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Public support for R&D, knowledge sourcing and firm innovation: Examining a mediated model with evidence from the manufacturing industries[§]

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Abstract

The aim of this study is to examine how firms realize the benefits associated with public support for R&D programs. To do so, this research proposes and tests the hypothesis that the level of knowledge sourcing applied by a firm during the innovation process mediates the relationship between granted R&D subsidies and a firm's innovative performance. Using a panel of Spanish manufacturing companies, the findings provide evidence to indicate that the degree of firms' investments in intramural R&D and the levels of openness in their innovation serve as mediating mechanisms between R&D subsidies and firm innovation, as measured by patent application and new product introduction counts. The study advances the literature on innovation management and technology-policy evaluation by showing how firms use their knowledge-sourcing strategies to exploit opportunities provided by public intervention.

Keywords: Intramural R&D, open innovation, firm innovative performance, innovation policy, mediation analysis.

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1. Introduction

Innovation is a challenging process. It requires that firms build skills for finding solutions to potential problems emerging during the process of technology and new product development. As documented by studies on innovation management, knowledge-sourcing strategies play an important role in providing firms with needed problem-solving capabilities for their innovations (e.g., Katila and Ahuja, 2002; Pisano, 2000; Roper et al. 2008). In this literature, knowledge sourcing is viewed as a driver shaping firms' innovative performance. However, because innovation is fundamentally a knowledge production process, it suffers from imperfect appropriability (Arrow, 1962). The fact that firms cannot entirely appropriate the returns generated by their innovations leads them to under invest in R&D activities (Gelabert et al. 2009). Because these activities provide a base for sustaining knowledge sourcing, imperfect appropriability may affect firms' innovative performances. Public intervention in technology and innovation is then justified as an instrument to mitigate the negative impact of market imperfections on firms' knowledge-sourcing behaviors.

Considering the presence of market imperfections, the contribution of public intervention has been evaluated according to the occurrence of *additionality* effects associated with a variety of policy schemes (e.g., R&D subsidies, public loans, tax-credit incentives). The positive impact of public assistance in terms of additional firms' R&D expenditures are viewed as a form of *input additionality*, while the positive effects in terms of further innovation outcomes are considered as a manifestation of *output additionality*[1]. Recent studies have started to use a complementary perspective to assess the influence of public intervention on the innovation process itself. The focus is on the assessment of behavioral changes in supported firms induced by R&D assistance programs, or what is called *behavioral additionality*[2].

Despite the progress provided by prior studies on innovation-policy evaluation, surprisingly little is known about the channels through which the impact of policy R&D

[1] See the works of David et al. (2000), Klette et al. (2000), and Mairesse and Mohnen (2010) for a review of the results reported by prior studies on input and output additionality.
[2] Studies on behavioral additionality include Buisseret et al. (1995); Clarysse et al. (2009), Falk (2007), Georghiou and Clarysse (2006).

schemes translates into an enhanced innovative performance of firms (see the work of Kang and Park (2012) who examined this issue). Although some works have started to identify potential mechanisms to describe links between government R&D support and firm innovation (Hewitt-Dundas and Roper, 2010; Roper et al. 2004), the explanatory power of the identified mechanisms remains understudied. Moreover, works on input and output additionality still offer a fractional view of the total impact of R&D policy on firm innovation based on increases in supported firms' inputs or outputs. For instance, few works, with the exception of Czarnitzki and Licht (2006) and Hussinger (2008), examine whether policy-induced effects on firms' inputs translate into innovation outcomes. A small number of studies have used a behavioral approach to identify mechanisms that explain connections between the grant of public R&D support and firms' innovation outcomes (Falk, 2007). As policy schemes also lead to changes in firms' R&D adoption behavior (including internal and external R&D), a better understanding of how such changes shape innovation outcomes is needed to determine the entire effect of public intervention.

In an attempt to fill these gaps, in this study, we propose and test a theory of how firms' knowledge-sourcing behavior *mediates* the connection between publicly supported R&D funding and firms' innovative performance. Using a panel of Spanish manufacturing companies for the period 1998-2005, the study provides evidence consistent with the mediation hypothesis that knowledge-sourcing dimensions, such as the *degree of firms' investments in intramural R&D* and the *levels of openness in their innovation* explain how supported firms realize the benefits derived from R&D subsidies provided by National programs implemented in Spain. Uncovering the mediating role of these knowledge-sourcing dimensions is relevant to improve understanding of the causal links prevailing among government R&D policies, firms' R&D adoption behaviors, and firms' innovation outcomes.

This research contributes to the previous literature in the following respects. First, by using the insights provided by studies on innovation management, this research advances the literature on technology policy evaluation, proposing mechanisms that elucidate how public assistance shapes firms' innovation. In doing so, this research addresses the extended concern

that policy evaluation studies focus more on assessing the results of public intervention and less on clarifying of how these results are generated (Clarysse et al. 2009; Falk, 2007). Second, the research advances the literature on innovation management by revealing the critical role R&D policy schemes may have on defining how firms source knowledge for their innovations. This aspect indicates the importance of elements in a firm's environment (e.g., government policies and regulation schemes) in influencing its strategic choices in areas, such as R&D investment implementation and R&D collaboration formation. Third, this research provides new insights about the contribution of firms' actions (e.g., knowledge-sourcing activities) to exploit their available resources (e.g., received public assistance). It is shown that supported firms' knowledge-sourcing behavior is a critical element for boosting external resources provided by public assistance. These insights contribute to the literature founded on the resource-based view, showing how firms can articulate actions to transform their resources as sources of competitive advantages by developing new technologies and products.

To the best of our knowledge, only Kang and Park (2012) have conducted an analysis of the mediating role of R&D activities to determine firms' patenting capabilities, but for the case of the biotechnology industry. In this study, a multi-industry sample of companies is considered to account for well-documented industry-idiosyncratic effects that influence firms' knowledge-sourcing behavior and their innovations (Malerba, 2007; Laursen and Salter, 2006). Moreover, a robust empirical design is implemented, one that accounts for the presence of endogeneity that might affect the assessment of the relationships under question.

The layout of the paper is as follows. In the next section the theoretical foundation for examining the links among public support with R&D subsidies and the knowledge-sourcing behavior of firms and their innovative performance is presented. In subsequent sections the data, methods, and results of the study are described and the concluding remarks voiced.

2. Theoretical framework

In order to generate technologies or make new product introductions, firms have to source knowledge to build their problem-solving capabilities (Katila and Ahuja, 2002). Firms can source knowledge for their innovations in several ways. As documented by prior studies on

organizational learning, a firm's investment in R&D comprises a prominent mechanism for achieving knowledge intended to solve underlying problems emerging during the innovation process (Nerkar, 2003; Pisano, 2000). These investments uncover the effort made by a firm in searching and implementing solutions to improve the performance of a technology and/or a product design. Firms may also obtain knowledge from external sources. Given the presence of increasing competition, greater technology complexities, and shorter product-life cycles, knowledge provided by firms' intramural R&D is no longer enough to achieve a leading-edge in innovation. To handle this issue, firms have started to develop technology and product development models that are largely characterized by the growing use of external knowledge sources (Chesbrough, 2003; Dahlander and Gann, 2010; Lichtenthaler, 2011). The formation of alliances (e.g., non-equity links and joint ventures) along with the use of market-based arrangements (e.g., in-licensing, R&D outsourcing, and the hiring of knowledge workers) are two established mechanisms that assist firms in obtaining required problem-solving capabilities from external sources (Grant and Baden-Fuller, 2004).

A firm's knowledge-sourcing behavior can be characterized by its effort in obtaining valuable solutions to generate innovations. In this study, two dimensions are used to measure this effort: The degree of firm's investments in intramural R&D, and the degree of openness prevailing in its innovations. An important part of the process of knowledge sourcing is conducted through intramural R&D activities, so it is anticipated that high levels of investments in these activities will reveal the scale and/or scope dimensions of a firm's internal knowledge-sourcing activities. Similarly, links to other actors and organizations widely determine the portfolio configuration of firms' external knowledge-sourcing activities. The use of wide-ranging mechanisms of external knowledge sourcing should uncover the level of openness applied by a firm during the innovation process. Thus, these dimensions are viewed here as observable characteristics that would reveal how firms source knowledge for developing their technology and new products.

In line with the literature on behavioral additionality, we posit that public assistance induces changes in the knowledge-sourcing behavior of supported firms that have subsequent

effects on their innovative performance. Because the coverage of public R&D funding reduces the costs of performing R&D activities, this public assistance provides supported firms with a basis for expanding their knowledge-sourcing activities. In doing so, public intervention makes superior innovation outcomes of supported firms more likely. Because technology policy stimulates firms to raise the degree of R&D involvement (within and/or outside their organizational boundaries) and given the recognized role of knowledge sourcing in shaping innovation, we postulate that the level of knowledge sourcing applied by supported firms mediates the relationship between public support and innovation. Figure 1 presents a mediated model that describes the direct and indirect links established between the public support grants for R&D and firms' innovative performances.

[Insert Fig. 1 here]

In what follows, we will explain in more details the hypotheses that sustain the set of relationship postulated in the model depicted in Figure 1.

2.1 Innovative performance effects derived from public R&D funding

Part of the literature on innovation-policy evaluation is focused on assessing the direct effect of public assistance on a firm's innovation output, or output additionality. Roper et al. (2004) and Hewitt-Dundas and Roper (2010) identify a set of mechanisms that link public support for R&D and firms' innovative performance. These authors indicate that government R&D programs help supported firms build stocks of knowledge for their innovation, increase their abilities to conduct future research projects, form innovative capabilities, and develop their human resources. More recently, Roper and Hewitt-Dundas (2012) propose public support for R&D enhances firms' innovativeness through a "legacy effect", relating to the presence of output additionality. Specifically, induced innovation outputs in one period create advantages that enable supported firms to innovate in subsequent periods.

Without identifying which of the aforementioned mechanisms prevail in explaining the relation between public assistance and firms' innovation, an important stream of works provide evidence showing the existence of output additionality. Klette et al. (2000) review a set of

micro-econometric studies to assess the impact of alternative policy intervention schemes. The results show a range of effects, including enhanced patenting capabilities and sales and employment growth, which are in line with the existence of additionality effects. More recent evaluation studies confirm the presence of output additionality relating to direct and indirect R&D policy schemes, namely, R&D subsidies and tax credit incentives, respectively. As regards "marketable outputs", Hujer and Radić (2005) examine the impact of R&D subsides in the case of Germany, finding evidence of additionality as measured by the firms' propensity to make new product/service introductions. In terms of indirect schemes, Cappelen et al. (2011) confirm R&D tax credits raise the propensity of firms to patent and launch new products in the case of Norway. As regards "commercial output", Hewitt-Dundas and Roper (2010) find that public support for Ireland and Northern Ireland increases firms' sales relating to upgraded as well as new product introductions. For the case of indirect mechanisms of public support, Bérubé and Mohnen (2009) show that highly supported firms in Canada, those receiving grants and R&D tax-incentives, have a high propensity to introduce new products and be more successful in their commercialization than their non-supported counterparts that receive only R&D tax-incentives.

Some works have begun to assess whether induced input additionality, or the effects of public intervention on R&D activities, translates necessarily into output additionality. In this regard, Czarnitzki and Licht (2006) find evidence to indicate that policy-induced R&D positively determines surveyed firms' patenting capabilities in the case of Germany. Similarly, Hussinger (2008) examined a sample of German manufacturing companies and reported that policy-induced R&D contributes to enhanced new product sales. Czarnitzki et al. (2007) also assessed the impact of public intervention and R&D collaboration on the firms' patenting activity for Finland and Germany. Their results indicate that R&D collaboration and public support induce firms to invest more in R&D. In turn, induced R&D, through collaboration and/or public intervention, is translated into a superior output as measured by patent activity. This result is particularly strong for the case of Finland.

Taken together, previous evidence strongly supports the existence of output additionality relating to direct as well as indirect R&D schemes. Focusing the attention on direct schemes of R&D support and on the effects derived from their coverage, Hypothesis 1 for this study states that:

> **Hypothesis 1**: The amount of granted R&D subsidy is positively associated with a firm's innovative performance.

We now develop a set of hypotheses with the aim of advancing potential mechanisms to describe how the effects of public assistance transmit into an enhanced innovation in supported firms.

2.2 The effects of knowledge sourcing on a firm's innovative performance

Knowledge sourcing occurring through a firm's R&D has important consequences for its innovation outcomes. Alternative patterns of knowledge sourcing may have an impact on firm innovation. First, an extension of the present R&D projects allows firms to search recurrently in familiar technological trajectories, or what is called a local, internal search. This type of search enables the emerging of important learning-by-doing effects that, in turn, may bring efficiency gains in the way firms create knowledge for their innovation development. For instance, in performing current R&D projects on a larger scale, requirements to be fulfilled in the process of technology and product development are better understood because of the firms' accumulated experience in conducting such projects (Pisano, 2000). Second, sourcing knowledge that explores new technological trajectories and spans the space in which firms may generate solutions for their technology and product development process. In this case, new possibilities of knowledge association materialize, which contribute to augmenting firms' innovation capabilities. By exploring new technological trajectories, firms are better placed to prevent competency-traps and technological obsolescence that may impair their abilities to develop novel technologies or to make new product introductions (Leonard-Barton, 1992; Rosenkopf and Nerkar, 2001).

The benefits derived from the prior identified patterns of knowledge sourcing are widely documented. For instance, Katila and Ahuja (2002) provide evidence to indicate that both

"search depth" (deeply in current technological fields) and "search scope" (broadly in new technological fields) determine firms' capacities to make new product introductions. Similarly, Nerkar and Roberts (2004) find that knowledge accumulation in familiar technological fields leads firms to a better fulfillment of their customers' needs, which eases the introduction of improved products. Moreover, knowledge accumulation in unfamiliar technological fields enhances firms' capacities to solve problems in different ways, which leads to the generation of more valued innovations.

From the preceding discussion, it is clear that high degrees of investment in intramural R&D are positively correlated with a firm's enhanced capacity to generate innovations. Hence, Hypothesis 2a states that:

> **Hypothesis 2a**: The degree to which a firm invests in intramural R&D enhances its innovative performance.

Firms can also benefit from increasing levels of openness about their innovations. First, the use of external sources of knowledge brings new possibilities of knowledge recombination (Fleming, 2001; Rosenkopf and Nerkar, 2001). In cases in which firms form alliances with technologically similar partners or acquire in markets external knowledge sources that are close to their own expertise, firms can develop valuable knowledge associations. This holds true because technological relatedness gives partners a profound understanding of the exchanged and/or acquired technologies, leading them to a better identification of new knowledge combinations with potential value for producing improved technologies and products. Moreover, external knowledge sourcing in areas unrelated to a firm's technological expertise spans the pool of knowledge to be searched, providing new-fangled opportunities to recombine diverse pieces of knowledge, but in radically different ways. Searching for knowledge beyond the firm's organizational boundaries contributes to reaching technological renewal, which impedes lock-in effects and leads to new technologies and products (Rosenkopf and Almeida, 2003; Rothaermel and Deeds, 2004).

Several streams of literature document the effects of openness on firm innovation. Studies on inter-firm collaboration networks have started to provide evidence to indicate that

firms weaving links with other organizations reach relevant information flows that shape their innovative capabilities (e.g., Ahuja, 2000; Phelps, 2010; Powell et al. 1996). Similarly, studies about organizational search find that firms that extensively used knowledge coming from outside their organizational boundaries have higher innovation rates (Rosenkopf and Nerkar, 2001). For instance, Laursen and Salter (2006) report evidence showing that wide and deep patterns of external knowledge sourcing positively correlate with a firm's innovative performance. In addition, the literature on innovation and technology indicates that R&D collaboration, technology in-licensing, R&D outsourcing, and hiring of qualified employees are effective mechanisms to source external knowledge and subsequently contribute to determining a firm's innovation (Cassiman and Veugelers, 2006; Laursen et al. 2010; Roper et al. 2008; Hess and Rothaermel, 2011).

By assuming high degrees of openness in a firm's innovation positively correlate with the wide used of previously documented patterns of external knowledge sourcing and these patterns of knowledge sourcing have a positive impact on a firm's innovative performance, Hypotheses 2b can be stated as follows:

> **Hypothesis 2b**: The degree of openness in a firm's innovations enhances its innovative performance.

In order to link public support for R&D projects to firms' innovative performances, the attention is now shifted to the question of how public intervention affects knowledge-sourcing dimensions associated with Hypotheses 2a and 2b.

2.3 The effect of public R&D funding on a firm's knowledge-sourcing strategy

Along the line of the literature on behavioral additionality, here we posit that reception and coverage of public support for R&D changes the knowledge-sourcing behavior of the supported firms. First the influence of public assistance on *the degree of firm's investments in intramural R&D* is considered. There are important spillover-effects that stem from the public supported R&D projects that may have a subsequent impact on the R&D adoption behavior of supported firms. These spillovers can enable firms to develop their ongoing projects (internal, local knowledge sourcing) and/or begin new ventures (internal, distant knowledge sourcing). As

a result, the "scale" and/or "scope" of the supported firms' intramural R&D will be affected by the presence of these knowledge spillovers. Second, because the coverage of R&D funding increases the firms' involvement in R&D, this policy scheme enables supported firms to accumulate experience in the organization and management of R&D projects, facilitating the development of capabilities in these areas. Resultant capabilities may produce productivity gains that advance the progress of further R&D projects (existing and/or new projects). Using this line of reasoning, Roper et al. (2004) indicate that these productivity gains impact subsequent R&D development through an improvement in the firms' research management capabilities and through an enhancement of capabilities in targeting future R&D activities. Because experience gained in conducting publicly funded R&D makes it possible for supported firms to reinforce current projects and/or start new ones, these firms are better positioned to strengthen their investments in R&D. By assuming the intensity of the previously described effects will depend on the amount of public funding received by supported firms, Hypothesis 3a is the following:

> **Hypothesis 3a**: The degree of firms' investments in private R&D is related positively to the amount of the granted R&D subsidy.

In order to explain policy-induced changes in *the degree of openness in firm innovation*, we highlight the role of the following mechanisms. First, because R&D subsidies reduce the cost of undertaking R&D activities, supported firms face enhanced possibilities to reinforce their *learning capabilities*. In particular, public intervention may have a critical role in determining supported firms' levels of *absorptive capacity* (ACAP). As shown by prior studies in organizational learning, experience gained in conducting R&D internally makes it possible for firms to recognize, understand, and apply the R&D performed by others (Cohen and Levinthal, 1990; Lane and Lubatkin, 1998). Therefore, as the granting of R&D subsidies raises firms' involvement in R&D, assisted firms will face enhanced possibilities to build their ACAP, and consequently, they will be better positioned to open their innovation activities more extensively. For instance, as high levels of ACAP induce firms to explore external knowledge sources, they will be more able to participate in R&D alliances with dissimilar technological

partners, leading them to widen the scope of their innovation activities (Lavie and Rosenkopf, 2006). Furthermore, a firm's ACAP has a critical role in enabling the use of external knowledge coming from alternative strategies to R&D collaboration. As documented by other studies, a firm's ACAP also favors knowledge sourcing occurring through mechanisms, such as R&D outsourcing (Cassiman and Veugelers, 2006; Mowery, 1983), technology in-licensing (Laursen et al. 2010), and hiring of knowledge workers (Hess and Rothaermel, 2011). This fact shows that high levels of firms' ACAP are consistent with the use of alternative ways of external knowledge sourcing. Assuming public support for R&D contributes to the development of the supported firms' ACAP, increasing levels of openness in the innovations of these firms is expected because of public programs for supported R&D.

Second, the receiving of public assistance affects the ability of the supported firms to signal the quality of their innovative activities. This holds true because the approval obtained by public agencies helps supported firms to certify the technical and commercial validity of their R&D projects (Lerner, 1999). Given the reduction in information asymmetries related to the value and technological attributes of these projects, public support can play a significant role in attracting potential partners as well as qualified employees. This may reduce the costs of searching for and selecting external knowledge sources involved in the process of opening supported firms' innovations. More recently, some works have confirmed this conclusion, indicating that this attracting effect is particularly relevant in the case of small and medium enterprises (SME) and in the case of firms operating in high-tech industries (Kleer, 2010). Third, by increasing R&D funding opportunities, supported companies may access knowledge more easily through the markets for technology. Compared to R&D collaboration, knowledge access through these markets involves pecuniary transactions and in that sense, involves a direct cost that is reduced progressively as public R&D funding is maintained.

From the previous discussion, it follows that public R&D funding has an impact on firms' behaviors that goes beyond the increased incentives to form R&D cooperation. An important implication is that public intervention not only helps correct *market failures* by increasing firms' incentives to form R&D cooperation, but further contributes to reducing

system failures that usually hamper external knowledge sourcing occurring through other mechanisms[3]. Although traditionally public support for R&D is directed mainly to promoting R&D cooperation with universities and public research centers, here we posit that R&D policy schemes may also have an unintended effect on the external knowledge-sourcing behaviors of firms. Public support for R&D can bring about a wider impact on a firm's external knowledge-sourcing behavior than that traditionally recognized. Altogether, previous arguments lead to the formulation of Hypothesis 3b:

> **Hypothesis 3b**: The degree of openness in the firm's innovations is positively related to the amount of the granted R&D subsidy.

2.4 The mediating role of a firm's knowledge-sourcing strategy

As the coverage of R&D funds is enhanced, supported firms are better placed to undertake R&D activities that are based internally and/or externally. This leads firms to develop their knowledge-sourcing activities. Extensions in the scale and/or scope of their R&D projects, as well as increases in the level of openness in their innovation process, are therefore expected. The acquisition of problem-solving capabilities arising from the induced knowledge-sourcing activities enables supported firms to augment their innovative capabilities. This may translate into a better process of technology and new product development. In line with these suggestions, the intensity in knowledge sourcing is anticipated to mediate the connection between public support for R&D and the firms' innovation. Thus, we expect that the effect of public assistance on firms' innovation (Hypothesis 1) becomes weaker once the influence of the knowledge-sourcing dimensions described above is taken into consideration. This fact involves that these knowledge-sourcing dimensions are conceived of as mechanisms uncovering the potential benefits of public intervention in terms of firms' innovative performances. Consistent with this reasoning, Hypothesis 4 is postulated as follows:

[3] These failures refer to situations that reduce firms' incentives to form links with external actors (Gök and Edler, 2012). These failures include the increasing costs of knowledge access to the markets for technology, lack of experience in sourcing external knowledge in markets, and risks and uncertainties in the development of the projects for which external knowledge sources will be used. These factors could be relevant for inhibiting external knowledge sourcing, particularly in the case of small businesses, recently founded firms, or those with limited resources.

Hypothesis 4: The level of knowledge sourcing of firms mediates the relationship between the amount of public R&D subsidies and the firm innovative performance.

The next section describes the data and methods used in this study to test the hypotheses arrived at above. Attention is focused on the treatment of recognized difficulties associated with the empirical evaluation of the effects arising from public support for R&D.

3. Empirical analysis

3.1 Data

The analysis in this study makes use of data coming from the *Survey of Business Strategy* (ESEE, its Spanish acronym). The ESEE is a firm-year level panel conducted by the Public Enterprise Foundation, in collaboration with the Spanish Ministry of Industry, Energy and Tourism. Starting from 1990, the survey gathers fine-grained information on several dimensions of firms' business strategies and includes an average sample of 1800 manufacturing companies. The ESEE is an unbalanced panel because some companies stopped providing information for reasons such as mergers, shutdown or liquidation. To preserve representativeness, new companies are included in the survey each year. With respect to its scope, the ESEE provides information on firms operating in all the Spanish manufacturing industries, classified according to the two digit-level NACE industry classification (Statistical classification of economic activities in the European Community). The survey is exhaustive for firms with more than 200 employees. For firms having between 10 and 200 employees, a stratified random sample by industry and firm size intervals is collected.

As relevant information about the use of knowledge-sourcing strategies (e.g., R&D alliances, technology in-licensing, or R&D outsourcing) was incorporated into the survey from 1998, we built a longitudinal sample for the period 1998-2005. The methods used in the study require no gaps in the within-firm time series[4]. This requirement leads us to gather a sample that comprises observations (firms) with at least two consecutive values for all the variables under

[4] In particular, these requirements are imposed in the estimation of the model used here to explain the firms' innovative performances.

consideration[5]. After taking away observations with missing values, the sample includes 1,594 firms and 10,309 firm-year observations. This sample has characteristics that are relevant for the purpose of this study. First, its longitudinal design is appropriate to test the mediation hypothesis proposed in the theoretical framework. Because testing for mediation involves causation, the independent, mediation, and dependent variables should not coincide in time (Ndofor et al. 2011; MacKinnon et al. 2007; Cole and Maxwell, 2003). This implies measuring the variable *public support for R&D* prior in time to the variables *degree of firm's intramural R&D* and *degree of openness in firm innovation*, which in turn have to be measured preceding the outcome variable *firm innovative performance*. Second, compared with other datasets (e.g., Spanish Community Innovation Survey), the sample design in the ESEE does not over-represent the set of R&D performer companies. This fact reduces the risk of producing biased results while assessing the innovative performance effects of public support (Santamaria et al. 2010).

3.2 Measures

3.2.1 Dependent variables

Innovative performance: Innovative performance is characterized in terms of marketable results. Specifically, two alternative measures of innovation are used: *patent application counts* and *new product introduction counts*. The aim of selecting these measures is to capture different dynamics of firms' innovation processes that can be affected by public intervention and by a firm's knowledge-sourcing strategy. Specifically, these indicators measure two alternative dimensions of firm innovation: the firms' capabilities on technology, and new product development. Patent counts characterize the part of the innovation process in which firms use sourced knowledge to invent and produce new technologies. New product introduction counts show firms' abilities to apply sourced knowledge in generating products with the capacity to fulfill emerging and/or existing consumers' needs.

[5] An alternative option consists in building a strong balanced panel design. We believe the alternative option may create biases toward larger firms that are at the same time those with a high probability to survive during the period under study. In this case, the validity of our results may be affected.

3.2.2 Mediator variables

Degree of firm's investments in intramural R&D: To characterize this dimension of the firm's knowledge-sourcing strategy, the following procedure was adopted. First, the indicator *R&D intensity*, measured as firms' R&D private expenditure divided by firms' total sales, was built. Second, the quartiles of the variable *R&D intensity* for each year of the sample were calculated. The quartile *j* at time *t* is labeled with Q_{jt}. Then, these quartiles were used to create an ordered-ranking variable that categorized surveyed-firms according to different levels of R&D intensity. This variable takes the value 0 in the case of non-R&D performers and values from 1 to 4 to classify those firms performing R&D with levels distributed between Q_{1t} and Q_{4t}. The reasons for using this operationalization are as follows. In the study of the behavioral effects derived from public support for R&D, we think this variable enables examination of whether public intervention modifies firms' R&D adoption behavior in a substantial way. If public assistance leads firms to reach higher ordered categories on this variable, this is interpreted as a signal indicating significant behavioral changes in a firm's efforts in performing R&D. Because variations across prior categories allow firms to vary their position in the distribution of the variable *R&D intensity* substantively, those changes are assumed to reflect better information about variations in the "scale" and "scope" of the supported firms' R&D projects.

Degree of openness in the firm's innovation: Consistent with the open innovation literature, it is assumed firms can source external knowledge by implementing the following strategies: (i) forming alliances (Grant and Baden-Fuller, 2004; De Man and Duysters, 2005), (ii) acquiring knowledge in markets for technology (Arora et al. 2004; Laursen et al. 2010), (iii) hiring qualified employees (Chesbrough, 2003; Hess and Rothaermel, 2011), and (iv) using consultants' expertise to obtain information about relevant technologies (Weigelt and Sarkar, 2009). To determine the extent to which the surveyed firms source external knowledge extensively, the following procedure was adopted. First, dummies of the firms' assessments of their use of the four external sources were built. The first dummy takes a value of 1 when the firms stated they participated in R&D alliances in the form of joint ventures and/or non-equity-

based agreements. The second dummy is equal to 1 when the firms acquired knowledge in the marketplace by means of licensing-in or R&D contract-based arrangements. The third dummy takes the value of 1 in cases where the firms claimed they hired employees with experience in R&D coming from other companies or from public institutions (e.g., universities, public research centers). The last dummy is equal to 1 when the firms used consulting services to obtain information about valuable technologies. The dummies were added up to create a ranked-ordering measure that varies from 0 to 4. It is assume that firms with a maximum score open their innovation activities extensively by sourcing external knowledge. In contrast, as the score becomes lower, firms are assumed to sustain their innovation activities less by sourcing external knowledge. This composite has a satisfactory degree of internal consistency (Cronbach's alpha = 0.71).

3.2.3 Independent variable

Public funding for R&D: In this study, public support for R&D was measured as the logarithm of the amount received in subsidies annually by each firm from national R&D support programs. The data allow discrimination among three alternative sources of funding (regional, national, and other funding programs). By taking advantage of this fact, the focus of attention was placed on funding provided by national programs established by the Spanish government. In doing so, we aim to mitigate the presence of the heterogeneity that might affect the evaluation of the effects derived from public support. This heterogeneity may arise because of differences across programs in terms of technology policy objectives, selection rules, amount of funding and eligibility conditions (Busom and Fernández-Ribas, 2008). The use of an aggregate measure would make it difficult to distinguish between the effects of public support on both innovation performance and knowledge-sourcing dimensions from those due to the specific characteristics of the funding programs. Support granted by other funding programs raises further concerns that led to the exclusion of the variable other funding programs as an independent variable. There is a presumption that an important part of this funding comes from European agencies. Because openness in firm innovation is a requirement commonly imposed by these agencies to grant support for R&D, the inclusion of European funding as a part of the

independent variable could create an endogeneity problem that would affect the hypothesis testing procedure.

3.2.4 Control variables

Next, five control variables were included. First, we controlled for the firms' predispositions to explore new technologies because this aspect can determine firms' knowledge-sourcing behaviors. Exploration search may lead firms to widen the scope of their intramural R&D activities and the breadth of their external knowledge sources. Exploration was measured by the variable *technological assessment*, which is a dummy variable that takes the value of 1 when firms asserted they evaluated alternative technologies and/or technological change perspectives. Second, we controlled for *firm size* because larger firms may have richer endowment of tangible and intangibles resources that enable them to organize and exploit R&D activities (internally and/or externally). Larger firms are less financially constrained. Being less financially constrained may affect the configuration of firms' knowledge-sourcing strategies as well as their innovative performances. Firm size was measured as the logarithm of the number of employees. Third, we controlled for the *firm's export intensity* because of its influence on stimulating knowledge sourcing and innovation. Firms with high levels of export intensity are expected to source knowledge extensively and to innovate more to compete effectively in international markets. Export intensity was measured as firm's exports divided by firm total sales. Fourth, we controlled for the influence of *market structure*. Firms operating in highly concentrated markets may source knowledge intensively in order to improve their technologies and products and subsequently exploit their current positions in the market. In contrast, market concentration may inhibit the search for knowledge and undertaking innovation activities because of lack of competition. We measured market structure using a dummy variable that takes the value of 1 if firms stated that they operate in a market with less than 10 competitors.

Finally, we controlled for the presence of *industrial technological opportunities*. Firms operating in industries with high technological opportunities face higher incentives to reinforce their knowledge-sourcing strategies as a way to access to such opportunities. The presence of technological opportunities may improve the entire process of technology and product

development, affecting a firm's innovative capabilities. We measured technological opportunities as total industry R&D expenditures normalized by total industry sales[6]. To allow for a non-linear relationship between technological opportunities and firms' innovative performances, on the one hand, and the knowledge-sourcing dimensions on the other, the square of the measure of technological opportunities was also included.

3.3 Methods

To test the set of hypotheses previously described, the following procedure was adopted. First, two sets of models were estimated, one for examining the determinant of a firm's innovative performance and the other for studying the drivers of the knowledge-sourcing dimensions under consideration. Subsequently, Baron and Kenny's (1986) widely used method was implemented to test for the mediation hypothesis derived from the framework[7]. A mediation effect is present when (i) public funds for R&D influence a firm's innovative performance significantly, (ii) public funds for R&D significantly affect both knowledge-sourcing dimensions, (iii) knowledge-sourcing dimensions determine a firm's innovative performance significantly once the influence of public support for R&D is controlled, and (iv) the effect of public support for R&D on a firm's innovative performance reduces or vanishes when the mediator variables are included.

Finally, in the case of each model, the potential endogeneity of public support was taken into account. Prior research on innovation-policy evaluation has identified two sources of endogeneity (e.g., Almus and Czarnitzki, 2003; Busom, 2000; Gelabert et al. 2009). The first source arises from the *self-selection* of firms in the participation stage. This is due to the presence of specific observable and unobservable characteristics that explain a firm's innovation and its knowledge-sourcing behavior along with its incentives to participate in policy programs for promoting R&D. The second source of endogeneity arises from *the decision rules adopted by the agencies* that assign the R&D grants. These agencies can provide support to the more

[6] We measured industry R&D expenditure and sales at two-digit NACE.

[7] This method has recently been implemented in studies on innovation-policy evaluation (Autio et al., 2008). More applications are found in fields such as organizational design for R&D (Leiponen and Helfat, 2011), R&D management (Lejarraga and Martínez-Ros, 2010), and alliance performance (Heimeriks and Duysters, 2007).

innovative firms or to those with previous experience in knowledge sourcing (called picking-the-winners-effect) as a way to show the effectiveness of their public R&D funding programs. The sources of endogeneity suggest that factors determining the amount of public support may also affect a firm's innovation and knowledge-sourcing behavior. While the presence of observable and unobservable elements influencing the access and amount of public support are likely to shape a firm's innovation and its strategies of knowledge acquisition, it follows that public intervention might be neither endogenous to firms' innovative performance nor to the firm's knowledge-sourcing behavior.

3.3.1 Model explaining firms' innovative performances

In order to test Hypotheses 1and 2, the following procedure was adopted. Given the panel design of the sample and the nature of the dependent variables (patent application counts and new product introduction counts), we reviewed the literature on count-panel data analysis to choose the model that accounted better for the presence of endogeneity (e.g., Montalvo, 1997; Wooldridge, 1997; Hausman et al. 1984). The choice led us to implement a count-panel data model with fixed effects and endogenous covariates. This model was estimated using a Generalized Method of Moments (GMM) estimator with Wooldridge moment conditions (for more details, see Windmeijer, 2000; Wooldridge, 1997). The implemented specification is advantageous for several reasons. First, compared to the standard fixed-effects estimator in count-panel data developed by Hausman et al. (1984), the estimator used here provides consistent estimations even in the presence of non-strict exogenous covariates (Wooldridge, 1997). Second, the treatment of endogeneity is not limited to the public support indicator, but can also be extended to other covariates of the model. By viewing the knowledge-sourcing dimensions as predetermined variables, the model allows consistent estimations of the effects that such dimensions may have on the firm innovative performance to be estimated.

3.3.2 Model explaining knowledge-sourcing dimensions

Given that the measures of knowledge-sourcing dimensions are ordered ranking variables, we used regression analysis for ordinal response variables to analyze Hypothesis 3. To do so, we followed Papke and Wooldridge (2008) and Wooldridge (2002) to treat the

presence of endogeneity in the context of models with ordinal response variables and panel data. Specifically, the presence of time-invariant unobserved heterogeneity was accounted for by implementing the method developed by Chamberlain (1984). In order to allow time-constant omitted factors to be correlated with the covariate under consideration (the controls previously described), in the estimation, the time average of these covariates was included.

Furthermore, the fact that *time-varying omitted factors* might be correlated with the public funds for R&D was taken into consideration. To handle this issue, we used an instrumental-variable estimation approach. We reviewed the extant literature about innovation-policy evaluation to choose valid instruments for the case (e.g., Busom, 2000; Hussinger, 2008)[8]. The variable *foreign capital*, measured as the percentage of foreign participation in the share capital of a firm, was taken as an exclusion restriction. We posit that this foreign capital should drive the amount a firm receives of public R&D funds but not its knowledge-sourcing behavior. As suggested by González et al. (2005), agencies granting R&D funds prefer to support domestic firms rather than affiliates of foreign-owned companies. Thus, we anticipate a negative relationship between the amount of R&D funding and the presence of foreign ownership. Moreover, because R&D adoption choices in the case of subsidiaries of foreign companies are taken probably at the level of their corporate headquarters, it was anticipated the variable *foreign capital* would not affect the knowledge-sourcing strategies of these types of companies significantly.

Taking into account the previous concerns, we implemented a two-step estimator as follows. In the first stage, we estimated a pooled Ordinary Least Squares (OLS) regression model in which the log of public R&D funding is regressed on the control variables previously described, the variable foreign capital as well as the firm-level average of all the covariates (including the time average of the exclusion restriction). In the second stage, we estimated a pooled ordered-probit model, where each of the knowledge-sourcing dimensions is determined

[8] In line with other studies, we also considered the following instruments: Public funds for R&D at the industry level, public funds for R&D at regional levels (Gelabert et al. 2009), and interaction terms between the accumulated patent count and public funds for R&D (Hussinger, 2008). We ruled them out because these instruments affected at least one of the knowledge-sourcing dimensions under consideration significantly.

by the endogenous variable (log of public R&D funding), the control variables, the firm-level average of all the covariates, and the residuals corresponding to the first-stage estimation. According to the method developed by Rivers and Vuong (1988), the estimated coefficient of the residuals provides a valid test for the presence endogeneity of public funds to support R&D.

4. Results

Table 1 lists the descriptive statistics and bivariate correlations for the variables under question. Given the existence of moderately high correlations for the case of some pairs of variables and that the presence of multicollinearity is particularly problematic in the estimation of mediated models; the threat of this issue was assessed by estimating the *variance inflation factor* (VIF). Furthermore, as a form to mitigate potential multicollinearity, the measure of industrial technological opportunity was centered on its mean before creating its squared term. After doing so, average VIFs for all the covariates were found to be 2.05, with a maximum value of 3.42 in the case of the models explaining the firm innovative performance, and 1.92, with a maximum value of 3.60, in the case of the models explaining the knowledge-sourcing dimensions. In all the cases, the VIFs were very below of the conservative ceiling of 5 (Cohen and Cohen, 1983).

[Insert Table 1 here]

Table 2 shows the estimations of the parameters for the models explaining the firm innovative performance. The estimations were obtained using *ExpEnd*, a gauss routine for the non-linear GMM estimation of exponential models with endogenous covariates (Windmeijer, 2002). Lagged values of the covariates measured at firm-level are used as valid instruments (see the note of Table 2 for more details). Variables measured at the industry levels are assumed to be exogenously determined. Table 2 also includes the Sargan's test for the over-identifying restrictions. This statistic provides a test for verifying if the instruments under question are appropriately orthogonal to the residuals. As indicated by Table 2, all the cases using Sargan's test confirmed the validity of the instruments used in the estimations. Moreover, in order to test

for the presence of residual serial correlation, Table 2 shows the values for first and second-order autocorrelation tests as described by Windmeijer (2002).

[Insert Table 2 here]

Models 1 to 4 present the results when predicting firm innovation in terms of patent application counts, whereas Models 5 and 6 report the results when predicting firm innovation in terms of new product introduction counts. With respect to patents, the results reported in Model 1 indicate that the coverage of public funds for R&D positively determines the patent application counts. This finding gives support to the presence of output additionality and confirms Hypothesis 1. Model 2 shows that the effects of both knowledge-sourcing dimensions are positive and statistically significant, giving strong support to Hypothesis 2a and 2b. Despite its reduction, the effect of public funds granted for R&D initiatives remains positive and statistically significant once the influence of knowledge-sourcing dimensions is controlled. However, Models 1 and 2 suffer from first-order autocorrelation, indicating the presence of a misspecification problem. To cope with this issue, in Model 3 and 4, the lag of the patent counts to implement a dynamic specification was included using a linear feedback model as developed by Blundell et al. (2002). Previous results are robust for the presence of patent persistence effects. The impact of public funds granted for R&D remains positive and statistically significant, in line with Hypothesis 1. Model 4 indicates that both knowledge-sourcing dimensions positively determine the firms' patent activities, in line with Hypotheses 2a and 2b. Compared to the degree of investments in intramural R&D, the impact of the level of openness the firms' patent activity is particularly strong. After controlling for the influence of knowledge sourcing, the impact of public funds for R&D shrinks, but remains positive and statistically significant. This suggests that the presence of output additionality rests even after accounting for the firms' knowledge-sourcing strategies. With this specification, the existence of a first-order correlation remains, but there is no second-order correlation. This confirms Models 3 and 4 are well specified (Windmeijer, 2002).

Models 5 and 6 show the results for the case in which the firms' performances are expressed in terms of new product introduction counts. Model 5 confirms Hypothesis 1, revealing a positive and significant effect of public funds for R&D on a firm's new product introduction counts. This shows output additionality in terms of new product introductions. Knowledge-sourcing dimensions also have a positive and statistically significant influence on new product introduction activity, supporting Hypotheses 2a and 2b. Interestingly, Model 6 shows that the effect of public funds for R&D is no longer statistically significant when the influence of knowledge-sourcing dimensions is considered. This is in line with the premise that the effect of public funds on new product introductions includes a large part relating to the way firms source knowledge for their innovations. Neither first nor second-order autocorrelation is detected in this case, suggesting these models are well specified[9].

In general, the results for the control variables have the expected signs. The effect of *technological assessment* is positive and strongly significant in all the cases, showing that firms' predispositions to explore new technologies contributes to enhancing firm innovation. *Firm size* has a positive and statistically significant effect on both dimensions of firm innovation, in line with the premise that complex organizations are better positioned to innovate. *Export intensity* has a positively significant influence on innovation, indicating that internationalization is a push-force inducing innovation. *Market structure* matters, particularly in the case of explaining firm patent activity. Market concentration favors the firm capacity to apply for patents. Interestingly, the effect of *industrial technological opportunities* tends to be negative in the case of firm patent activity. This suggests the presence of competitive rather than diffusion spillover effects (Cincera, 1997). With respect to new product introductions, there is evidence showing the existence of a curvilinear effect. Specifically, finding suggests that competitive spillovers prevail over diffusion spillovers, once a certain threshold of technological opportunity is achieved.

[9] Consistent with this fact, further experimentation with other specifications shows that the lag for new product introduction counts fails to be statistically significant. Thus, no persistent effects are detected in this case.

Table 3 contains the results relevant for Hypotheses 3 and 4. The estimations were obtained from pooled ordered-probit models with instrumental variables and fixed-effects. The corresponding first-stage estimation is reported by Model 9. Results from Model 7 and 8 confirm public funds for R&D positively determined not only the degree of firm investments in intramural R&D, but also the degree of openness in a firm's innovation. These findings confirm Hypotheses 3a and 3b and are line with the proposition that public funds for R&D give rise to behavioral changes in the way firms source knowledge across the innovation process. As regards the control variables, it is observed that the effect of *technological assessment* is positive and statistically significant in both models, showing that exploration leads firms to source knowledge more extensively. *Export intensity* affects the degree of openness consistent with the idea that internalization enhances firms' incentives to search external knowledge broadly. *Industrial technological opportunities* determine the degree of firms' investment in intramural R&D, but surprisingly, not the level of openness.

[Insert Table 2 here]

Hypothesis 4 predicts that the degree of firms' investments in intramural R&D and the degree of openness in their innovations will mediate the relationship between the amount received of public R&D funding and their innovative performance. By implementing the causal-step method of Baron and Kenny (1986), we verified the existence of mediation in the process of technology and new product development. With respect to patents, findings from Models 1 to 8 indicate the existence of *partial mediation*. Public funds for R&D not only directly impact a firm's patent activity, but also have an indirect effect through the firm's investment intensity in intramural R&D and the degree of openness in its innovations. With respect to new product introduction counts, Models 1 to 8 show the existence of a *full mediation*. This result implies that knowledge-sourcing dimensions are the channels by which the impact of public funds for R&D translates into a firm's enhanced product innovation capacity and no direct effects influence this capacity. In addition, the effectiveness of public intervention in promoting

product innovation depends on the effects of policy R&D schemes for inducing firms to source knowledge in a more extensive way.

Concerning the validity of the instrument implemented in the estimation, results of the first-stage in Model 9 show that the estimated parameter of foreign capital has a negative and statistically significant impact on the amount granted of public funds for R&D. This partial correlation gives some support to the validity of this instrument. Moreover, results from Models 7 and 8 indicate that reduced-form residuals derived from the first-stage estimation have a statistically significant effect on both knowledge-sourcing dimensions, thus justifying the use of instrumental variables.

To assess the validity of the earlier results, several robustness checks were conducted. In Models 7 and 8, we used the ordered logistic model developed by Baetschmann et al. (2011), which accounts for the presence of fixed-effects. The residuals obtained from the first-stage estimation were plugged into this model to account for time-variant heterogeneity. Given the presence of potential inter-relations between the knowledge-sourcing dimensions under consideration, we tested for Hypotheses 3a and 3b by estimating a pooled bivariate ordered-probit model, which accounts for the potential interdependencies of these dimensions. These interdependencies are not a cause of concern in the test of Hypothesis 1 because the VIF values indicated the absence of multicollinearity. Hypotheses 1 and 4 were tested using the continuum variable, namely, R&D intensity, as a proxy for the degree of investments in intramural R&D instead of its ordered-ranking version. To model R&D intensity in Model 7, we implemented a Tobit specification with fixed effects and endogenous variable as described by Gelabert et al. (2009). Models 1-6 were also estimated using the variable R&D intensity in place of its ordered-ranking counterpart. In all the cases tested, similar results to those previously reported were obtained.

5. Discussion and conclusions

This study examines whether knowledge-sourcing behavior of firms supported by public funds, defined by the degree of investments in intramural R&D and the level of openness in innovation, comprises a mechanism that explains the potential benefits of public R&D funds.

Using a panel of Spanish manufacturing companies, this study is among the first to estimate a mediated model for examining the causal links between R&D subsidies, firms' knowledge-sourcing behaviors, and firms' innovative performances.

The results of this study strongly support the premise that the level of knowledge sourcing applied by supported firms mediates the relationship between the grant of public R&D funding and firms' innovative performances. Full mediation is found in the link between the granting of public R&D funding and a firm's capacity to make new product introductions. This result indicates that output additionality in terms of new product introductions vanishes once the levels of knowledge sourcing implemented by supported firms is considered. In addition, partial mediation is found in the link between coverage by public R&D funds and firms' patent applications. In this case, public intervention influences patent activities of supported firms directly, producing output additionality, and indirectly through its influence on the firms' knowledge-sourcing behaviors. Although this study implements a different approach, the results confirm the findings reported by Czarnitzki and Licht (2006) and Hussinger (2008) that public intervention has a direct effect on firms' innovation and an indirect effect that transmits through policy-induced increases in the firms' R&D. The results add to prior studies by indicating that public R&D funding affects firms' innovation not only by inducing a larger scale and/or scope in its intramural R&D activities, but further, by stimulating a greater degree of openness about its knowledge-sourcing activities. Although prior studies have begun to examine the impact of public intervention on R&D collaboration (Afcha, 2011; Busom and Fernández-Ribas, 2008), no evidence has been reported about the effects of such intervention on firms' adoption of other external knowledge-sourcing strategies.

5.1 Implications

The findings of this study have relevance for both innovation management and innovation policy. With respect to innovation management, previous findings suggest that firms' strategies (e.g., knowledge-sourcing actions) may play a critical role in boosting their available resources (e.g., coverage of public assistance). By increasing their involvement in intramural R&D activities and/or by opening their innovation extensively, supported firms make

the most of the receiving public funds to generate innovations. An implication of this fact is that strategies that assist firms in reinforcing knowledge-sourcing activities will also contribute to grasping the potential benefits of public assistance. This suggestion is in line with the work of Wong and He (2003), who show that public R&D support is more effective in stimulating innovation when firms create an internal organizational culture for innovation. Likewise, practices promoting the implementation of open innovation models, namely, the use of information technologies, cross-functional teams and incentives based on more open-orientated-metrics, may further lead firms to give leverage to their knowledge-sourcing activities, favoring thus the realization of the benefits of public support for R&D. In that sense, the findings are in accordance with emerging studies on resource management (e.g., Ndofor et al., 2011; Sirmon et al., 2011) that highlight the role of firms' actions in articulating the exploitation of their resources.

With respect to innovation policy, this study shows that public assistance effectiveness in enhancing firm innovation relies on the influence of policy schemes on increasing assisted firms' involvement in knowledge-sourcing activities. Thus, programs encouraging the acquisition of problem-solving capabilities (within and/or outside firms' organizational boundaries) may result in further innovations. For instance, policies that improve the efficiency of markets for technology (e.g., creating or developing property rights), promote cooperation (e.g., founding of R&D consortia), or enable mobility of knowledge workers (e.g., among private and public institutions) may support firms in increasing the degree of openness in their innovations. In doing so, these policies can also lead firms to acquire skills and problem-solving capabilities that subsequently contribute to the realization of the benefits derived from public assistance. Similarly, policies allowing firms to develop their human resources (e.g., technical training programs) may also facilitate the undertaking of knowledge sourcing through intramural R&D activities and then grasp the potential benefits attributable to public intervention. Taken together, these suggestions inform innovation-policy makers by indicating that important complementarities may exist between alternative policy instruments. Innovation-policy design including a package of schemes can be more effective than programs based on

insolated policy instruments. For instance, the contribution of R&D subsidies to promoting firm innovation can increase if policies promoting the use of open innovation models in firms are also applied. An implication of this fact is that innovation policy combining several schemes may correct not only market failures (underinvestment in R&D), but also system failures (lack of connectivity across organizations).

5.2 Limitations

The results of this research are subject to some limitations, which at the same time, open new avenues for future research. First, the empirical design infers firms' knowledge-sourcing behavior using the outcomes derived from such behavior. This prevents examination of the emergence of new specific behaviors in knowledge sourcing that are induced by public intervention. In terms of the conceptualization of behavior additionality advanced by Gök and Edler (2012), our operationalization of knowledge-sourcing, or the degree of a firm's investment in intramural R&D and degree of openness in a firm's innovation, remains simple and only encompasses the scale and scope dimensions of the assisted firms' R&D behavior (internally and externally based). Thus, it is recognized that more research is needed to detect the emergence and evolution of specific organizational routines that can explain how supported firms realize the benefits of public interventions. Second, the study is focused on the manufacturing industry, leaving apart the analysis of the links between public intervention, firms' behavior and innovation outcomes for the case of the service industry. Because service companies largely innovate by using non-R&D activities, they draw on different knowledge-sourcing strategies from that prevailing in manufacturing companies (Tether and Tajar, 2008). The role of service firms' knowledge-sourcing activities in realizing the benefits of public assistance remains largely understudied. Third, other R&D schemes are not fully considered in the analysis of the data. The role of regional innovation policy and the effects of European programs in shaping firms' knowledge-sourcing behavior and the consequences of induced behavioral changes need much more attention. In addition, examination of complementarities between alternative policy instruments and their potential effects on firms' knowledge-sourcing behavior and their innovation outcomes are issues deserving more attention.

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***Figure 1*. Model explaining the links between the R&D subsidies and the firms' innovative performances.**

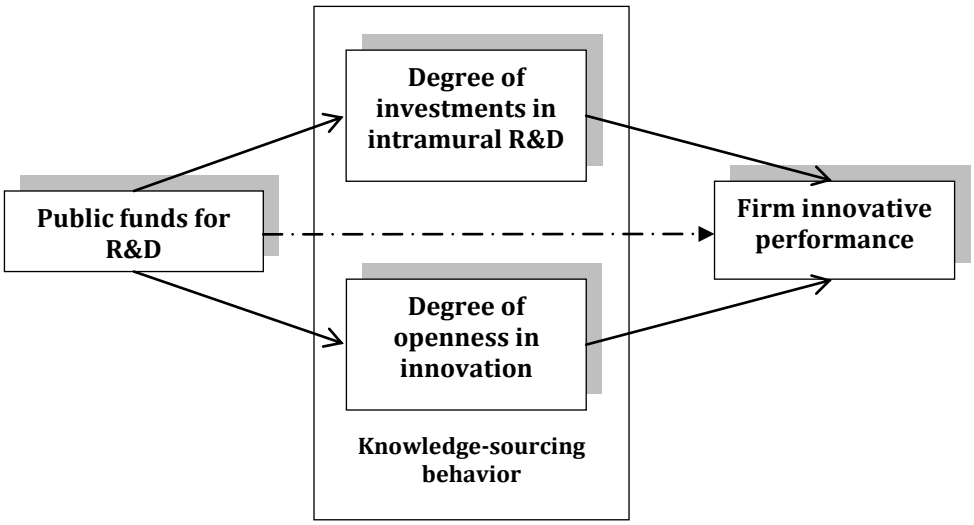

Table 1. Correlations and Descriptive Statistics

Variables	Mean	*SD*	Min	Max	1	2	3	4	5	6	7	8	9	10	11	12
1. Patent applications	0.41	4.64	0	158	1.00											
2. New product introductions	1.88	12.09	0	423	0.00	1.00										
3. Degree of investments in intramural R&D	0.71	1.27	0	4	0.15*	0.13*	1.00									
4. Degree of openness in innovation	1.01	1.32	0	4	0.14*	0.10*	0.64*	1.00								
5. Public funding for R&D§	0.31	1.31	0	11.50	0.21*	0.06*	0.44*	0.41*	1.00							
6. Technological assessment	0.32	0.46	0	1	0.09*	0.06*	0.41*	0.61*	0.25*	1.00						
7. Firm size§	4.12	1.45	0.69	9.47	0.12*	0.08*	0.42*	0.61*	0.33*	0.36*	1.00					
8. Firm export intensity	18.64	26.02	0.00	100.00	0.06*	0.10*	0.37*	0.44*	0.21*	0.27*	0.55*	1.00				
9. Market structure	0.56	0.50	0	1	0.00	0.01	0.16*	0.22*	0.09*	0.16*	0.28*	0.16*	1.00			
10. Technological opportunities (industry level) †	0.00	0.98	-1.04	7.38	0.05*	-0.01	0.22*	0.19*	0.19*	0.10*	0.14*	0.14*	0.06*	1.00		
11. Technological opportunities squared (industry level) †	0.97	4.27	0.00	54.44	0.02	-0.01	0.11*	0.12*	0.13*	0.06*	0.10*	0.08*	0.05*	0.92*	1.00	
12. Foreign capital	16.99	36.31	0.00	100.00	0.01	0.03	0.23*	0.35*	0.14*	0.19*	0.48*	0.37*	0.20*	0.11*	0.04*	1.00

Note: § log values; † values centered at their means; * correlations are significant at $p<0.01$.

Table 2. Regression Results for Firms' Innovative Performance

Independent variable	Number of patents				New product introductions	
	Model 1	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**
Lag of the number of patents	_	_	0.069*** (0.002)	0.048*** (0.001)	_	_
Technological assessment	1.558*** (0.125)	0.584*** (0.047)	1.213*** (0.047)	0.051** (0.019)	0.097** (0.041)	0.162*** (0.039)
Firm size	0.381*** (0.100)	0.331*** (0.084)	0.657*** (0.084)	0.580*** (0.055)	0.451*** (0.101)	0.308*** (0.073)
Export intensity	0.585*** (0.055)	0.376*** (0.036)	0.623*** (0.036)	0.445*** (0.024)	0.046* (0.024)	0.126** (0.010)
Market structure	0.315 (0.199)	0.606*** (0.102)	0.435*** (0.106)	0.834*** (0.035)	0.121* (0.062)	0.004 (0.040)
Industrial technological opportunities	0.689** (0.253)	0.215* (0.127)	0.141 (0.101)	0.038 (0.047)	0.466** (0.197)	0.282** (0.140)
Industrial technological opportunities squared	-0.188*** (0.051)	-0.123** (0.039)	-0.114*** (0.026)	-0.124*** (0.022)	-0.160*** (0.033)	-0.115*** (0.030)
Public funds for R&D	0.147*** (0.028)	0.065** (0.026)	0.276*** (0.017)	0.186*** (0.014)	0.065* (0.034)	0.030 (0.030)
Degree of investments in intramural R&D	_	0.206*** (0.018)	_	0.091*** (0.011)	_	0.157*** (0.018)
Degree of openness in innovations	_	0.504*** (0.036)	_	0.540*** (0.021)	_	0.153*** (0.029)
Time dummies	*Included*	*Included*	*Included*	*Included*	*Included*	*Included*
Test for serial correlation						
First-order serial correlation	-1.739*	-1.959**	-1.740*	-2.055**	-0.006	0.327
Second-order serial correlation	-1.098	-0.015	1.031	1.523	-1.173	-1.385
Over-identification test						
Sargan's test	56.0212	89.4286	80.6906	106.9141	45.6057	81.3003
p-value	0.2283	0.2443	0.1216	0.2759	0.6115	0.4697

Notes: (i) Parameters are two-step GMM estimators using Wooldridge moment conditions. Estimations assume that firm-level explanatory variables should be taken as predetermined. Therefore, past values of these variables are used as valid instruments. (ii) Lag values of the dependent variable are also used as instruments in Models 3 and 4. A maximum of four lags for each predetermined variable was implemented in all the specifications. (iii) The variable *public funds for R&D* is measured at time *t-2*, while the variables *degree of investments in intramural R&D* and *degree of openness in innovation* are measured at time *t-1*. Robust standard errors in parentheses: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table 3. Regression Results for Knowledge-Sourcing Dimensions

Independent variable	Degree of intramural R&D Model 7	Degree of openness in innovation Model 8	Log of public funds for R&D Model 9
Public funds for R&D	0.082*** (0.012)	0.063*** (0.019)	–
Technological assessment	0.076* (0.044)	0.116*** (0.041)	-0.007 (0.042)
Firm size	0.176 (0.111)	-0.026 (0.088)	-0.063 (0.047)
Export intensity	-0.027 (0.034)	0.052* (0.029)	0.008 (0.020)
Industrial technological opportunities	0.242*** (0.088)	-0.012 (0.091)	0.028 (0.123)
Industrial technological opportunities squared	-0.035*** (0.012)	-0.003 (0.014)	-0.007 (0.022)
Market structure	0.030 (0.049)	-0.023 (0.046)	-0.037 (0.037)
Foreign capital	–	–	-0.051* (0.031)
$\Lambda_{\text{Technological assessment}}$	1.008*** (0.102)	1.605*** (0.083)	0.598*** (0.092)
$\Lambda_{\text{Firm size}}$	0.033 (0.115)	0.420*** (0.091)	0.301*** (0.057)
$\Lambda_{\text{Export intensity}}$	0.195*** (0.041)	0.040 (0.034)	0.002 (0.027)
$\Lambda_{\text{Industrial technological opportunities}}$	0.475*** (0.103)	0.349*** (0.099)	0.327** (0.152)
$\Lambda_{\text{Industrial technological opportunities squared}}$	-0.104*** (0.019)	-0.056*** (0.018)	-0.020 (0.043)
$\Lambda_{\text{Market structure}}$	0.109 (0.098)	0.136* (0.080)	-0.051 (0.070)
$\Lambda_{\text{Foreign capital}}$	-0.036* (0.019)	0.020 (0.015)	0.005 (0.040)
Residuals	0.125*** (0.014)	0.094*** (0.018)	–
Constant	–	–	-0.775*** (0.119)
Time dummies	*Included*	*Included*	*Included*
Goodness of fit	$\chi^2(21) = 916.870$***	$\chi^2(21) = 1620.422$***	F(20,1593) = 6.742***
Pseudo R-squared	0.236	0.295	–
R-squared	–	–	0.167
Observations (NxT)	8,715	8,715	8,715

Notes: (i) Parameters are estimated using a pooled ordered-probit regression model. (ii) The term Λ (variable) stands for the firm-level mean of the corresponding variable. (iii) The term *Residuals* refer to the errors of the first-stage estimation reported by Model 9. Robust standard errors in parentheses: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.