The Relevance of Different Open Innovation Strategies for R&D Performers

Relevancia de distintas estrategias *"Open Innovation"* para las empresas que hacen I+D

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Summary: 1. Introduction. 2. Beyond Internal R&D: OI Strategies. 3. OI Strategies: Expected Relationships by Innovation Nature. 4. Methodology. 5. Empirical Results. 6. Discussion and Conclusions. 7. References.

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ABSTRACT: The Open Innovation (OI) paradigm has emphasized the role of external knowledge in aiding internal R&D efforts. While most research based on this model has focused on high-tech sectors, this paper attempts to extend it to more mature industries. The study also analyzes a wide range of OI strategies and their relationships with different innovation outcomes. The empirical results, based on a large sample of Spanish manufacturing firms, show that OI strategies are highly effective tools for making internal R&D efforts more successful, both in high- and low-tech sectors. In addition, the study finds evidence that market-based strategies are positively correlated to achieving process innovations, while partnering strategies have a similar relationship with product innovations. More formalized OI strategies, such as joint ventures, show positive relations with the achievement of patent results.

Key words: Open Innovation strategies; internal R&D; innovation outputs; panel data; Spain; Low-tech sectors

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RESUMEN: El paradigma *"Open Innovation"* (OI) enfatiza el papel del conocimiento externo como apoyo a los esfuerzos internos en I+D. La mayoría de investigaciones realizadas sobre este modelo se han centrado en sectores intensivos en tecnología, mientras que en este trabajo se expande su aplicación a sectores más maduros. El estudio también analiza un amplio rango de estrategias OI y su relación con distintos resultados innovadores. El análisis empírico, basado en una amplia muestra de empresas manufactureras españolas, indica que las estrategias OI son mecanismos altamente efectivos para que los esfuerzos internos en I+D sean más fructíferos, tanto en sectores de alta como baja intensidad tecnológica. Además, el estudio aporta evidencia sobre la relación positiva entre estrategias basadas en relaciones de mercado y la consecución de innovaciones en proceso, mientras que las estrategias de colaboración tienen un vínculo similar con las innovaciones de producto. Estrategias de colaboración más formales, como las joint ventures, muestran una relación positiva con la obtención de patentes.

Palabras clave: Estrategias *"Open Innovation";* I+D interno; resultados innovadores; datos de panel; España; sectores de baja intensidad tecnológica

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1. Introduction

A number of studies related to the economics of innovation and technological change have highlighted the role of internal R&D activities as a critical source of firm-level innovations (Freeman 1994; Kleinknecht 1996; Hirsch-Kreinsen et al. 2005). However, performing R&D activities could not be a sufficient condition to obtain innovative results. As innovation occurs primarily through new combinations of resources, ideas, and technologies, a fertile innovation environment relies on a constant inflow of knowledge from other places (Fey and Birkinshaw, 2005). In addition to internal R&D, firms typically tap knowledge sources external to the firm through technological consultants, R&D outsourcing, cooperative agreements, or the hiring of qualified researchers with relevant knowledge. Even the largest innovation-active organizations cannot rely solely on internal sourcing; they also require knowledge from beyond their boundaries (Chesbrough and Crowther, 2006; Rigby and Zook, 2002).

Many authors have argued for the benefits of opening the innovation process to external knowledge flows, suggesting that the ability to combine internal and external information inputs can increase the productivity of in-house activities (Cassiman and Veugelers, 2006). This view fits the so-called "Open Innovation" model (Chesbrough, 2003a). Up to now, however, this new paradigm has been applied only to firms in high-tech sectors and concern is growing about its utility as a paradigm for industrial innovation in more traditional and mature industries (Chesbrough and Crowther, 2006). Indeed, recent studies show that an open attitude towards external sources of knowledge has been revealed as especially important for the innovation process of low and medium-tech industries (Tsai and Wang, 2009).

The contribution of this paper is to empirically analyze how distinct modes of organization for external sources of innovation –Open Innovation (OI) strategies– are related to the innovation outcomes of firms performing internal R&D. We also expect that the relevance of these OI strategies can be expanded to more mature industries (i.e. low-tech sectors) in addition to the well-known role that external sources exert in high tech settings. To accomplish with this goal we examine a wide range of OI strategies, from market-based sources –such as external

R&D, purchase of consulting services and hiring of employees- to hybrid forms of collaboration –joint ventures and non-equity alliances. Finally, we analyze whether the relationships of these OI strategies will vary depending on the nature of the innovation outcome pursued (product and process innovations, and patents).

This study's empirical analysis is based on a large sample of Spanish manufacturing firms from 1998 to 2002. This sample has been used by many other researchers to study innovation topics (see for instance, Beneito, 2006). The use of such a sample adds value to this study because – to the best of our knowledge – only Laursen and Salter (2006) have empirically examined the "Open Innovation" model with a large-scale database. The descriptive results show that the success of the innovation process of firms performing internal R&D is not simply related to these internal efforts. Approximately 70% of internal R&D performers achieve at least one innovation outcome. Nevertheless, in the sub-sample of firms that rely solely on internal R&D (without employing any OI strategy) this percentage drops to 50%. In contrast, near 80% of firms that complement internal efforts with OI strategies achieve some innovation results. Thus, a lack of openness in firms' internal R&D efforts could be explaining this difference.

The paper is organized as follows. The next section reviews the most relevant literature on the impact of various external sources on firms' innovation outputs. The third section outlines the methodology, describing the data and variables; it also includes a descriptive analysis. Section four reports the results of the empirical models, and the final section explains the study's conclusions, limitations and managerial implications.

2. Beyond Internal R&D: OI Strategies

Research indicating that innovation and technical progress are the main drivers for economic growth (Solow, 1957) has lead researchers and managers to associate a strong internal R&D capability with innovativeness (Gassmann, 2006: 223). Nevertheless, Chesbrough (2003a) suggests that many innovative firms have shifted to an OI model, using a wide range of external actors and sources to achieve and sustain innovation. The "do-it-yourself" attitude in the innovation process has been superseded by a rich picture of different actors working together in order to succeed in the commercial exploitation of new ideas (Laursen and Salter, 2006: 132).

Chesbrough (2003a, b) emphasizes the interdependencies in the innovation process, arguing that the decline in the strategic advantage of internal R&D is related to the greater range of producers of knowledge. As most innovation is the result of mixing resources, ideas, and technologies in novel ways, a productive innovation environment requires the constant entry of knowledge from other places (Fey and Birkinshaw, 2005). Most end products embody an increasingly broad set of technologies that require highly specialized capabilities. The upshot of this situation is that firms can no longer hope to do everything in-house (Iansiti, 1997). Thus, the open innovation process redefines the boundaries between firms and their environments. These boundaries become more porous as firms are embedded in loosely coupled networks of different actors, collectively and individually working towards commercializing new knowledge. Our main research expectation, then, is that external inputs are positively correlated with the productivity of in-house activities (Cassiman and Veugelers, 2006). In other words, R&D performers are able to complement their internal efforts and achieve innovation results by using OI strategies.

The importance of OI strategies beyond the high-tech sector – specifically in more traditional and mature industries – remains an open question and continues to generate debate (Chesbrough and Crowther, 2006). Although studies on the OI paradigm have been applied mainly in high-tech sectors, some authors have highlighted the importance of openness in more traditional industries. In fact, these industries achieve innovations by adapting and integrating outputs from high-tech firms, and by collaborating with customers in problem solving. In these industries, then, relationships among the different parties are a central part of the innovation process (Hansen and Serin, 1997; Palmberg, 2004; Robertson and Patel, 2007). Based on these arguments, we would expect a positive relationship between OI strategies and innovation results, both in high-tech and low-tech sectors.

Nevertheless, OI is a wide label that includes different sources. Firms take advantage of several external knowledge sources such as technological consultants, R&D outsourcing, cooperative agreements (joint ventures and non-equity alliances), or the hiring of qualified researchers with relevant knowledge (Arora and Gambardella, 1990; Bessant and Rush, 1995; Cockburn and Henderson, 1998; Veugelers and Cassiman, 1999). In the next sections we briefly describe all of them.

2.1. External R&D

External R&D is the activity by which a client hires the services of an external organization to perform a specific piece of R&D. Building on transaction cost economics (Pisano, 1990; Williamson, 1985) and property rights theory (Grossman and Hart, 1986), the theoretical framework underpinning R&D outsourcing stresses the advantage of tapping available – and often more specialized – knowledge. Several benefits of R&D contracting, then, exist. They include managing capacity problems, speed, gaining access to new areas of knowledge, and sharing of costs (Haour, 1992).

External R&D, however, may create considerable transaction costs, largely because of loss of control over technological leakage or opportunistic behavior by contracted firms. First, contracting firms will typically lose the capability to develop the service or technology in-house. Second, contracting firms will often have to give the contracted firm access to knowledge about related activities for it to perform its work effectively. This makes contracting firms vulnerable to further knowledge losses. Third, the contracted firm is likely to work with many client firms and will thus provide a conduit for knowledge to flow from contracting firms to their competitors (Fey and Birkinshaw, 2005: 603).

Despite the problems raised by transaction cost theory, both anecdotal and rigorous empirical research suggests that in-house and external R&D are complementary (Cassiman and Veugelers, 2006; Cockburn and Henderson, 1998). In addition to conducting internal R&D activities, then, firms can reinforce their technological competences by contracting R&D and other external knowledge, and communicating, diffusing and assimilating it into their organizations (Prahalad and Hamel, 1990).

2.2. Technology Consultants

Consultants are normally used as a source of external knowledge to solve technological problems arising in the firm (Creplet et al, 2001; Muller and Zenker, 2001). Consultants often interact with numerous firms across a variety of industries and therefore may transfer tacit knowledge that has been gained through this experience of learning, integrating and sharing information. What consultants offer, then, is "contextual knowledge" that provides firms with an objective perspective of their current situation (Wood, 2002). Many times they also help to transform latent needs into explicit ones (Muller, 2001), translating firms' problems into specific demands and thus taking a first step on the road to a technical solution (den Hertog and Bilderbeek, 2000). In short, the function of consultants is to provide or modify the behaviors of firms (Creplet et al, 2001). More specifically, consultants improve the abilities of firms to perform R&D activities and to interact with other agents (Koschatzky, 2004; Siegel et al, 2003; Van Helleputte and Reid, 2004), to manage innovation processes (Bessant and Rush, 1995) and, ultimately, to get new products (Smallbone et al, 1993).

2.3. Hiring employees

A firm can acquire new knowledge embodied in new personnel (Veugelers and Cassiman, 1999). In fact, the role played by individuals in transporting knowledge among firms is crucial for the knowledge production function of the firm (Madsen et al, 2003). Despite its importance, however, the use of mobility as an inter-firm learning mechanism has not received much empirical attention (Song et al, 2003).

Knowledge that is tacit and complex is embedded in individuals, which makes it extremely difficult to acquire by other OI strategies (Kogut and Zander, 1992). Thus, the importance of hiring new personnel grows when knowledge tends to be "sticky" (Song et al, 2003). Mobility of personnel, however, is not simply a one-time transfer of information, as in the case of technology licensing. It may also facilitate the transfer of capabilities, permitting further knowledge building (Kim, 1997), and can induce changes in the way firms operate (Argote, 1993). For example, hiring new personnel can provide better access to other external knowledge (Song et al, 2001). Moreover, some recent studies point to the existence of a positive relationship between hiring new personnel and the innovation outcomes of the firm (Díaz-Díaz et al, 2006).

2.4. Joint Ventures

Technological joint ventures are legal entities in which equity ownership is shared between firms that pool capabilities in order to develop common innovation activities (Oxley, 1997). Research joint ventures allow a wide diversity of capabilities to be assembled to complete specific research tasks. They provide firms with the opportunity for frequent contact while collaborating on R&D activities and make it possible to avoid potentially inefficient internalizations (Caloghirou et al., 2003). The close relationship between the partners in a joint venture frees them of the need for a complete specification of the rights and obligations of the collaborating firms. An administrative hierarchy is established to assure control rights over the use of the pooled resources and cooperation activities. The alliance's joint board of directors allows constant communication and coordination of the collaborative activities by the parent firms (Oxley, 1997), which in turn makes it possible for joint ventures to react to unanticipated contingencies more efficiently (Sampson, 2004; 2007).

In summary, this more hierarchical organization is a superior way of transferring complex knowledge or tacit information (Kogut and Zander, 1992). Joint ventures, then, facilitate knowledge flow, safeguard against leakage (Sampson, 2004), and protect partners from opportunistic behavior (García Canal, et al., 2008) better than non-equity alliances. The counterbalance to these benefits, however, is the complexity and cost of setting up a joint venture. This is why this type of collaboration is reserved for situations in which the pluses of increased coordination and control are sufficiently large to outweigh the additional management and supervision costs that arise.

2.5. Non-equity alliances

Non-equity alliances are collaborations in which shared equity ownership does not occur. Behavioral routines are less developed, and the allocation of decision power is far less formalized than in joint ventures. In many non-equity alliances some of the hierarchical controls of equity modes may exist in order to favor inter-organizational learning, and it is common for personnel to be exchanged and for meetings to be attended by both partners' representatives (Colombo, 2003). Non-equity alliances feature more decentralized decision making, which speeds routine decisions but is inefficient when coordination is required or when certain safeguards are required to share knowledge between partners.

The diversity and type of partner that firms decide to collaborate with is important in non-equity alliances. Becker and Dietz (2004) explicitly state that technological collaboration with different partners raises the likelihood of achieving product innovation. In fact, collaborating with different partners should substantially enhance innovation due to the amount and variety of knowledge to be shared, thereby enabling the alliance partners to fill out their initial resource and skill endowments. Increasing the number of parties involved, however, certainly brings greater risks of opportunistic behavior. Overall, though, knowledge diversity and information from a variety of sources facilitate the innovative process (Laursen and Salter, 2006). They enable the individual to make novel associations and linkages (Cohen and Levinthal, 1990) and ultimately improve innovation performance (Liker et al., 1999; Nieto and Santamaria, 2007).

3. OI Strategies: Expected Relationships by Innovation Nature

Although the expected relationship between OI strategies and innovation results is positive, the previous description of different external sources of knowledge leads to some further considerations. In particular, we strongly agree with Gassmann (2006) on the need for a contingency approach to the management of innovation and OI strategies that takes account of, among other aspects, the idiosyncrasies of each firm and innovation. With the aim of casting more light on the Open innovation model (Chesbrough, 2003a), then, this paper postulates that the role of different OI strategies will differ according to the type of innovation pursued.

Indeed, the role of external sources of knowledge on innovative activities differs between product and process innovations (Gooroochurn and Hanley, 2007; Reichstein and Salter, 2006). A process innovation entails achieving improvements in the systems of process equipment, work force, task specification, material inputs, information flows and so forth that are employed to produce a product or service (Utterback and Abernathy, 1975). Process innovations imply increases in production efficiencies (Garcia and Calantone, 2002) and may be related to stepwise and incremental changes (Lee and Park, 2006). Product innovations, on the other hand, are linked to the generation, introduction and diffusion of a new product. Their complexity tends to grow in relation to their similarity to inventions or their role in the opening of a new market (Lee and Park, 2006).

Gooroochurn and Hanley (2007) argue that process innovations are more likely to be achieved through market-based sources than product innovations are. Their transaction cost arguments are founded on the idea that the danger of information leaking and being exploited by a contracted firm diminishes in the case of process innovations. Mowery and Rosenberg (1989) suggest that R&D contracting is more likely to occur for generics, non-firm specific R&D that allows for specialization advantages (e.g., routine research tasks like materials testing), and process rather than product innovations. Thus, when pursuing process innovations, firms would expect that OI strategies such as external R&D, consultants or hiring employees will be the most relevant ones. Partnerships, however, tend to be used where technology is more complex (Narula, 2001) given the need of more interaction and knowledge transfer. In particular, joint R&D within well-organized networks enhances the innovation activities of the cooperation partners and increases the probability of achieving new products (Vonortas, 1997). OI strategies such as joint ventures and non-equity alliances, then, are likely to be a critical tool in stimulating product innovations.

Although patents suffer several serious shortcomings as indicators of innovation (Laursen and Salter, 2006), they do provide another perspective on the firm's innovation process and complete the picture of the role of OI strategies. Firms that rely greatly on formal mechanisms (such as patents and copyrights) to protect innovations are less likely to engage in external innovation, preferring to keep the generation of ideas in-house (Gooroochurn and Hanley, 2007). As joint ventures are closer to a firm than less hierarchical non-equity alliances, firms that resort to OI strategies to achieve patentable results would seem likelier to opt for equity forms such as technology joint ventures. Moreover, patentable results are likely to require more intensive interdisciplinary knowledge transfers than less innovative products. For this to take place, collaboration and knowledge transfers must be frequent and efficiently managed. Joint ventures may be favorable environments for this kind of process. On this basis, it would be reasonable to expect that more formalized OI strategies (i.e. joint ventures) will be positively related with the achievement of patents.

4. Methodology

4.1. Sample and Data

The database used for the empirical analysis is the Spanish Business Strategies Survey (SBSS). This is an annual firm-level panel of data compiled by the Spanish Ministry of Industry and the Public Enterprise Foundation; it has been used by many other researchers to study innovation (Beneito, 2006; Cuervo-Cazurra and Un, 2007; Huergo, 2006; among others). The SBSS contains an interesting and wide set of variables on Spanish firms operating in all manufacturing industries of the classification NACE-Rev.1. This database is not specifically designed to analyze technological activities. The SBSS does not restrict its focus to innovative firms and firms' R&D activities, but offers a more complete picture of the firm. These features make it possible to go far beyond internal R&D activities to consider different external sources of innovation, as well as some characteristics of product and factor markets as determinants of innovation. In addition, the SBSS offers other advantages over standard data bases that typically have a very high percentage of firms that perform R&D activities, which could give rise to biased results (Bayona et al., 2001; Cassiman and Veugelers, 2002; Tether, 2002).

The sample is representative of the population of Spanish manufacturing firms. Firms with between ten and 200 employees are selected through a random stratified sample (according to firm size and industry classification), and firms with more than 200 are surveyed on a census base (Huergo, 2006). This paper's empirical analysis is based on the balanced sample of firms with information available for the complete period from 1998 to 2002. Since only those firms performing internal R&D activities were analyzed, the final sample is a balanced panel composed of 1,676 observations from R&D performers that have remained in the survey during the whole five-year period.

4.2. Variables and measures

4.2.1. *Dependent variables: innovation outputs*

The dependent variables are relative to firm innovation performance in a specific period t. In order to capture the different innovation outputs, along with the distinct levels of complexity, four separate measures were used: innovation result, product innovation, process innovation, and the propensity to patent.

Innovation result is a dichotomous variable that captures (in a general way) whether the firm achieved any kind of innovative outcome: product innovations and/or process innovations and/or patents.

Product innovation was assumed to have taken place when the firm declared it had introduced completely new products or products with important modifications, products with new functions resulting from innovation, or had made changes to the design, presentation, materials or composition of the product. Product innovation is a dichotomous variable that takes value 1 when product innovation has occurred; otherwise its value is 0.

Process innovation was assumed to have happened when the firm indicated it had introduced some significant modification in the production process. This modification may involve the introduction of new machines or new methods of organization, or the introduction of both. Process innovation is also a dichotomous variable.

Lastly, propensity to patent is an effective way of capturing the achievement of more significant and complex innovations. In fact, the requirements to register a patent are usually more stringent than for other innovations (Beneito, 2006). Patent is a dichotomous variable that takes value 1 when the firm stated it had registered at least one patent; otherwise its value is 0.

4.2.2. *Independent variables related to OI strategies*

The database includes information on the external sources that a firm accessed through different mechanisms. In particular it is possible to identify if a firm: decided to contract R&D external activities (External R&D); turned to a technological consultant (Consultant); or had recently hired engineers, personnel with business experience in R&D and/or personnel with experience in public systems R&D (Hiring personnel). In addition, two hybrid mechanisms to gain access to external sources of innovation were also distinguished: joint ventures and technological collaborations without shared equity ownership between firms, with a smaller degree of organizational control and greater flexibility (i.e. non-equity alliances). In order to capture some subtleties, in this last case an additional division was established between heterogeneous alliances and homogeneous alliances. The first typology captures non-equity alliances with more than one type of partner (clients, suppliers, universities, technology institutes and/or competitors), while the second measures alliances with only one type of partner. The different OI strategies were measured via dichotomous variables. To avoid problems of simultaneity with the innovation generation process, all these external strategies were lagged one period.

Finally, to capture the effort on internal R&D, the intensity of internal R&D was included (internal R&D expenses compared to total sales). This variable was also lagged one period.

4.2.3. *Industry and environmental factors*

Eighteen industry dummies were used to capture the effect on innovation of sector characteristics related to life cycles and technological regimes. The firms' activity classification is an aggregation of the two-digit manufacturing industries classification in the NACE-Rev. 1 (for similar classifications, see Huergo, 2006). In addition to the sectoral dummies, environmental factors are highly important for understanding the relationship between technological choices and innovation outputs. Indeed, previous literature (Cohen, 1995; Kamien and Schwartz, 1982) has pointed out that demand and market conditions are critical factors in innovation performance. To measure these conditions, different variables related to product and factor market characteristics were used.

Concentration of competitors was one of the market characteristics analyzed (Competitors). The concentration of competitors determines the dynamism of the market the firm is operating in and the consequent greater or lesser need to undertake innovation activities (Schumpeter, 1942). It is measured as the percentage of the market that is controlled by the four largest competitors (Kumar and Saqib, 1996). Product and factor market characteristics were also included by considering client and supplier pressures (Cuervo-Cazurra and Un, 2007). Client pressure is measured in terms of the concentration of clients; this is calculated as the percentage of sales to the firm's three largest clients (Client pressure). Similarly, supplier pressure is measured in terms of concentration of suppliers, in this case calculated as the percentage of total purchases from the three main suppliers (Supplier pressure). Lastly, this study follows Huergo (2006) in including a variable to measure growth of market demand. This is a dichotomous variable that takes value 1 when the firm stated that its main market was expanding; otherwise its value is 0 (Expansion).

4.2.4. *Firm-specific characteristics*

Controls for firm-specific characteristics were introduced. Sales (Sales) controls for the relative scale of the firm – the natural logarithm of this measure is included in order to limit the impact of skewness. The age of the firm (Age) – calculated as the number of years since a firm's foundation – measures firm experience and learning, and is a commonly used variable in empirical studies of innovation (Kumar and Saqib 1996). Following Galende and Suárez (1999), firms' financial autonomy and resources were captured by introducing level of debt – measured as the ratio of total debts to total liability (Leverage). Because numerous studies have recognized the effect of ownership structure on innovation and tracked its influence by focusing on foreign ownership (see Becheikh et al., 2006), the percentage of foreign equity in a firm's capital (Foreign) was added.

The descriptive statistics and correlations of the independent and control variables (with the exception of the sector dummies) are reported in table 1. An analysis of the variance inflation factor (VIF) was conducted to test for multicollinearity. Individual VIF values greater than ten indicate a multicollinearity problem (Neter et al., 1989), along with average VIF values greater than six. The values presented in table 1 show that problems of multicollinearity do not exist in any of the models.

TABLE 1.—*Descriptive statistics, correlations, and collinearity diagnostics of the independent and control variables*

		Mean	St. Dev.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	VIF
1	Internal R&D Intensity	0.03	0.06															1.07
2	Joint ventures	0.12	0.33	0.07														1.19
3	Homogeneous alliances	0.21	0.41	0.01	-0.11													1.34
4	Heterogeneous alliances	0.47	0.50	0.05	0.28	-0.50												2.10
5	Consultant	0.39	0.49	-0.01	0.17	0.01	0.28											1.29
6	Hiring personnel	0.54	0.50	0.07	0.20	0.02	0.32	0.26										1.60
7.	External R&D	0.48	0.49	0.07	0.16	0.02	0.34	0.28	0.25									1.66
8	Sales	5.23	1.43	-0.02	0.25	-0.03	0.34	0.23	0.41	0.32								2.10
9	Age	32.07	23.37	-0.02	0.10	0.01	0.07	0.03	0.07	0.11	0.27							1.21
10.	Leverage	0.53	0.21	0.02	0.01	-0.07	0.03	-0.03	0.04	-0.08	-0.01	-0.14						1.05
11.	Foreign	31.51	44.79	-0.04	0.11	-0.07	0.18	0.04	0.18	0.07	0.36	0.12	0.05					1.33
12.	Client pressure	39.63	27.60	0.06	0.04	-0.05	0.03	-0.05	0.05	0.00	0.03	-0.15	0.08	0.12				1.10
13.	Supplier pressure	40.83	21.98	-0.04	-0.08	0.01	-0.06	-0.09	-0.09	-0.09	-0.11	-0.03	-0.03	0.08	0.17			1.11
14.	Expansion	0.36	0.48	0.01	0.03	0.03	0.04	0.01	0.12	0.02	0.06	0.02	0.05	0.03	-0.03	-0.01		1.03
15.	Competitors	21.75	26.93	0.01	0.03	0.04	0.05	-0.01	0.07	0.09	0.10	0.06	-0.01	0.08	-0.10	-0.00	0.04	1.05
																	Mean VIF	1.35

4.3. A PRELIMINARY DESCRIPTIVE ANALYSIS

Table 2 shows some descriptive figures on the OI strategies followed by the R&D performers. The sample was divided between low- and high-tech sectors using the OECD's (2005) classification of manufacturing industries based on technology[1]. A preliminary consideration is that joint ventures and homoge-

[1] Low-tech includes firms in low-technology industries (textiles, food products, tobacco, wood, paper products, among others) and in medium-low technology industries (rubber and plastic products, coke, refined petroleum products, other non-metallic mineral products, basic metals, among others). High-tech includes firms in high-technology industries (aircraft and spacecraft, pharmaceuticals, office machinery, radio, TV and computing machinery, medical, precision and optical instruments) and medium-high technology industries (electrical machinery, motor vehicles, chemicals excluding pharmaceuticals, railroad and transport equipment, machinery and equipment, among others).

neous alliances are the OI strategies less chosen, while heterogeneous alliances, external R&D and hiring personnel are the OI strategies more frequently used by R&D performers. This pattern holds for both low-tech and high-tech industries, although usually firms in low-tech industries are less likely to adopt OI strategies. The exception is homogeneous collaboration, which is more frequently used by firms in low-tech industries, and consultants, which are similarly used in both industries.

TABLE 2.—*OI strategies of R&D performers*

	Joint ventures	Homogeneous alliances	Heterogeneous alliances	Consultant	Hiring personnel	External R&D
All Sectors	13.6%	23.8 %	57.2 %	44.1 %	57.9 %	57.4 %
Low Tech Sectors	9.2 %	25.8 %	49.6 %	42.9 %	47.9 %	52.2 %
High Tech Sectors	18.3 %	21.7 %	65.4 %	45.2 %	68.7 %	62.9 %

In addition, Table 3 displays some descriptive information on the innovative outcomes of R&D performers (considering whether OI strategies were used or not). It is notable that the great majority of R&D performers complement their in-house activities with at least one OI strategy. This underlines the importance that firms accord to these strategies. R&D performers that used some type of OI strategy were more successful than those that limited themselves to in-house activities. This finding holds true regardless of the innovation output considered and the technological context (low- and high-tech industries). These results simply confirm the expectation that OI strategies followed by R&D performers are correlated with the achievement of innovation outcomes. The objective of this study, however, goes beyond this basic comparison. In order to provide a robust explanation for these differences, an econometric analysis was performed.

TABLE 3.—*Innovative behavior of R&D performers, with or without OI strategies*

	Number of firms (%)	**Innovation results**	**Product Innovation**	**Process Innovation**	**Patent results**
ALL SECTORS					
R&D performers	**2,128 (32.74%)**	**70.13%**	**50.98%**	**56.19%**	**14.47%**
Without OI strategies	208 (9.77%)	51.44%	37.02%	27.39%	5.77%
With OI strategies	1,920 (90.23%)	78.89%	52.5%	59.32%	15.41%

Table 3 *(cont.).—Innovative behavior of R&D performers, with or without OI strategies*

	Number of firms (%)	Innovation results	Product Innovation	Process Innovation	Patent results
LOW TECH SECTORS					
R&D performers	**1,103 (24.08%)**	**72.89%**	**49.41%**	**56.3%**	**10.88%**
Without OI strategies	143 (12.96%)	51.75%	37.76%	25.17%	6.29%
With OI strategies	960 (87.04%)	77.54%	51.15%	60.94%	11.56%
HIGH TECH SECTORS					
R&D performers	**1,025 (53.39%)**	**74.14%**	**52.68%**	**56.1%**	**18.34%**
Without OI strategies	65 (6.34%)	50.77%	35.38%	32.31%	4.62%
With OI strategies	960 (93.66%)	79.73%	53.85%	57.71%	19.27%

5. Empirical Results

Given the binary character of the dependent variables, probit models were specified. To address concerns of unobserved heterogeneity, a random-effects panel probit model was employed. Our decision to use a random-effects model instead of a fixed-effects model was based on the following: i) Our sample was drawn from a large population; in this setting, it might be more appropriate to view individual specific constant terms as randomly distributed across cross-sectional units (Greene 2000, p 567); ii) Estimates computed using fixed-effects model can be biased for panels over short periods. This is not a problem with random-effects models (Heckman 1981; Hsiao 1986). Given that all the firm-year observations in our sample were present for only five years, random-effects was the preferred approach; iii) Fixed-effects models cannot include time-independent covariates. This limitation means excluding some of the control variables (like, for example, the sectoral variables) that are crucial for understanding the innovation behavior of firms. Our analysis could be limited without these variables.

The models displayed in table 4 make it possible to explore the relationship between OI strategies and innovation results and their specificities depending on the technological intensity of the firm's sector. Separate analyses for the two sub-samples of low-tech and high-tech sectors were performed to capture the sectoral differences.

TABLE 4.—*Open Innovation strategies on Innovation Results of R&D Performers*

	Model A	**Model B1**	**Model B2**
	All industries	*Low tech industries*	*High tech industries*
Internal R&D intensity	1.171 (1.48)	0.953 (0.77)	1.414 (1.34)
Open Innovation strategies			
Joint ventures	-0.022 (-0.14)	-0.162 (-0.56)	0.124 (0.62)
Homogeneous alliances	0.482*** (3.62)	0.485** (2.50)	0.509** (2.55)
Heterogeneous alliances	0.478*** (3.75)	0.338* (1.78)	0.627*** (3.39)
Consultant	0.312*** (2.96)	0.590*** (3.64)	0.040 (0.27)
Hiring personnel	0.199* (1.89)	0.342* (2.16)	0.039 (0.26)
External R&D	0.130 (1.22)	0.332* (2.01)	-0.029 (-0.20)
Firm's specificities			
Sales	0.201*** (4.09)	0.200*** (2.64)	0.217*** (3.14)
Age	-0.001 (-0.12)	-0.001 (-0.09)	-0.002 (-0.53)
Leverage	0.017 (0.07)	0.305 (0.86)	-0.374 (-1.01)
Foreign	-0.002 (1.34)	-0.002 (-0.86)	-0.002 (-1.23)
Industry factors			
Client pressure	-0.001 (-0.32)	-0.003 (-1.00)	0.001 (0.45)
Supplier pressure	-0.006** (-2.52)	-0.006* (-1.86)	-0.005 (-1.43)
Expansion	0.171* (1.76)	0.151 (1.02)	0.203 (1.52)
Competitors	0.002 (1.05)	0.003 (0.95)	0.001 (0.43)
Intercept	-1.491*** (-2.85)	-1.583** (-2.32)	-0.630 (-1.07)
Number of observations	1,676	897	779
Wald test of full model: χ^2	163.08***	98.84***	54.06***
Log pseudo-likelihood	-910.90	-470.76	-428.07

Unstandardized regression coefficients are shown (robust standard errors). T-values are between parentheses. Sectoral and yearly dummies are included in the models.
* p < 0.10; ** p < 0.05; *** p < 0.01

The results of Model A clearly show the importance of OI strategies for R&D performers' innovation outcomes. In particular, market-based mechanisms such as consultants or hiring personnel, as well as non-equity alliances (both heterogeneous and homogeneous), show a positive and significant coefficient on the achievement of innovation results. As expected, the effect of firm size (Sales) is positive and highly significant. And as regards market characteristics, the growth of demand (Expansion) is positively and significantly related to the success of the innovation process. On the other hand, pressure from main suppliers (Supplier pressure) is negatively related to the generation of innovation results.

Splitting the sample between low-tech (Model B1) and high-tech (Model B2) sectors produces some highly interesting results. First, a wider array of OI strategies show a positive and significant coefficient on the likelihood of successful innovation outcomes in low-tech sectors, compared to high-tech ones. Second, it is worthy to highlight the importance in low-tech sectors of marked-based strategies (external R&D, hiring of personnel and, especially, use of consultants). Thus, Open innovation models can certainly be applied in these contexts. Third, in high tech sectors non equity alliances and, specially, heterogeneous ones are those positively and significantly related to innovation outputs. The effect of size is positive and significant in both sub-samples. And as regards market characteristics, supplier pressure is negatively and significantly related to innovation outcomes only in low-tech sectors.

Table 5 contains the results of the analysis for OI strategies and different innovation outcomes: process innovation, product innovation and patents. Concerning the relationship between OI strategies and the achievement of process innovations (Model C1), we find that external R&D, hiring of personnel and use of consultants show a positive and highly significant coefficient. None of the partnering strategies, however, is significant. Internal R&D intensity only has a slightly positive coefficient. And of the controls, both size (Sales) and the growth of demand (Expansion) are positive and significant factors for the achievement of process innovations.

As regards the effect of OI strategies on the achievement of product innovations (Model C2), we find that the coefficients for non-equity alliances (both heterogeneous and homogeneous) are clearly positive and highly significant. Joint ventures, however, do not show a significant coefficient on the achievement of product innovations. Of the market-based strategies, only consultants have a positive and slightly significant relationship with the likelihood of product innovation outcomes. Neither external R&D nor hiring new researchers show a significant coefficient. The intensity of internal R&D does make a difference, though, as its coefficient is positive and clearly significant. Of the firm-specific controls, firm size once again is positively related to innovation results. And as before, pressure from suppliers is negatively related to the likelihood of achieving innovations. In this case, one other market factor should be noted. Pressure from main competitors (Competitors) is significantly and positively related to the achievement of product innovations.

Lastly, the effect of OI strategies on the propensity of patenting (Model C3) is analyzed. The coefficients of joint ventures and external R&D are positive and highly significant. We interpret this to mean that more formal OI strategies are important for the achievement of patents, while more informal alternatives (non-equity alliances, consultants or the hiring of researchers) do not have the same impact. Here again, firm size and pressure from main competitors are positively related to this innovation result.

TABLE 5.—*Open Innovation strategies on different innovation outputs*

	Model C1	**Model C2**	**Model C3**
	Process innovations	*Product innovations*	*Patent results*
Internal R&D intensity	1.259* (1.73)	1.555** (2.01)	0.792 (0.75)
Open Innovation strategies			
Joint ventures	-0.010 (-0.06)	-0.151 (-0.96)	0.505*** (2.65)
Homogeneous alliances	0.040 (0.28)	0.662*** (4.60)	-0.006 (-0.03)
Heterogeneous alliances	0.116 (0.84)	0.764*** (5.50)	0.284 (1.24)
Consultant	0.417*** (3.82)	0.186* (1.75)	0.085 (0.54)
Hiring personnel	0.320*** (2.87)	0.054 (0.49)	0.173 (0.97)
External R&D	0.293*** (2.66)	0.061 (0.55)	0.660*** (3.61)
Firm's specificities			
Sales	0.282*** (5.08)	0.142*** (2.69)	0.203** (2.35)
Age	-0.002 (-0.79)	-0.001 (-0.11)	-0.005 (-1.22)
Leverage	0.099 (0.36)	-0.138 (-0.51)	-0.355 (-0.83)
Foreign	-0.001 (-0.97)	-0.002 (-1.48)	-0.003 (-1.29)
Industry factors			
Client pressure	-0.001 (-0.19)	-0.003 (-1.47)	-0.003 (-1.05)
Supplier pressure	-0.003 (-1.17)	-0.010*** (-3.88)	-0.006 (-1.49)
Expansion	0.375*** (3.73)	0.068 (0.69)	0.009 (0.06)
Competitors	-0.001 (-0.50)	0.004** (2.31)	0.005* (1.69)
Intercept	-2.398*** (-4.01)	-1.552*** (-2.63)	-3.001*** (-3.23)
Number of observations	1,676	1,676	1,676
Wald test of full model: χ^2	150.31***	134.68***	77.90***
Log pseudo-likelihood	-945.19	-955.52	-457.18

Unstandardized regression coefficients are shown (robust standard errors). T-values are between parentheses. Sectoral and yearly dummies are included in the models.
* $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$

6. Discussion and Conclusions

Although previous literature has amalgamated the concepts of "innovating firms" and "firms performing R&D internally", a large number of internal R&D performers declare they do not obtain product or process innovations. This paper argues, following Chesbrough's (2003a, b) Open innovation concept, that OI strategies could greatly help internal R&D performers profit from their efforts. This study also takes into account the recent debate on the applicability of this concept outside high-tech sectors, specifically in more traditional and mature industries (Chesbrough and Crowther, 2006). In addition, the role played by distinct modes of organization of OI strategies in the achievement of different innovation outcomes is analyzed.

This paper's empirical results strongly support the view that OI strategies are related to the success of firms' R&D efforts. Moreover, they are positively related in both high-tech and low-tech sectors, thus providing evidence of the importance of OI in these sectors. We also found that market-based sources (such as consultants, external R&D and the hiring of personnel) show a higher positive relationship in low-tech sectors. This result makes sense as the external knowledge needed in such sectors is usually already standardized or close to it so that it can be gathered using market mechanisms. This result supports the view of some authors (Chesbrough and Crowther, 2006; Robertson and Patel, 2007) that innovation usually takes place in low-tech sectors through the adaptation and integration of outputs developed by firms in high-tech sectors. Consultants, new personnel and external R&D clearly play a role in such a process of adaptation and integration. On the other hand, firms in high-tech sectors benefit more from non equity alliances, and especially from those of a more heterogeneous nature. Innovation process in high-tech sectors are usually far from being standardized so that complexity and uncertainties pervade the process and market mechanisms do not work so well under these circumstances (Williamson, 1991). In addition, as knowledge required is dispersed and interdisciplinary, heterogeneous alliances are a key strategy to gather together all the capabilities needed to innovate.

The empirical results also support the view that modes of organization of OI strategies vary in their relationship with different innovation outputs. This study finds that market-based sources are positively related to the achievement of process innovations, while partnering mechanisms are more correlated with product innovations. Product and process innovations, although highly interrelated (Utterback, 1994), differ in that the former usually involve more uncertainty and potential leakage of knowledge. Finding the required knowledge via market-length transactions, then, is harder. The specificity of the knowledge reduces the likelihood that it will be available on a market basis (Williamson, 1985), while the uncertainty means that many ex-post contingencies are likely to arise. As a result, contracts tend to be very incomplete, allowing possibilities for opportunistic behaviour (Robertson and Gatignon, 1998; Teece, 1988) and making trust a crucial factor in the success of the relationship. Process innovations, however, tend to be less specific. In fact, they have been associated with second-order innovations (Reichstein and Salter, 2006) and are usually implemented by imitation of best practices. Organizations performing in knowledge markets, such as consultants, offer accurate knowledge of these practices because they develop relationships with many different firms (Wood, 2002).

This paper also finds that the degree of formalization of the relationship seems to be the most important characteristic for the achievement of patents. Consequently, joint ventures and external R&D are the OI strategies most positively related to obtain patents. These two strategies are always formalized through highly detailed contracts, something that is less usual for alliances that develop in more informal ways or for relationships with consultants.

These results could have important implications for R&D managers. Internal R&D performers are more likely to achieve innovations when OI strategies are implemented, in both high and low-tech industries. Moreover, once a firm is engaged in internal R&D activities, subsequent increases in the internal R&D level do not have much impact on innovation results. Thus, the key to avoiding failure seems to be opening the innovation strategy of the firm, and not intensifying isolated R&D efforts.

Policy initiatives in this area have focused on fostering collaboration between organizations, especially in high-tech sectors. This paper, however, finds that both collaborations and other OI strategies are extremely helpful for firms, and that their effects are specific to the type of innovation pursued. To aid this process, public initiatives should create an environment to ease the market flows of knowledge and to widen the focus of their initiatives to include firms in all sectors (Metcalfe, 1997; Teubal, 1997, 2002), and promote legal frameworks that adequately protect contractual relationships among firms.

This study has some limitations that could be the object of fruitful future research. First, the intensity of use of each mode of OI strategy was impossible to measure. Consequently, binary variables informing only if each strategy was used (but not by how much) had to be resorted to. The same comment applies to the measure of innovation results. Second, this paper has focused on the mode of OI strategies, but has not considered the characteristics of the different partners chosen to develop the OI strategy. Third, another interesting line of research would be to analyze the complementarities that may exist among the different OI strategies. This approach would make it possible to explore which combinations are more successful for which innovation outputs.

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