{\rho}\hat{\lambda}_2 + (1/2)\hat{\sigma}^2) & \text{if } ap_{it} = 1 \\ 0 & \text{if } ap_{it} = 0 \end{cases} \qquad (27)$$

The estimated expected R&D subsidies adopt reasonable values. The average probability of receiving a R&D subsidies among applicants is 66%, the average expected R&D subsidies coverage conditional on its being granted is 45%, and the average expected R&D subsidies is 9%. Only a small proportion of the expected conditional subsidy coverage take values higher than 100%. There are five observations for which the predicted unconditional expected R&D subsidies coverage takes a value higher than 100%. For these five observations we replaced the predicted value by 99% to calculate $-\ln(1-\hat{\rho}_{it}^{e})$ . In columns (3) and (5) we estimate parameter vectors $\lambda_3$ and $\lambda_5$ omitting the lagged R&D dummy and the initial conditions. We calculate $\hat{\rho}_{it}^{e}\_1$ as follows:

$$\hat{\rho}_{it}^{e}\_1=\begin{cases}\Phi(z_{it}^{\rho}\hat{\lambda}_3)\exp(z_{it}^{\rho}\hat{\lambda}_5+(1/2)\hat{\sigma}^2) & if\ ap_{it}=1\\ 0 & if\ ap_{it}=0\end{cases} \tag{28}$$

In column (4) we obtain the parameter vector $\lambda_4$ estimating the probit for the whole sample (not just for R&D subsidies applicants). We calculate $\hat{\rho}_{it}^{e}\_2$:

$$\hat{\rho}_{it}^{e}\_2=\Phi(z_{it}^{\rho}\hat{\lambda}_4)\exp(z_{it}^{\rho}\hat{\lambda}_5+(1/2)\hat{\sigma}^2) \tag{29}$$

With the estimated expected subsidy coverage $\hat{\rho}_{it}^{e}$ we can get consistent estimates of $\gamma$ and $\delta_0$ under the following assumptions:

$$E[\hat{\rho}_{it}^{e}\ \varepsilon_{1it}\mid w_{1it}]=0$$

$$E[\hat{\rho}_{it}^{e}\ a_{1i}\mid \overline{\rho}_{i}^{e},w_{1it},y_{i0}]=0$$

$$E[\hat{\rho}_{it}^{e}\ \varepsilon_{2it}\mid ap_{it},w_{0it}]=0$$

$$E[\hat{\rho}_{it}^{e}\ a_{2i}\mid \overline{\rho}_{i}^{e},w_{0it},y_{i0}]=0$$

where $\overline{\rho}_{i}^{e}$ is the mean of $\hat{\rho}_{it}^{e}$ and embodies all the elements of the individual error terms $a_{1i}$ and $a_{2i}$ that are correlated with $\hat{\rho}_{it}^{e}$.

Table 6: Descriptive statistics of variables included in the subsidy regressions

| | | standard deviation | | | | |
|---|---|---|---|---|---|---|
| | mean | overall | between | within | min | max |
| Dependent variables | | | | | | |
| Subsidy dummy | 0.08 | 0.26 | 0.24 | 0.16 | 0 | 1 |
| Subsidy coverage | 0.02 | 0.10 | 0.09 | 0.07 | 0 | 1 |
| ln(Subsidy coverage) | -0.14 | 0.57 | 0.48 | 0.37 | -5.79 | 0 |
| Explanatory variables | | | | | | |
| Subsidy dummy $_{t-1}$ | 0.07 | 0.26 | 0.24 | 0.16 | 0 | 1 |
| Subsidy dummy | 0.08 | 0.27 | 0.28 | 0 | 0 | 1 |
| ln(Subsidy coverage) $_{t-1}$ | -0.14 | 0.57 | 0.51 | 0.37 | -5.79 | 0 |
| ln(Subsidy coverage) | -0.14 | 0.57 | 0.59 | 0 | -5.79 | 0 |
| No subsidy dummy $_{t-1}$ | 0.93 | 0.26 | 0.24 | 0.16 | 0 | 1 |
| No subsidy dummy | 0.92 | 0.27 | 0.28 | 0 | 0 | 1 |
| R&D dummy $_{t-1}$ | 0.32 | 0.47 | 0.43 | 0.22 | 0 | 1 |
| R&D dummy | 0.33 | 0.47 | 0.47 | 0 | 0 | 1 |
| Size $_{t-1}$ | 162 | 315 | 352 | 66 | 2 | 6,648 |
| Age | 25 | 19 | 19 | 6 | 1 | 169 |
| Technological sophistication | 0.07 | 0.12 | 0.12 | 0.06 | 0 | 1 |
| Domestic exporter dummy $_{t-1}$ | 0.47 | 0.50 | 0.47 | 0.21 | 0 | 1 |
| Foreign capital dummy | 0.18 | 0.38 | 0.37 | 0.12 | 0 | 1 |
| Market power dummy $_{t-1}$ | 0.31 | 0.46 | 0.41 | 0.24 | 0 | 1 |

The variable ln(Subsidy coverage)$_{t-1}$ is the natural logarithm of subsidy shares for subsidy shares greater than zero and zero for subsidy shares equal to zero.

Descriptive statistics for the actual R&D subsidy coverage and the three measures of expected R&D subsidies coverage are reported in Table 6.

**Levels equation** – The dependent variable used in the levels equation is the natural logarithm of R&D expenditure. The explanatory variable of interest is $-\ln(1-\hat{\rho}_{it}^{e})$ . The main control is the mean of $-\ln(1-\hat{\rho}_{it}^{e})$ . The remaining explanatory variables are derived from equation (5). Some of these are lagged by one period to ensure that they are predetermined. Average variable costs (lagged by one period) are used as a proxy for future marginal costs ( $c_{it+\tau}$ ). Future demand shifters ( $z_{it+\tau}$ ) are captured by two dummy variables (both lagged by one period) that report whether the main market of the supplier is in recession or expansion. The elasticity of demand with respect to product quality ( $\varepsilon$ ) and of product quality with respect to R&D ( $\phi$ ) are approximated by the advertising/sales ratio (lagged) and the average patents. Finally, a supplier's market share and a dummy variable representing concentrated markets (both lagged by one period) are used as indicators of the elasticity of demand with respect to price ( $\sigma$ ).

**Selection equation** –The dependent variable of the selection equation is a dummy indicating whether or not the supplier performed R&D at period t. The explanatory variables in the selection equation are a combination of the variables in the levels and the threshold equations (see equation (15)). Thus, apart from the variables included in the optimal R&D equation the selection equation also contains some extra variables specific to the threshold equation. These variables are the lagged dependent variable $(y_{it-1})$ and a set of variables aimed at capturing fixed costs ( $f_{it}$ ): quality controls. We also control for the subsidy applicant dummy $(ap_{it})$ . It is reasonable to assume that larger suppliers will make larger R&D investments. For this reason, in addition to all the variables listed above, we include a set of size dummies and the total sales (in logarithms) of the suppliers in both equations. Sales are assumed to be predetermined given that are only affected by year $t-\tau$ R&D expenditures. Moreover, we also include year and supplier dummies to account for variations in the business cycle and any sector-specific characteristics. Means of the explanatory variables (other than $-\ln(1-\hat{\rho}_{it}^{e})$ ) will not be included in the regressions. Descriptive statistics and definitions of all the explanatory variables are reported in Tables 8, 9 and 10.

Table 7: Subsidy regressions used to calculate expected subsidy coverage

| Sample used in the regressions: | Subsidy applicants | Subsidized suppliers | Subsidy applicants | All suppliers | Subsidized suppliers |
|---|---|---|---|---|---|
| Dependent variable: | Successful applicant dummy | ln(Subsidy coverage) | Successful applicant dummy | Subsidy dummy | ln(Subsidy coverage) |
| Parameters estimated: | $\lambda_1$ | $\lambda_2$ | $\lambda_3$ | $\lambda_4$ | $\lambda_5$ |
| | (1) | (2) | (3) | (4) | (5) |
| Subsidy dummy $_{t-1}$ | 1.08 (0.11)$^{***}$ | | 1.57 (0.11)$^{***}$ | 2.00 (0.06)$^{***}$ | |
| Subsidy dummy | 1.31 (0.16)$^{***}$ | | | | |
| ln(subsidy coverage) $_{t-1}$ | | 0.24 (0.04)$^{***}$ | | | 0.45 (0.04)$^{***}$ |
| ln(subsidy coverage) | | 0.55 (0.04)$^{***}$ | | | |
| No subsidy dummy $_{t-1}$ | | -0.56 (0.10)$^{***}$ | | | -0.83 (0.09)$^{***}$ |
| No subsidy dummy | | -0.85 (0.11)$^{***}$ | | | |
| R&D dummy $_{t-1}$ | 0.30 (0.15)$^{**}$ | -0.42 (0.13)$^{***}$ | | | |
| R&D dummy | 0.06 (0.15) | -0.29 (0.12)$^{**}$ | | | |
| Size $_{t-1}$ | 0.00 (0.00)$^{*}$ | -0.00 (0.00)$^{**}$ | 0.00 (0.00)$^{**}$ | 0.00 (0.00)$^{***}$ | -0.00 (0.00)$^{**}$ |
| Age | 0.00 (0.00) | -0.00 (0.00) | 0.00 (0.00)$^{*}$ | 0.00 (0.00)$^{**}$ | -0.01 (0.00)$^{***}$ |
| Tech. sophistication | 0.87 (0.38)$^{**}$ | 0.16 (0.16) | 1.18 (0.39)$^{***}$ | 1.10 (0.15)$^{***}$ | -0.10 (0.18) |
| Domestic exporter $_{t-1}$ | 0.22 (0.14) | -0.11 (0.09) | 0.28 (0.13)$^{**}$ | 0.42 (0.05)$^{***}$ | -0.10 (0.10) |
| Foreign capital dummy | 0.10 (0.17) | -0.13 (0.09) | 0.10 (0.16) | 0.22 (0.07)$^{***}$ | -0.26 (0.10)$^{**}$ |
| Market power dummy $_{t-1}$ | 0.02 (0.11) | 0.12 (0.06)$^{**}$ | 0.04 (0.10) | 0.17 (0.05)$^{***}$ | -0.03 (0.06) |
| Constant | -0.21 (0.45) | 0.06 (0.24) | 0.11 (0.45) | -2.93 (0.20)$^{***}$ | -0.93 (0.23)$^{***}$ |
| Estimation method | Probit | OLS | Probit | Probit | OLS |
| # of observations | 1,585 | 1,082 | 1,585 | 14,278 | 1,082 |
| # of suppliers | 633 | 545 | 633 | 3,000 | 545 |
| R2 | | 0.39 | | | 0.26 |
| Pseudo R2 | 0.44 | | 0.36 | 0.45 | |

Notes: ***, ** and * indicate significance at a 1%, 2% and 3% level respectively. Clustered-robust standard errors shown in parenthesis. The dependent variable in columns (1) and (3) is a dummy variable with value one for successful applicants and value zero for rejected applicants. The dependent variable in column (4) is a dummy variable with value one for successful applicants and value zero for the remaining suppliers in the sample (rejected applicants and non-applicants). The dependent variable in columns (2) and (5) is the natural logarithm of the subsidy coverage.

Table 8: Descriptive statistics of the actual R&D subsidy coverage and the different measures of expected subsidy coverage

| | standard deviation | | | | |
|---|---|---|---|---|---|
| mean | overall | between | within | min | max |
| All suppliers in the sample | | | | | |
| 0.02 | 0.11 | 0.11 | 0.09 | 0 | 0.97 |
| 0.02 | 0.11 | 0.11 | 0.08 | 0 | 0.96 |
| 0.02 | 0.11 | 0.11 | 0.09 | 0 | 0.94 |
| 0.02 | 0.09 | 0.08 | 0.07 | 0 | 0.88 |
| All applicants | | | | | |
| 0.20 | 0.22 | 0.26 | 0.17 | 0.02 | 0.97 |
| 0.20 | 0.19 | 0.16 | 0.08 | 0.02 | 0.96 |
| 0.20 | 0.18 | 0.17 | 0.11 | 0.04 | 0.95 |
| 0.20 | 0.17 | 0.14 | 0.12 | 0.02 | 0.92 |
| Successful applicants | | | | | |
| 0.22 | 0.28 | 0.26 | 0.18 | 0.03 | 0.97 |
| 0.22 | 0.24 | 0.22 | 0.11 | 0.02 | 0.98 |
| 0.22 | 0.21 | 0.18 | 0.13 | 0.02 | 0.96 |
| 0.22 | 0.22 | 0.17 | 0.14 | 0.03 | 0.98 |

Table 9: Variable definition

Dependent variables

*R&D expenditures:* cost of intramural R&D activities and R&D contracted with external laboratories.
*R&D dummy:* dummy that takes the value one if R&D expenditure is positive.

Explanatory variables of interest

*Expected subsidy coverage ():* computed via expression (3). Product of the predicted probability of receiving a subsidy (estimated from subsidy applicants) and the expected value of the subsidy (estimated from successful subsidy applicants) for subsidy applicants, zero for non applicants.
*Expected subsidy coverage 1 ():* computed via expression (3). Product of the predicted probability of receiving a subsidy (estimated from subsidy applicants) and the expected value of the subsidy (estimated from successful subsidy applicants) for subsidy applicants, zero for non applicants.
*Expected subsidy coverage 2 ():* computed via expression (2) as the product of the predicted probability of receiving a subsidy (estimated from all suppliers in the sample) and the expected value of the subsidy (estimated from successful subsidy applicants).

Controls

*Advertising/sales ratio:* advertising expenditure over sales.
*Average patents:* yearly average number of patents registered by the suppliers (excluding the patents registered by the supplier).
*Average variable costs:* total variable costs divided by nominal output (sales) so they really measure costs per unit revenue. Total variable costs are constructed as the sum of labour costs, intermediate input costs and subcontracted production costs.
*Concentrated market:* dummy variable that takes the value one if the supplier reports that its main market consists of fewer competitors.
*Expansive market:* dummy variable that takes the value one if the supplier reports that its main market is in expansion.
*Initial condition:* dummy that takes value one if the supplier performs R&D in the first year of the sample used for conducting the estimates and zero otherwise.
*Market share:* market share reported by the suppliers in its main market.
*Quality controls:* dummy variable that takes the value one if the supplier carries out quality controls on a regular basis.
*Recessive market:* dummy variable that takes the value one if the supplier reports that its main market is in recession.
*Sales*: total sales made by the supplier.
*Size dummies:* set of six dummy variables.
*Subsidy applicant dummy ($ap_{it}$):* dummy that takes the value one if the supplier has applied for a subsidy (i.e., has received a subsidy or claims that has searched external funding without success).
*Time dummies:* set of yearly dummy variables.

Table 10: Descriptive statistics

| | | | standard deviation | | | | |
|---|---|---|---|---|---|---|---|
| | | mean | overall | between | within | min | max |
| Dependent variables | | | | | | | |
| | Ln(R&D expenditures) | 12.18 | 1.85 | 1.88 | 0.74 | 4.04 | 15.89 |
| | R&D dummy t | 0.32 | 0.47 | 0.43 | 0.21 | 0 | 1 |
| Explanatory variables | | | | | | | |
| | R&D dummy t-1 | 0.32 | 0.47 | 0.43 | 0.22 | 0 | 1 |
| | R&D dummy | 0.33 | 0.47 | 0.47 | 0 | 0 | 1 |
| | | 0.03 | 0.16 | 0.20 | 0.10 | 0 | 4.61 |
| | | 0.03 | 0.15 | 0.14 | 0.10 | 0 | 6.21 |
| | | 0.03 | 0.09 | 0.08 | 0.06 | 0 | 1.93 |
| | | 0.03 | 0.13 | 0.20 | 0.00 | 0 | 4.61 |
| | | 0.03 | 0.11 | 0.14 | 0.00 | 0 | 3.21 |
| | | 0.03 | 0.07 | 0.08 | 0.00 | 0 | 1.10 |
| | Subsidy applicant dummy | 0.11 | 0.31 | 0.28 | 0.19 | 0 | 1 |
| | Market share t-1 | 0.10 | 0.17 | 0.16 | 0.08 | 0 | 1 |
| | Concentrated market dummy t-1 | 0.53 | 0.50 | 0.43 | 0.29 | 0 | 1 |
| | Advertising sales ratio t-1 | 0.01 | 0.03 | 0.03 | 0.01 | 0 | 0.72 |
| | Average supplier patents | 0.24 | 0.66 | 0.32 | 0.57 | 0 | 12.56 |
| | Ln(Average variable costs t-1) | -0.09 | 0.14 | 0.11 | 0.10 | -0.96 | 0.94 |
| | Recessive market t-1 | 0.19 | 0.40 | 0.30 | 0.31 | 0 | 1 |
| | Extensive market t-1 | 0.27 | 0.44 | 0.33 | 0.34 | 0 | 1 |
| | Quality controls | 0.42 | 0.49 | 0.44 | 0.28 | 0 | 1 |
| | 21-50 workers | 0.27 | 0.44 | 0.39 | 0.21 | 0 | 1 |
| | 51-100 workers | 0.10 | 0.31 | 0.26 | 0.17 | 0 | 1 |
| | 101-200 workers | 0.10 | 0.30 | 0.28 | 0.16 | 0 | 1 |
| | 201-500 workers | 0.17 | 0.37 | 0.35 | 0.15 | 0 | 1 |
| | >500 workers | 0.08 | 0.26 | 0.26 | 0.09 | 0 | 1 |
| | Ln(Sales) | 15.64 | 1.92 | 1.94 | 0.28 | 9.55 | 22.36 |

Notes: m( ) denotes the mean of the variable in parentheses.

## 13 RESULTS

Table 11 shows the estimates obtained with the dynamic panel data type-2 tobit model. In the optimal R&D equation the parameter associated with the expected subsidy coverage is substantially below unity. One potential explanation for this low coefficient is that in our regressions we consider some suppliers with subsidies covering almost 100% of their R&D expenditures. This would explain the lack of sensitivity of R&D with respect to the subsidy coverage. When we restrict to supplier with subsidies lower than 20% and 30% the coefficient comes close to one (see Table 12) meaning that subsidies are not misused (subsidy is invested in R&D).

The expected subsidy coverage parameter is also significant in the selection equation, indicating that subsidies not only affect the level of investment in R&D but also the decision to perform R&D (the point estimate does not vary when we restrict to suppliers with 20% and 30% subsidy shares). An illustrative magnitude of subsidies' inducement effects is given by the average marginal effect of an increase in suppliers' probability of performing R&D caused by a discrete change in the expected subsidy coverage from zero to a positive magnitude (assuming $y_{it-1} = 0$ and evaluating all other regressors at the mean). A discrete change in the expected subsidy coverage from 0 to 10% (0 to 20%) is associated with an increase in suppliers' probability of performing R&D of 14 (35) percentage points. The effect is increasingly important for larger discrete changes in the expected subsidy coverage.

Table 11: Results of the dynamic panel data type-2 tobit

| | (ln of) Optimal R&D expenditure | | R&D decision | | (ln of) R&D threshold | |
|---|---|---|---|---|---|---|
| | [a] | s.d.[b] | [a] | s.d.[b] | [a] | s.d.[b] |
| R&D dummy t-1 | | | 1.60 | (0.05)*** | -0.20 | (0.09)** |
| Initial condition | 0.49 | (0.07)*** | 1.71 | (0.11)*** | 0.27 | (0.11)** |
| | 0.31 | (0.10)*** | 2.48 | (0.70)*** | | |
| | 0.26 | (0.15)* | 0.04 | (0.33) | 0.25 | (0.16) |
| Applicant dummy | | | 1.20 | (0.14)*** | -0.15 | (0.08)** |
| Market share t-1 | 0.15 | (0.11) | -0.04 | (0.15) | 0.16 | (0.11) |
| Concentrated market dummy t-1 | -0.03 | (0.04) | 0.05 | (0.05) | -0.04 | (0.04) |
| Advertising sales ratio t-1 | 2.37 | (0.72)*** | -0.23 | (0.77) | 2.40 | (0.73)*** |
| Average supplier patents | -0.01 | (0.03) | 0.06 | (0.04) | -0.02 | (0.03) |
| ln(Average variable costs t-1) | -0.11 | (0.14) | -0.51 | (0.17)*** | -0.05 | (0.15) |
| Recessive market t-1 | 0.01 | (0.05) | 0.02 | (0.06) | 0.01 | (0.05) |
| Extensive market t-1 | -0.02 | (0.04) | 0.04 | (0.05) | -0.03 | (0.04) |
| Dummy foreign capital | | | 0.03 | (0.06) | 0.00 | (0.01) |
| Quality controls | | | 0.10 | (0.05)** | -0.01 | (0.01) |
| Skilled labour | | | 0.23 | (0.07)*** | -0.03 | (0.02)* |
| 21-50 workers | 0.26 | (0.09)*** | 0.14 | (0.08) | -0.02 | (0.01) |
| 51-100 workers | 0.58 | (0.12)*** | 0.09 | (0.11) | -0.01 | (0.02) |
| 101-200 workers | 0.81 | (0.12)*** | 0.00 | (0.13) | 0.00 | (0.02) |
| 201-500 workers | 0.97 | (0.14)*** | 0.21 | (0.15) | -0.03 | (0.02) |
| >500 workers | 1.19 | (0.17)*** | -0.08 | (0.20) | 0.01 | (0.03) |
| ln(Sales) | 0.43 | (0.03)*** | 0.21 | (0.04)*** | 0.40 | (0.03)*** |
| Constant | 2.91 | (0.52)*** | -6.20 | (0.54)*** | 3.69 | (0.61)*** |
| Supplier and time dummies | Yes | | Yes | | Yes | |
| | 0.19 | (0.04)*** | | | | |
| | -0.30 | (0.04)*** | | | | |
| | 0.72 | (0.05)*** | | | | |
| | | | 0.11 | (0.05)** | | |
| | | | | | 0.77 | (0.11)*** |
| | 1.00 | (0.01)*** | | | | |
| | | | 0.13 | (0.05)** | | |
| | | | | | 0.97 | (0.01)*** |
| AME R&D dummy t-1 | | | 0.37 | | | |
| Log likelihood | | | -9,482.94 | | | |
| Number of observations | 1,151 | | 15,450 | | 15,450 | |
| Number of suppliers | 5,126 | | 3,000 | | 3,000 | |

a) b1, b2 and b0 refer to the parameters of equations (12), (16) and (13) respectively. The coefficients of the threshold equation have been calculated as

b) Standard errors are shown in parentheses. The standard errors of the threshold equation have been calculated according to the delta method. ***, ** and * indicate significance at a 1%, 5% and 10% level respectively. Gaps indicate exclusion restrictions.

c) The AME measures the average marginal effect as the average outcome probability taking $y_{it-1}$ fixed at 1 minus the average outcome probability taking $y_{it-1}$ fixed at 0 and evaluated at the average values of the covariates (see Stewart 2007).

Table 12: Robustness check 1: results of the dynamic panel data type-2 tobit using observations with $\rho_{it} < 0.20$ and $\rho_{it} < 0.30$

| | (1) | (2) |
|---|---|---|
| | Levels equation | |
| Dummy R&D | 0.39 (0.06)*** | 0.40 (0.06)*** |
| | 0.64 (0.13)*** | 0.58 (0.12)*** |
| | 0.12 (0.17) | 0.18 (0.16) |
| Constant | 2.19 (0.48)*** | 2.21 (0.49)*** |
| Other variables | Yes | Yes |
| # of observations | 1,092 | 1,098 |
| # of suppliers | 4,379 | 4,446 |
| | Selection equation | |
| Dummy R&D t-1 | 1.61 (0.05)*** | 1.61 (0.05)*** |
| Dummy R&D | 1.69 (0.11)*** | 1.67 (0.11)*** |
| | 2.26 (0.72)** | 2.38 (0.71)*** |
| | 0.05 (0.34) | 0.03 (0.34) |
| Constant | -6.17 (0.54)*** | -6.19 (0.54)*** |
| Other variables | Yes | Yes |
| # of observations | 15,120 | 15,256 |
| # of suppliers | 5,111 | 5,126 |
| Log likelihood | -9,266.18 | -9,369.21 |

Notes: ***, ** and * indicate significance at a 1%, 2% and 3% level respectively. The dependent variables are the natural logarithm of R&D expenditures and a dummy with value one if the supplier performs R&D. Besides the shown coefficients the regressions also include all the controls included in Table 8.

This is reasonable because suppliers become increasingly interested in R&D as the expected subsidy coverage increases and R&D expenditures become almost entirely subsidized. We get similar estimates of the subsidy coefficients in the levels and the selection equations with standard estimators (see Table 13) and when we only use the main controls (see Table 14). Table 15 (column (1)) shows that the results hold when we use $\hat{\rho}_{it}^{e}\_1$ instead of $\hat{\rho}_{it}^{e}$. It also shows that $\hat{\rho}_{it}^{e}\_2$ (the expected subsidy coverage measured is not resistant to the inclusion of the means. The results are very similar to theirs (even though we use different survey years). When we include the lagged R&D dummy in column (3) the coefficient of the selection equation is still significant but much lower. When we include the mean in columns (4) subsidies are not significant anymore because $\hat{\rho}_{it}^{e}\_2$ does not have enough within variation to disentangle its direct effect from the Mundlak means.

Table 13: Robustness check 2: results with standard estimators

| | Levels equation | | | Selection equation |
|---|---|---|---|---|
| | Pooled OLS (1) | Fixed effects (2) | Random effects (3) | Wooldridge (2005) (4) |
| Dummy R&D t-1 | | | | 1.56 (0.06)*** |
| Dummy R&D 0 | 0.56 (0.10)*** | | 0.47 (0.09)*** | 1.61 (0.09)*** |
| | 0.34 (0.11)*** | 0.45 (0.09)*** | 0.41 (0.09)*** | 2.29 (0.68)*** |
| | 0.67 (0.20)*** | | 0.26 (0.16) | 0.28 (0.41) |
| Constant | 3.07 (0.82)*** | 5.31 (1.02)*** | 2.56 (0.63)*** | -6.76 (0.60)*** |
| Other variables | Yes | Yes | Yes | Yes |
| # of observations | 1,151 | 1,151 | 1,151 | 15,450 |
| # of suppliers | 5,126 | 5,126 | 5,126 | 3,000 |
| R2 | 0.54 | | | |
| Log likelihood | | | | -2,591.07 |

Notes: ***, ** and * indicate significance at a 1%, 2% and 3% level respectively. Clustered-robust standard errors in parentheses in column (1). The dependent variables are the natural logarithm of R&D expenditures and a dummy with value one if the supplier performs R&D. Besides the shown coefficients the regressions also include all the controls included in Table 10.

Table 14: Robustness check 3: results of the dynamic panel data type-2 to bit using only the main controls

| | All suppliers<br>(1) | Suppliers with<br>(2) | Suppliers with<br>(3) |
|---|---|---|---|
| | | Levels equation | |
| Dummy R&D | 0.44 (0.09)*** | 0.45 (0.09)*** | 0.48 (0.10)*** |
| | 0.29 (0.11)*** | 0.62 (0.14)*** | 0.54 (0.13)*** |
| | 0.35 (0.17)** | 0.23 (0.23) | 0.36 (0.20)* |
| ln(Sales) | 0.67 (0.02)*** | 0.68 (0.02)*** | 0.68 (0.02)*** |
| Constant | 0.29 (0.28) | -0.01 (0.30) | 0.03 (0.31) |
| Other variables | No | No | No |
| # of observations | 1,104 | 1,092 | 1,098 |
| # of suppliers | 4,524 | 4,379 | 4,446 |
| | | Selection equation | |
| Dummy R&D t-1 | 1.65 (0.05)*** | 1.65 (0.05)*** | 1.66 (0.05)*** |
| Dummy R&D | 1.68 (0.10)*** | 1.69 (0.10)*** | 1.68 (0.10)*** |
| | 2.33 (0.67)*** | 2.07 (0.71)*** | 2.20 (0.68)*** |
| | 0.07 (0.33) | 0.07 (0.33) | 0.06 (0.33) |
| Applicant dummy | 1.20 (0.14)*** | 1.14 (0.14)*** | 1.15 (0.14)*** |
| ln(Sales) | 0.23 (0.02)*** | 0.23 (0.02)*** | 0.23 (0.02)*** |
| Constant | -5.86 (0.25)*** | -5.86 (0.25)*** | -5.85 (0.25)*** |
| Other variables | No | No | No |
| # of observations | 15,120 | 15,120 | 15,256 |
| # of suppliers | 5,210 | 5,111 | 5,126 |
| Log likelihood | -9,807.26 | -9,573.10 | -9,681.77 |

Notes: ***, ** and * indicate significance at a 1%, 2% and 3% level respectively. The dependent variables are the natural logarithm of R&D expenditures and a dummy with value one if the supplier performs R&D.

Table 15: Robustness check 4: results of the dynamic panel data type-2 tobit using and

| | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| | | Levels equation | | |
| Dummy R&D | 0.38 (0.06)*** | | 0.58 (0.07)*** | 0.46 (0.07)*** |
| | 0.30 (0.09)*** | 0.86 (0.14)*** | 0.82 (0.13)*** | 0.17 (0.16) |
| | 0.67 (0.13)*** | | | 2.05 (0.26)*** |
| Constant | 2.15 (0.46)*** | 2.61 (0.48)*** | 2.59 (0.47)*** | 1.87 (0.48)*** |
| Other variables | Yes | Yes | Yes | Yes |
| # of observations | 1,104 | 1,104 | 1,104 | 1,104 |
| # of suppliers | 4,524 | 4,524 | 4,524 | 4,524 |
| | | Selection equation | | |
| Dummy R&D t-1 | 1.59 (0.05)*** | | 1.60 (0.05)*** | 1.60 (0.05)*** |
| Dummy R&D 0 | 1.66 (0.11)*** | | 1.87 (0.12)*** | 1.77 (0.12)*** |
| | 1.99 (0.80)** | 3.61 (0.31)*** | 0.95 (0.27)*** | -0.11 (0.30) |
| | 0.59 (0.43) | | | 4.33 (0.55)*** |
| Constant | -6.17 (0.54)*** | -8.05 (0.40)*** | -6.04 (0.52)*** | -5.74 (0.52)*** |
| Other variables | Yes | Yes | Yes | Yes |
| # of observations | 15,120 | 15,120 | 15,120 | 15,120 |
| # of suppliers | 2,621 | 2,621 | 2,621 | 2,621 |
| Log likelihood | -9,473.38 | -11,179.48 | -9,720.53 | -9,666.40 |

Notes: ***, ** and * indicate significance at a 1%, 2% and 3% level respectively. The dependent variables are the natural logarithm of R&D expenditures and a dummy with value one if the supplier performs R&D. Besides the shown coefficients the regressions also include all the controls included in Table 10.

The significance of the lagged dependent variable in the selection equation indicates that true state dependence exists. It is thus possible to conclude that there is a behavioural effect in the sense that the decision to perform R&D in one period enhances the probability of R&D being performed in subsequent periods too. Specifically, firms that perform R&D in one given period have a probability that is 28% higher of performing R&D in the next period than firms that did not perform R&D (see the average partial effect reported at the bottom of Table 11). A direct consequence of the existence of true state dependence is that the R&D threshold also depends on past R&D performance giving rise to an entry and a continuation threshold. The distance between the two thresholds is $\eta = 0.1$ meaning that the continuation threshold is 10% lower than the entry threshold. The advertising to sales ratio, as a proxy of the elasticity of demand with respect to quality ε, has a positive and significant impact on both R&D expenditure and on the decision to perform R&D but is not significant in the threshold. High average variable costs (as a proxy for marginal cost c) seem to be an obstacle for R&D performance but do not significantly affect the thresholds. The quality controls and skilled labour dummies, designed to capture fixed costs (excluded from the optimal R&D equation on theoretical grounds) are found to have a positive and significant effect on R&D performance and a negative effect on the thresholds (although this negative effect is only significant in the case of the skilled labour dummy). Finally, the variables aimed at accounting for scale effects, such as the set of size dummies and the sales volume, have a positive and significant impact on optimal R&D expenditure. The sales volume also positively affects the propensity to perform R&D and the threshold. This is a logical result that confirms that larger suppliers make larger R&D investments reflecting their larger capacity or the more pressing requirement to achieve a perceptible impact in their already large volume of business.

## 14 R&D AND SUBSIDY COVERAGE THRESHOLDS

The R&D thresholds are calculated from the estimated parameters of equation (14) according to the following expressions:

$$\tilde{x}_{it}^{E} = \exp(w_{0it}\hat{\beta}_0 + (1/2)\hat{\sigma}_{\varepsilon 0}^{2})$$
$$\tilde{x}_{it}^{C} = \exp(-\hat{\eta} + w_{0it}\hat{\beta}_0 + (1/2)\hat{\sigma}_{\varepsilon 0}^{2})$$

Similarly, the subsidy thresholds are calculated using the estimated parameters of equations (13) and (14) as the subsidies that make the suppliers indifferent between performing R&D or not, i.e., equalizing optimal and threshold R&D (equations (13) and (14)), giving the following expressions:

$$\tilde{\rho}_{it}^{E} = 1 - \exp\left(\frac{w_{1it}\hat{\beta}_1 - w_{0it}\hat{\beta}_0}{\hat{\gamma}}\right)$$
$$\tilde{\rho}_{it}^{C} = 1 - \exp\left(\frac{w_{1it}\hat{\beta}_1 + \hat{\eta} - w_{0it}\hat{\beta}_0}{\hat{\gamma}}\right).$$

Kernel densities of the R&D and subsidy thresholds are provided in Figure 3, which is complemented by Table 16. As expected, continuation thresholds take on average lower values than those adopted by entry thresholds. Regarding subsidy coverage, around 34% of the entry thresholds concentrate in values higher than 40% which implies that most suppliers need to have their R&D expenditure almost entirely subsidised in order for them to engage in R&D. It is equally true that 6% of the entry thresholds take negative values meaning that there is a mass of suppliers which does not require subsidies to engage in R&D. Not surprisingly, the percentage of suppliers with negative continuation thresholds is much larger, with a value close to 18%. This implies that almost half of the suppliers in the sample are self-sufficient to continue performing R&D in the absence of public support.

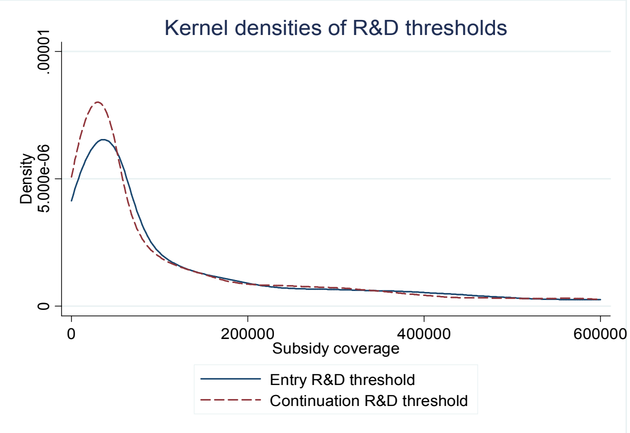

Figure 3: Kernel densities of R&D and subsidy coverage thresholds

Table 16: Distribution of R&D and subsidy coverage thresholds

| R&D thresholds | | | | | Subsidy thresholds | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | $\tilde{x}^E$ | | $\tilde{x}^C$ | | | $\tilde{\rho}^E$ | | $\tilde{\rho}^C$ | |
| | % | Cum. | % | Cum. | | % | Cum. | % | Cum. |
| < 50,000 | 34 | 34 | 40 | 40 | < 0 | 6 | 6 | 18 | 18 |
| 50,000-100,000 | 15 | 57 | 14 | 61 | 0 - 0.2 | 10 | 28 | 13 | 51 |
| 100,000-150,000 | 7 | 64 | 7 | 68 | 0.2 - 0.4 | 6 | 34 | 33 | 84 |
| 150,000-200,000 | 6 | 70 | 5 | 73 | 0.4 - 0.6 | 22 | 56 | 15 | 100 |
| 200,000-250,000 | 4 | 73 | 4 | 77 | 0.6 - 0.8 | 44 | 100 | 0 | 100 |
| >200,000 | 27 | 100 | 23 | 100 | 0.8 - 1 | 0 | 100 | 0 | 100 |

## 15 PERMANENT INDUCEMENT EFFECTS

The first question we set out to address is whether subsidies can achieve permanent inducement effects. By knowing the entry and continuation subsidy thresholds, it is possible to classify suppliers in three different scenarios according to their dependence on subsidies. The first scenario considers suppliers that have positive entry and exit thresholds ( $\tilde{\rho}^E > 0 \,\&\, \tilde{\rho}^C > 0$ ). These firms should be permanently subsidised to ensure the profitability of their R&D activities. The second scenario ( $\tilde{\rho}^E \leq 0 \,\&\, \tilde{\rho}^C \leq 0$ ) considers suppliers that have negative entry and exit thresholds and, hence, find R&D profitable even in the absence of subsidies. The third scenario ($\tilde{\rho}^E > 0 \,\&\, \tilde{\rho}^C \leq 0$), considers suppliers with positive entry thresholds but negative continuation thresholds. The last scenario opens up the possibility of using subsidies to induce permanent entry into R&D through temporary increases in a supplier's expected subsidies. Column 1 in Table 17 shows that 18% of the observations in the sample require subsidies to start performing R&D but can continue performing R&D without them; 15% can perform R&D regardless of the subsidies; and the remaining 58% always require a subsidy to persist in R&D activities. Interestingly (see column 1B), 50% of the observations that only need entry subsidies are actually already performing R&D, while the other 40% has still to be induced into engaging in R&D activities. Further, almost all the suppliers (63%) that do not depend on subsidies are R&D performers and virtually none (just 3%) of the firms that always need subsidies perform R&D.

Table 17: Classification of suppliers according to their dependence on subsidies

| Groups of suppliers according to their dependence on subsidies | | (1) Observations in the sample | | (2) Firms in the sample | | (3) Firms in the population | |
|---|---|---|---|---|---|---|---|
| | | A | B | A | B | A | B |
| 1 | $\tilde{\rho}^E > 0 \,\&\, \tilde{\rho}^C > 0$ | 58 | 3 | 58 | 3 | 60 | 4 |
| 2 | $\tilde{\rho}^E \leq 0 \,\&\, \tilde{\rho}^C \leq 0$ | 15 | 63 | 13 | 95 | 4 | 98 |
| 3 | $\tilde{\rho}^E > 0 \,\&\, \tilde{\rho}^C \leq 0$ | 18 | 50 | 10 | 51 | 6 | 56 |
| 4 | $\tilde{\rho}^E > 0 \,\&\, \tilde{\rho}^C \leq 0$, $\tilde{\rho}^E \leq 0 \,\&\, \tilde{\rho}^C \leq 0$ | | | 8 | 73 | 5 | 72 |
| 5 | $\tilde{\rho}^E > 0 \,\&\, \tilde{\rho}^C \leq 0$, $\tilde{\rho}^E > 0 \,\&\, \tilde{\rho}^C > 0$ | | | 6 | 41 | 4 | 40 |

A) Proportion of observations or suppliers that fall into each group out of the total.
B) Proportion of suppliers in each group that perform R&D (the proportion is calculated with respect to the total number of observations in each group, not with respect to the total number of suppliers in the sample)

In column (2) we refer to firms instead of observations and find that some of the suppliers that need only a trigger subsidy to become stable R&D performers change from one scenario to another over the sample years. For instance, 8% of the suppliers need entry subsidies in certain periods but can enter into R&D without such a requirement in others. Another similarly sized group (6%) alternates between periods of dependence on entry subsidies and periods of dependence on both entry and continuation subsidies. In column (3) we report the values for the whole population of Indian suppliers. The figures show that 15% (6+5+4) of Indian suppliers need subsidies to enter into R&D but not to continue. Only 4% of the suppliers can perform R&D without subsidies (almost all of which actually perform R&D). This value is notably lower than that obtained in column (2), reflecting the fact that this group is comprised mainly of large suppliers, which are in fact over-represented in the sample. The opposite is true for the proportion of suppliers that need subsidies to both start and continue performing R&D which amounts to 60% of the population. On the basis of these results, we can conclude that there is a case for using subsidies to induce firms to go permanently into R&D by means of one-shot trigger subsidies. Around 8.6% (6*(1-0.56) + 5*(1-0.72) + 4*(1-0.4)) of Indian suppliers can be permanently brought into R&D by means of trigger subsidies (this number lowers to 4.6% (6*(1-0.56) + 5*(1-0.72)) if we disregard suppliers in row 5 which require continuation subsidies in some periods). Table 18 provides information on the distribution of entry subsidies of those firms that can be permanently induced. Remarkably, the subsidy coverage required to induce permanent entry is quite large for most of these suppliers: 26% and 16% of all "induceable" suppliers need subsidies above 30% and 40% of their R&D expenditures respectively to engage in R&D.

Table 19 provides a break down by industries. The percentage of R&D suppliers varies widely across industries ranging from 3% in printing products to 44% is office and data processing machinery (see column 1).

Table 18: Percentage of suppliers that can be permanently induced with each range of subsidy coverage (out of the suppliers that can be permanently induced and are not performing R&D yet)

| Entry subsidy coverage (in %) | % of suppliers |
|---|---|
| 10 | 8 |
| 20 | 26 |
| 30 | 19 |
| 30 | 26 |
| 40 | 16 |

Note: these numbers are an extrapolation for the whole supplier

Table 19: R&D and subsidies' permanent inducement effects by industries

| | Current % of R&D suppliers | Maximum % of R&D suppliers (4) + (5) | % of suppliers with | | |
|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) |
| Low technological suppliers | | | | | |
| Automobile parts | 10 | 14 | 86 | 12 | 2 |
| Steel | 29 | 49 | 51 | 37 | 12 |
| Textiles and clothing | 17 | 20 | 80 | 14 | 6 |
| Leather, leather and skin goods | 20 | 21 | 79 | 17 | 4 |
| Timber, wooden products | 8 | 10 | 90 | 8 | 2 |
| Printing products | 3 | 4 | 96 | 3 | 1 |
| Paper | 12 | 17 | 83 | 14 | 3 |
| Non-metallic mineral products | 13 | 18 | 82 | 15 | 3 |
| Metal products | 16 | 21 | 79 | 17 | 4 |
| Furniture | 16 | 20 | 80 | 17 | 3 |
| Other manufacturing products | 7 | 10 | 90 | 10 | 0 |
| Medium technological regime industries | | | | | |
| Food products | 13 | 14 | 86 | 10 | 4 |
| Rubber and plastic products | 22 | 26 | 74 | 18 | 8 |
| Ferrous and non-ferrous metals | 33 | 52 | 48 | 35 | 17 |
| Agricultural and industrial machinery | 40 | 48 | 52 | 33 | 15 |
| Motor vehicles | 32 | 39 | 61 | 29 | 10 |
| High technological regime industries | | | | | |
| Chemical products | 52 | 59 | 41 | 19 | 40 |
| Office and data processing machinery | 44 | 65 | 35 | 38 | 27 |
| Electrical goods | 39 | 43 | 57 | 25 | 18 |
| Other transport equipment | 40 | 44 | 56 | 29 | 15 |

Notes: these numbers are an extrapolation for the whole manufacture.

Most suppliers in low-tech industries need both entry and continuation subsidies but the percentage decreases for medium-tech and high-tech industries (see column 3). The percentage of suppliers with positive entry thresholds and negative continuation thresholds is remarkable in all industries and particularly in the medium-tech and high-tech ones (see column 4). This implies that there is room for increasing the percentage of R&D suppliers in all industries. Column (2) shows the maximum percentage of R&D suppliers that can be attained in every single industry by adding up the numbers of columns (4) and (5).

## 16 EVALUATION OF R&D INDUCING SUBSIDY POLICIES

The second question we set out to address concerns the effectiveness of an inducing policy aimed at inducing all the suppliers with positive entry thresholds and negative continuation thresholds. To carry out this evaluation we assume that subsidies are granted at t=0 and then set equal to zero from t=1 onwards. Thus, all we need to do is to contrast the inducement costs, namely the total amount of subsidies granted at t=0, with the stream of R&D investments that are subsequently manifested.

In order to infer these inducement costs, it is convenient to express the subsidy thresholds in absolute terms rather than as a proportion of a supplier's R&D expenditure. This can be easily achieved by multiplying the subsidy coverage threshold by the R&D threshold: $subsidy^E = \tilde{\rho}^E \tilde{x}^E$ and $subsidy^C = \tilde{\rho}^C \tilde{x}^C$. Then, the cost of inducing all the suppliers that only need entry subsidies is obtained by adding up the entry subsidies $(subsidy^E)$ of all suppliers with $\tilde{\rho}^E > 0 \; and \; \tilde{\rho}^C \leq 0$ that are not performing R&D yet. This implies that subsidies aimed at inducing permanent R&D performance have to subsidize lower quantities than subsidies awarded to active R&D firms. In any case, we must admit that our estimate seems a lower bound of the true inducement costs. The yearly R&D investments that would be triggered by this inducing policy from t=1 onward. This implies that, considering an optimistic scenario (solid line of Figure 4) in which no induced firms abandon R&D activities after t=1. Under a more pessimistic scenario (dashed line of Figure 4) in which half of the induced firms abandon R&D after t=1 the R&D stock generated would reach a steady level in 20 years. This implies that the inducing policy would still be effective even if the inducement costs were tenfold the estimated ones and half of the induced suppliers failed to persist into R&D.

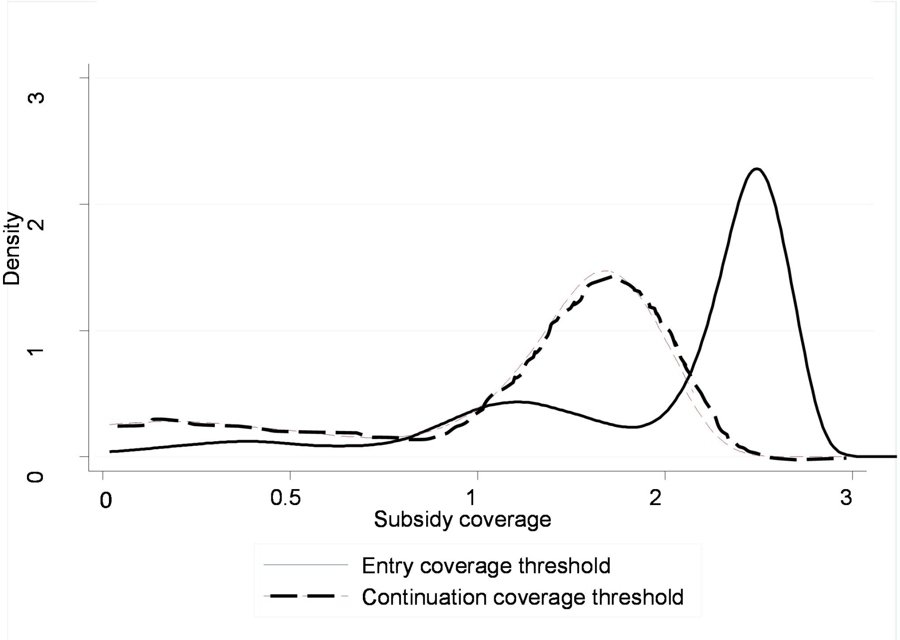

Figure 4: Kernel densities of subsidy coverage thresholds

To sum up, "extensive" subsidies can be used to expand the share of R&D in Indian suppliers from 10% to 20% which would in turn lead to an increase of R&D intensity (understood as total R&D expenditures over total sales) from 0.45% to 0.57%. Recall from expression (8) that the thresholds can be lowered by improving demand conditions, lowering the marginal and the fixed costs and shortening the lag between R&D and profits.

## 17 CONCLUSION

Researchers and policymakers alike have paid little attention to subsidies as a tool for expanding the base of R&D performers. But it is likely that there are sunk entry costs associated to R&D that can be smoothed out by subsidies and hence justify the existence of "extensive" subsides. In this paper we have sought to contribute fresh evidence regarding the feasibility and efficiency of such subsidies. We have framed our analysis around a dynamic model with sunk entry costs in which Indian suppliers decide whether to start, continue or stop performing R&D on the grounds of the subsidy coverage they expect to receive. The main appeal of this framework is that a Indian supplier's optimal participation strategy can be characterised in terms of two (rather than one) subsidy thresholds characterising entry and continuation. The existence of two thresholds proves crucial as it allows us to detect which Indian suppliers need subsidies to start but not to continue performing R&D. We are able to compute the subsidy thresholds from the estimates of a dynamic panel data type-2 tobit model with an R&D investment equation and an R&D participation equation. By including dynamics in the selection equation, we are able to estimate true state dependence, which is ultimately used to measure the distance between the two thresholds. The model is estimated for an unbalanced panel of about 3,000 Indian suppliers observed over a 13-year period. We find that expected subsidies significantly affect both R&D expenditure and the decision to perform R&D. In addition, we conclude that R&D performance is true state dependent which leads to the existence of two subsidy thresholds, one that determines entry into R&D and one that assures continuation of R&D. Using the estimated expected subsidy coverage thresholds we find that 21% of Indian suppliers need subsidies to enter but not to continue into R&D. Slightly more than half of the suppliers belonging to this group are already R&D performers, which means that the other half (6% of Indian suppliers) is still to be induced. Should they be induced, the proportion of R&D Indian suppliers would increase by about one half (from 10% to 20%). This result emphasises the importance of dynamic additionally, hitherto disregarded in analyses of subsidy effectiveness. The findings offered by this paper call for a revision of the classical subsidy granting schemes. Subsidies have traditionally been awarded to consolidated R&D performers. However, agencies have shown a certain reluctance to award subsidies to reduce the entry costs of R&D beginners. This is mainly because they do not really know whether there is scope for using subsidies to induce entry into R&D, and they are unaware of the costs involved. This paper has confirmed that subsidies can be used to defray the sunk costs and encourage entry into R&D. Besides, the costs of inducing all these suppliers have been found to be relatively moderate when compared with the R&D stock that would be generated. Of course, subsidies aimed at inducing entry may well generate moral hazard problems when actually implemented. For instance, Indian suppliers might be tempted to perform R&D during a period simply to receive the subsidy and, once received, cease their R&D activities. Similarly, they might over-invest in R&D so as to obtain larger subsidies. A solution might be to tie the provision of such funds to a commitment from the Indian suppliers to invest similar amounts in R&D during the subsequent years. Only Indian suppliers that intend to continue their R&D activities are likely to accept such a contract. Unquestionably, the optimal design of subsidies aimed at inducing sustained R&D merits careful consideration and constitutes a topic for future research.

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