



The effects of knowledge sourcing strategies on science-based firms' innovative performance: evidence from the Spanish manufacturing industry

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Abstract

This paper provides empirical evidence on the effect of the external knowledge sourcing strategies adopted by firms, on the development of both product and process innovation, and assesses to what extent this effect is influenced by the firm's internal technological capabilities. Our empirical investigation is based on a sample of more than 600 *science-based firms* active in innovation activities taken from the Spanish Innovation Survey 2004. We find that the effects of the knowledge sourcing strategies differ significantly across innovation types (product or process innovation). In addition, our results suggest that there are possible substitution effects between external sourcing strategies and internal R&D. Thus, the greater the firm's internal technological capability, the less important is the cooperation with scientific agents in determining product innovation.

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1. Introduction

Many current economic theories on and approaches to innovation, to a greater or lesser extent, hold that individual firms are seldom capable of innovating independently and that a firm's internal technical capabilities are insufficient to cope with the challenges of the global market. Likewise, studies in the field of business management indicate that the search for new product ideas, new forms of organization and/or solutions to existing problems goes beyond the firm's boundaries in exploring available capacities in other firms or institutions. In theory, a wider and more diverse search strategy will provide access to new opportunities and enable the firm to build new organizational competences based on the integration of complementary knowledge sets from external agents (Teece, 1986; March, 1991).

There is solid empirical evidence that the use of external knowledge sources is both an important theoretical issue and a growing phenomenon. In most OECD countries, for instance, the share of business expenditure on external R&D has gradually increased since the 1980s. In countries such as the UK and Germany, business expenditure on external R&D doubled in proportion to total expenditure on R&D, over a ten year period (Howells, 1999; Bönnte, 2003). Another clear indication of the higher use of external knowledge sources is the increasing number of inter-firm partnerships. In this respect, Hagedoorn (2002) shows that the number inter-firm R&D partnerships recorded in the MERIT-CATI database, increased from 10 during most of the 1960s to nearly 600 by the end of the 1990s. These trends have been accompanied by a decrease in the number of internal R&D departments and an erosion of the strategic advantage of in-house R&D activities (Chesbrough, 2003).

Nevertheless, some researchers have warned about the risk of overestimating the role played by external knowledge sources, arguing that in many industries, innovation efforts

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are not only made by firms themselves, but are in-house generated (Nelson, 2000). The studies conducted by Oerlemans et al. (1998) in the Netherlands and Freel (2003) in the UK, show that the firm's internal resources are the main determinants of their innovation performance, and that the creation of external networks has only a limited impact. Some authors have even suggested that in attempting to decentralize and outsource R&D activities firms may weaken their core competences (Coombs, 1996).

Linked to these trends, a theoretical and empirical literature has developed on the factors determining external knowledge acquisition and its effects on firms' innovative performance. Most of this literature focuses on the choice between external sourcing and internal development, the so-called *make or buy* decision (Veugelers and Cassiman, 1999; Beneito, 2003). A traditional approach to the analysis of this issue derives from transaction cost theory, which suggests that in the presence of asset specificity, uncertainty and opportunistic behaviour, transactions take place more efficiently and hierarchically within the firm than via the market (Williamson, 1985). Following this line of inquiry, external knowledge sourcing and in-house R&D are considered as substitutes, and in considering cost and risks, firms opt for either a make or a buy strategy. The later resource-based approach, however, emphasizes that competency development requires a firm to have an explicit policy on the use of external knowledge sources as an opportunity to learn, rather than as a way to minimize costs (Robins and Wiersema, 1995). This suggests that external knowledge should be used to complement rather than substitute for internal R&D.

Analysis of the complementarity between innovation strategies was extended by Cohen and Levinthal's seminal work (1989, 1990). They suggested that in-house R&D activities played the dual role of generating innovation and improving the firm's absorptive capacity, that is, the ability of the firm to identify, assimilate and exploit the

knowledge generated by competitors and extra-industry sources (Cohen and Levinthal, 1990). Thus, the greater the internal capabilities of the firm, the greater are the effects of the different external knowledge acquisition strategies on innovation performance. Based on the concept of absorptive capacity, several studies followed on the relationships between external and internal know-how or, in strategic terms, between external knowledge sourcing and in-house knowledge development. Arora and Gambardella (1990, 1994), for instance, found that firms that conduct more R&D have larger numbers of external links (equity participations, contractual and non contractual agreements, acquisitions) aimed at acquiring technology, while Veugerless (1997) found that external sourcing can often stimulate internal R&D activity, at least for firms with R&D departments.

Thus, there is empirical evidence on the importance of the firm's knowledge base for enabling the firm to identify and acquire external knowledge, and vice versa, on the role of externally acquired knowledge in enhancing internal R&D activities. On balance, however, the literature is not conclusive about the complementarity between internal and external technology sourcing with respect to the impact on firm's innovative performance. Such complementarity or synergy is assumed to exist if the implementation of one strategy increases the marginal returns from another (Milgrom and Roberts, 1990). In this line, there has been little empirical analysis and the findings from the few studies conducted are mixed. Laursen and Salter (2006) examine the relationships between the number of the firm's external knowledge sources (which they term 'external search breadth') and its innovation performance. They find an inverse U-shaped relationship, indicating that the breadth of the firm's external search strategies is beneficial only up to a certain level. They also find that internal R&D negatively moderates the relationship between external knowledge sources and innovation

performance, suggesting the existence of a substitution effect between openness to external search activities and internal R&D. In contrast, Cassiman and Veugelers (2006) find that in-house R&D and external knowledge acquisition are complementary with respect to the impact on innovative performance.

In this paper, we follow a similar approach in analysing the effect of different external knowledge sourcing strategies on firm's innovative performance and exploring the relationships between these strategies and in-house R&D. Extending Cassiman and Veugelers (2006), we investigate the effect of two strategies for acquiring external knowledge (buying and cooperating) and two types of external sources (industrial agents and scientific agents). This distinction is important as knowledge from these types of agents tends to be different in nature and therefore may not only serve different purposes but may also relate differently to a firm's internal capabilities. For instance, Cohen and Levinthal (1990) suggest that the knowledge drawn from extra-industry sources such as government and university labs, is typically less targeted to a firm's requirements and priorities than that drawn from materials and equipment suppliers, and therefore requires more expertise from the firm to exploit it efficiently. In addition, we include in our analysis acquisition of technology "embodied" in machinery and equipment as another external knowledge sourcing strategy. Although most of the existing studies on the effects of external knowledge sourcing focus on 'disembodied' knowledge acquisition strategies (R&D contracting or licensing agreements), the role of purchase of machinery and equipment in innovation is by no means negligible (Evangelista, 1999). Fourth Community Innovation Survey (CIS-4), for instance, shows that half the European firms reporting product or process innovation do not conduct in-house R&D, while approximately 70% engage in machinery, equipment and software acquisition.

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The analysis of external knowledge sourcing strategies uses firm level data from the Spanish innovation survey. Specifically, our empirical investigation rests upon a sample of 654 science-based firms (Pavitt, 1984). We focus on this sectoral category for two reasons. First, this sectoral category includes those firms for which the relative importance of internal and external knowledge sources is higher. Pavitt (1984), for instance, suggested that in science-based firms the main sources of knowledge are both the firms' internal R&D activities and scientific research carried out by universities and public research institutions. Likewise, Klevorick et al. (1995), indicated that the higher the level of technological opportunity in an industry, the higher the firm's incentives to draw on external knowledge sources. Second, as Cassiman and Veugelers (2006) suggest, a firm's reliance on more 'basic' types of know-how (i.e., the use of universities and research centres as information sources for innovation) affects the degree of complementarity between innovation strategies. In this sense, it is expected that in this sectoral category the complementarity between external knowledge sourcing and internal knowledge development, if exists, is more clearly identifiable.

Spain is a technology follower country, demonstrated by its science and technology indicator scores, which are among the lowest in the EU. For example, total expenditure on R&D in relation to GDP is half of the EU average, and cooperation between firms and research centres in Spain is lower than the European average (Castro and Fernández, 2006).

Bearing in mind these features of the Spanish innovation system, it is hoped that the results provided in this paper will facilitate comparison with and establish differences in innovation patterns with the technologically leading countries, which traditionally have been the focus of this type of analysis. Also, given that one of the priorities of Spanish innovation policy is to intensify the relationships between firms and public research

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institutions (European Commission, 2001), the results of the present study, which examines the effects of cooperation and other external knowledge sourcing strategies on firm's innovative performance, should have important implications for public policy.

The rest of the paper is organised as follows: In section 2 we outline the methodological aspects of the empirical study, describing the data used, the measures of the variables and the assessed econometric specifications. In section 3, we display the results and, finally, in section 4 we draw the main conclusions.

2. Data and methodology

2.1. Data

The data used in the empirical analysis come from the 2004 Technological Innovation in Companies Survey (TICS) conducted by Spain's National Statistical Institute. This survey is based on the Oslo Manual, and provides information on the innovative behaviour of Spanish firms during the period 2002-2004. The final database for 2004 includes 4,138 manufacturing companies, across 31 sectors based on Spain's National Classification of Economic Activities (CNAE). However, we have restricted our attention to the subsample of science-based firms. This subsample includes 720 firms. In addition, non-innovator companies were excluded from our analysis, because most variables can only be constructed for firms with innovation activities.⁴ After deleting observations with missing values, we were left with a sample of 654 science-based firms (Table 1).

⁴ The TICS data are structured in such a way that specific filter questions lead to the selection of firms that are innovators as opposed to non-innovators. Only the former have to answer the full questionnaire, including questions related to cooperation with external agents.

Table 1. Distribution of *innovator science-based firms* by economic activity. Data for TICS sample and population in 2004

Economic Activity	Sample	Sample (%)	Population	% Population
CHEMISTRY	400	61.16	840	67.25
PHARMACEUTICAL PRODUCTS	124	18.96	178	14.25
RADIO APPARATUS. TV AND COMMUNICATION	76	11.62	107	8.57
ELECTRICAL COMPONENTS	36	5.5	95	7.61
MANUFACTURE OF AIRCRAFT AND SPACECRAFT	18	2.75	29	2.32
<i>Total</i>	<i>654</i>	<i>100</i>	<i>1249</i>	<i>100</i>

2.2 Variables

Dependent variables

According to Oerlemans et al. (1998), the effects of internal and external resources on firms' innovation outcomes vary according to the industry in which the firm operates and the type of innovation developed. The literature on the sources and determinants of technological change has traditionally focused on the study of product innovation, and neglects process innovations (Reichstein and Salter, 2006). In our analysis we distinguish between these two types using dichotomous variables - related to product innovation (PRODIN) and process innovation (PROCIN) - based on the responses to two questions in the survey that enquire about whether the firm has introduced new or significantly improved products or processes during the period 2002-2004.

Explanatory variables

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The first group of explanatory variables relates to the different external knowledge acquisition strategies. We distinguish between bought-in knowledge (*buy*) and knowledge acquired through cooperation (*cooperation*). Within the *buy* strategy, we further distinguish among external R&D (*ERD*), technology embodied in machinery and equipment (*EQ*), and intangible technology in the form of patents, trademarks, software, etc. (*TECNO*). These strategies are measured using dummy variables that take the value of 1 if the firm has used the strategy during the period 2002-2004 and 0 otherwise.

Generally speaking, R&D outsourcing is associated with product innovation, and technological knowledge embodied in machinery and equipment is traditionally related to process innovation. The effect of intangible technology acquisition has been relatively under researched, although a positive relationship between this variable and the firm's innovative performance, is likely.

Strictly speaking, cooperation is not purely related to external knowledge acquisition because it builds on externally supplied knowledge and firm's internal capacities. The theoretical literature drawing on transaction cost economics, considers cooperation to be a 'hybrid' between hierarchical transactions within the firms (*make*) and arms-length transactions in the market place (*buy*). Cooperation allows firms to share costs and uncertainty, to realize economies of scale and scope, to exploit synergies from complementarities and even to win government support (Croisier, 1998; Becker and Dietz, 2004; Veugelers and Cassiman, 1999). To evaluate the effect of cooperation on innovation performance, we have used the replies to the TICS questions about whether the firm has cooperated with various external agents in R&D activities and innovation during the period 2002-2004. Based on previous classifications relating to the nature of external knowledge sources (Klevorick et al., 1993), we have created two variables: *CI* and *CNI*. The first relates to cooperation with industrial agents (clients, suppliers,

competitors, and sister companies); the second relates to cooperation with scientific agents or with agents outside the industry chain (commercial laboratories/R&D firms, universities, public research institutions and technological centres). These variables are measured on an ordinal scale (range 0-4) according to the number of collaborative agents in each category.

The second group of explanatory variables relates to the firm's internal technological capabilities. We include two variables traditionally considered to be indicators of firms' efforts to create and assimilate new knowledge. The first refers to the development of in-house R&D. The 2004 TICS database reports whether the firms carried out continuous or occasional in-house R&D activities in 2002–2004. Based on this, we built the variable *IRD*, which takes the value 0 if firms did not undertake internal R&D activities in 2002-2004, 1 if they occasionally engaged in R&D activities, and 2 if they had continuous in-house R&D. The second variable, *TRAINING*, refers to efforts made to train those staff involved in the implementation of a product or process innovation. This is a dummy variable that takes the value of 1 if the firm has carried out training during the period 2002-2004 and 0 otherwise.

Both internal R&D and innovation related training increase the firm's organizational knowledge base and its ability to utilize this knowledge (Caloghirou et al., 2004). Empirical studies demonstrate the importance of internal R&D as a determinant of product innovation, but are inconclusive about the influence of this variable on new process development. Freel (2003), for instance, found that internal R&D expenditure by science-based firms was not associated with process innovation, whereas Reichstein and Salter (2006) found evidence in favour of a significant and positive relationship between these variables. Likewise, there is no consensus on the influence of investment in staff training on new process development or the launch of new products.

On the other hand, it has been suggested that a firm's internal capacities condition the effects of external knowledge sourcing strategies on innovative performance. Thus, Harabi (1995) and Klevorick et al. (1995) argue that only those firms with a critical mass of knowledge are able to use the knowledge that exists in their environment to expand their innovation capabilities. Also, Cohen and Levinthal (1989, 1990) refer to the two faces of R&D, in terms of the different effects of internal R&D activities on the firm's innovation performance. This suggests that there is a direct and positive effect, since these activities engender new knowledge which can be used for the development of new or enhanced products and/or processes. In addition, there is an indirect effect resulting from the increase in the firm's absorptive capacity, which facilitates the acquisition and exploitation of external knowledge, at least if the firm is willing to overcome the 'not-invented-here' syndrome (Katz and Allen, 1982; Veugelers and Cassiman, 1999; Laursen and Salter, 2006). This effect is particularly relevant for scientific or technological knowledge whose absorption and use will require greater efforts on the part of the firm. This applies to knowledge acquired through cooperation with scientific agents or R&D outsourcing.

It would be expected, then, that the development of in-house R&D activities, especially if they are continuous, would be likely not only to increase the potential to generate product and process innovations, but also to emphasize the role of external scientific and technological knowledge as determinants of innovation. This implies that the greater the firm's internal capacities, the greater the effect of R&D contracting and cooperation with scientific agents on the firm's innovative performance.

Control variables

We also include as a control variable a measure for firm size (*SIZE*). Although the importance of size as a determinant of innovation has been extensively analysed, it is

difficult to determine *a priori* its real influence. The Schumpeterian hypothesis holds that, as large firms own the necessary resources (infrastructure, financial resources, production and marketing capabilities, R&D) to cope with the risks associated with innovation processes, they are more likely than their smaller counterparts to engage in innovative activities. Some recent empirical works have found evidence supporting this hypothesis (Freel, 2003; Reichstein and Salter, 2006). Other studies, however, have produced contracting results. Acs and Audretsch's (1988) work, for instance, shows that small and medium enterprises (less than 250 employees) are more innovation-intensive than larger firms, due, amongst other reasons, to their lower degree of rigidity when faced with innovations (Caloghirou et al., 2004).

In this analysis *SIZE* is measured as the logarithm of the firm's sales volume in 2004. Logarithmic specification has been acknowledged to be the most appropriate technique for measuring firm size and testing the Schumpeterian hypothesis (see Kamien and Schwartz, 1982; Cohen, 1995).

2.3 Econometric specifications

To meet the goal set in Section 1, we have defined the following econometric models:

$$INNOV_i^d = \alpha_0 + \alpha_1 ERD_i + \alpha_2 EQ_i + \alpha_3 TECNO_i + \alpha_4 CI_i + \alpha_5 CNI_i + \alpha_6 SIZE_i \quad (\text{model. 1})$$

$$INNOV_i^d = \alpha_0 + \alpha_1 ERD_i + \alpha_2 EQ_i + \alpha_3 TECNO_i + \alpha_4 CI_i + \alpha_5 CNI_i + \alpha_6 IRD_i + \alpha_7 TRAINING_i + \alpha_8 SIZE_i \quad (\text{model. 2})$$

$$INNOV_i^d = \alpha_0 + \alpha_1 ERD_i + \alpha_2 EQ_i + \alpha_3 TECNO_i + \alpha_4 CI_i + \alpha_5 CNI_i + \alpha_6 IRD_i + \alpha_7 TRAINING_i + \alpha_8 SIZE_i + \alpha_9 IRD_i * ERD_i + \alpha_{10} IRD_i * CI_i + \alpha_{11} IRD_i * CNI_i \quad (\text{model. 3})$$

where $i = 1, \dots, N$ (number of occurrences); $d = PRODIN, PROCIN$.

In the first model, we analyse the effect of external knowledge sources on a firm's innovation performance, regardless of its internal technological capabilities. In the second model, we include *IRD* and *TRAINING* as additional explanatory variables in order to determine to what extent internal capabilities influence the innovation outcome and to ascertain their impact on the effects of external knowledge sourcing. To explore this aspect further, model 3 includes three interactive terms, derived by multiplying *IRD* (moderating variable) by the *ERD*, *CI*, *CNI* (moderated) variables.⁵

Each of these three models was estimated employing 'new or significantly improved product introduction (PRODIN)', and 'new or significantly improved process introduction (PROCIN)' as dependent variables. This analysis yielded 6 logistic equations, which, based on the dichotomy of the dependent variables, were estimated using binary logistic regression.

3. Results

3.1 Descriptive evidence

Table 2 reports the basic statistics of and correlations between the explanatory variables used in the regression analysis. In line with Pavitt's (1984) the descriptive statistics show that science-based firms tend to innovate more in products than processes. The descriptive statistics also show that these firms cooperate more with scientific agents, specially with universities, and that the development of in-house R&D activities is the most frequent innovation strategy (93% of science-based firms conduct in-house R&D, and 80% of them continuously).

The correlation matrix reveals some interesting findings. First, Internal R&D activities show strong correlation with product but not process innovation. Second, internal R&D

⁵ These interactive terms indicate how the effect of external knowledge sources on the innovation outcome varies when the *IRD* variable is modified by 1 unit.

activity is positively related to cooperation strategies, and especially cooperation with scientific agents. This latter result may be an indication of the twofold effect of internal R&D, that the greater the effort on this activity, the greater the ability of the firm to identify and use sources of scientific knowledge. However, this positive relationship is not observed in the case of R&D outsourcing. A possible explanation for this result is that R&D contracting and in-house R&D compete over the same resources in the structure of business innovation expenditure. Consequently, the R&D outsourcing tends to diminish when the firm conducts in-house R&D.

Finally, in contrast to some studies (Martínez-Ros, 2000; Reichstein and Salter, 2006), we find that product and process innovation are not significantly correlated. It seems that for Spanish innovative firms, product and process innovation are independent of each other, and are associated with different knowledge sourcing strategies.

Table 2. Descriptive statistics and Spearman's correlation coefficients

	Mean	PRODIN	PROCIN	SIZE	ERD	EQ	TECNO	CI	CNI	IRD
PRODIN	77,7%	1								
PROCIN	68,0%	0,034	1							
SIZE	16,320 ^a (1,72) ^b	0,04	0,093(*)	1						
ERD	51,1%	0,034	0,097(*)	0,262(**)	1					
EQ	45,7%	0,123(**)	0,227(**)	0,052	0,180(**)	1				
TECNO	14,7%	0,067	0,117(**)	0,230(**)	0,181(**)	0,218(**)	1			
CI	0,524 ^a (0,94) ^b	0,126(**)	0,093(*)	0,272(**)	0,241(**)	0,122(**)	0,206(**)	1		
<i>C-Other firms</i>	13,9%									
<i>C-Suppliers</i>	14,8%									
<i>C-Clients</i>	14,8%									
<i>C-Competitors</i>	8,9%									
CNI	0,642 ^a (1,11) ^b	0,130(**)	0,099(*)	0,244(**)	0,344(**)	0,115(**)	0,146(**)	0,512(**)	1	
<i>C-Labs and Private R&D Institutes</i>	13,0%									
<i>C-Universities</i>	24,5%									

<i>C-Public</i>										
<i>Research</i>	13,0%									
<i>Institutes</i>										
<i>C-</i>										
<i>Technology</i>	13,8%									
<i>Centers</i>										
	1731 ^a									
IRD	(0,57) ^b	0,117(**)	-0,015	0,149(**)	0,049	-0,034	0,015	0,084(*)	0,118(**)	1
IRD (1)	13,5%									
IRD (2)	79,8%									
TRAINING	55,7%	0,091(*)	0,200(**)	0,091(*)	0,124(**)	0,319(**)	0,266(**)	0,173(**)	0,184(**)	0,129(**)

^a Average value

^b Standard deviation appear in parenthesis

** Correlation is significant at the 0,01 level (bilateral)

* Correlation is significant at the 0,05 level (bilateral)

3.2 Econometric analysis

Because we have restricted the analysis only to *innovator* firms, the coefficients in the logistic regressions may be biased. To address this potential problem we used two-part logit models. In the first stage of our analysis, we ran a selection model using all available observations and considering whether or not the firm was *innovator* as dependent variable (see Appendix 1)⁶. This allowed us to calculate the probabilities of

⁶ Consistent with the literature (Veugelers and Cassiman, 1999), we regress whether the firm was *innovator* on the following independent variables: firm size (*SIZE*), export orientation (*EXPORT*) belonging to a group (*GROUP*), as well as industry dummies. We also included four variables measuring the obstacles to innovation: cost (*FACcost*), lack of technological/market information (*FACknow*), lack of demand (*FACmark*) and need for innovation (*FACneed*).

each firm becoming an innovator (*Prob*), which is included as an additional independent variable in the main regression models, thus controlling for selection bias from including the effects for non-innovative firms (Greene, 1993)⁷.

Table 3 presents the results of main regression models, for process and product innovation.

Table 3. Determinants of process and product innovation. Results of the regression analysis.

Independent variables	Process Innovation			Product Innovation		
	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3
Prob	0.92 (1.09)	0.92 (1.12)	1.02 (1.12)	3.51*** (1.13)	3.01* (1.15)	2.95* (1.15)
SIZE	0.06 (0.06)	0.07 (0.06)	0.07 (0.06)	-0.04 (0.06)	-0.05 (0.06)	-0.05 (0.06)
ERD	0.16 (0.19)	0.16 (0.19)	-0.94 (0.60)	-0.03 (0.22)	0.03 (0.22)	0.27 (0.56)
EQ	0.90 ***(0.19)	0.74*** (0.19)	0.69*** (0.20)	0.54** (0.21)	0.58** (0.22)	0.59** (0.22)
TECNO	0.48 (0.30)	0.31 (0.31)	0.29 (0.31)	0.33 (0.33)	0.35 (0.34)	0.37 (0.34)
CNI	0.04 (0.10)	0.03 (0.10)	0.51 (0.53)	0.23** (0.12)	0.20* (0.12)	0.52 (0.47)
CI	0.06 (0.12)	0.04 (0.12)	0.37 (0.54)	0.19 (0.15)	0.20 (0.15)	0.01 (0.44)
IRD		-0.13 (0.16)	-0.36 (0.25)		0.51*** (0.16)	0.60** (0.24)
TRAINING		0.61*** (0.19)	0.59*** (0.19)		0.02 (0.22)	0.02 (0.22)
IRD*ERD			0.61 (0.33)			-0.15 (0.32)
IRD*CNI			-0.26 (0.28)			-0.17 (0.25)
IRD*CI			-0.18 (0.28)			0.11 (0.24)
Industries dummies	Included	Included	Included	Included	Included	Included
Intercept	-1.13 (1.21)	-1.16 (1.22)	-0.89 (1.25)	-1.34 (1.30)	-1.53 (1.31)	-1.70 (1.33)
Chi-squared (d.f)	49.44*** (11)	59.95*** (13)	65.36*** (16)	43.57*** (11)	53.67*** (13)	54.51*** (16)
Pseudo R^2	0.10	0.12	0.13	0.10	0.12	0.12
Observations	654	654	654	654	654	654

Data inside parenthesis are the corresponding standard errors

* $P < 0.1$

** $P < 0.05$

*** $P < 0.01$

Chi-square values for the degrees of freedom in the models seem to indicate rejection of the null hypothesis that all parameters except the intersection, are equal to zero with a significance level of 1%. *Prob* is not significant in most cases and when it is excluded

⁷ Running a separate regression for sample inclusion followed by the main regression model is appropriate when the intermediate dependent variable is observed rather than estimated, and more appropriate than a Heckman selection model, which uses the Mills ratio, since the dependent variable is binary rather than continuous (Manning et al., 1987, Haas and Hansen, 2005).

from the models, the main variables barely change. Thus, the hypothesis of sample selection bias can be rejected.

Model 1 reports the baseline model including only the control variables and the external knowledge sourcing strategies. This model indicates that the effect of the different modalities of external knowledge acquisition on the firm's innovation performance varies depending on the type of innovation. The results for process innovation show that the acquisition of technological knowledge embodied in machinery and equipment (*EQ*) has with greatest impact. The coefficients of the *EQ* variable are positive and highly significant, indicating that purchase of machinery and equipment is an important strategy to develop new processes. In contrast, neither of the cooperation strategies has a significant effect. These results show that in Spain, in contrast to other countries (see Freel, 2003 and Reichstein and Salter, 2006), the establishment of cooperation agreements with industrial agents does not enhance firms' production processes.

For product innovation, machinery and equipment acquisition (*EQ*) and cooperation with scientific agents (*CNI*) are the only strategies that are shown to have a positive and significant effect. Two important points emerge from these findings. First, cooperation is a useful strategy for the development of new products. Second, the choice of cooperation partners depends on the industrial sector. These results are consistent with the literature and show that the more technology-intensive the industry, the more important will be the knowledge from scientific agents for new product development. However, contrary to expectations, R&D outsourcing (*ERD*) was not found to be significant.

The effects of the firm's internal capacities are introduced in model 2 through the variables *IRD* and *TRAINING*. The influence of these variables on firms' innovative performance also depends on the type of innovation. In-house R&D (*IRD*) has a

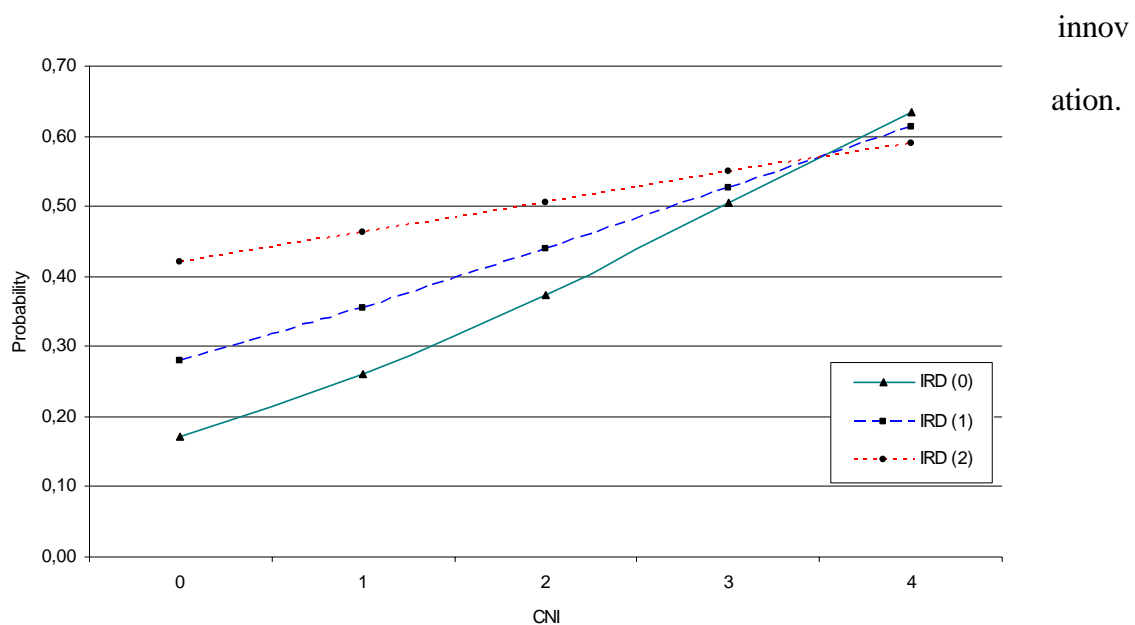
significant influence on product innovation, but its effect is not significant for process innovation. Internal training (*TRAINING*), on the other hand, significantly affects only process innovation.

Some additional comments are needed to clarify these results. The high significance of the *IRD* variable on product innovation highlights that far from losing relevance, implementation of in-house R&D activities is the main strategy for developing new products. On the other hand, it is hardly surprising that *IRD* was found to be not significant for process innovation. As it was above mentioned, studies on the effect of this variable on process innovation have produced mixed findings. In fact, our results coincide with those found by Freel (2003) for the UK. In any case, these findings highlight that in Spanish science-based firms, improvements to the productive process are not based on either research or cooperation with external agents, but are largely driven by the purchase of machinery and equipment. Moreover, the acquisition of new machinery and equipment usually requires some training of technical staff in how to use the new equipment, which explains the positive and significant effect of *TRAINING*.

In general, the inclusion of in-house R&D activities in the analysis has little effect on external knowledge sourcing strategies. Focusing on product innovation (where the *IRD* variable has a significant effect), only a change in the significance of the *CNI* variable is noted. This variable loses explanatory power when in-house R&D is considered, although it remains significant at 10%. In this sense, the results suggest, rather surprisingly, that a high level of internal technological capabilities derived from in-house R&D activities, reduces the importance of external acquisitions of scientific knowledge as a determinant of innovation. The model 3 estimations support this conclusion, provided that the interactive term *CNI*IRD* has a negative sign, although it is otherwise not significant.

Using the results from model 3 in Table 3 and holding all other covariates at their mean values, we plotted illustrative examples of the effects of cooperation with scientific agents (*CNI*) on product innovation, for various levels of in-house R&D activities (*IRD*). Figure 1 depicts these effects. We observe that when the *IRD* variable increases the slope of the line that draws the relationship between *CNI* and product innovation diminishes⁸. This suggests that where firms engage in in-house R&D, and even more so when they do so continuously, the marginal effects of cooperation with scientific agents on product innovation tend to decrease.

Figure 1. Relationships between cooperation with scientific agents and product



To summarize, our results do not support the complementarity hypothesis; rather, they indicate the existence of a possible substitution effect between external knowledge sourcing and internal knowledge development. Thus, although firms that perform internal R&D on a continuous basis tend to cooperate more with universities relative to other external agents, this cooperation does not seem to be oriented towards the

⁸ When the *IRD* variable changes from 0 to 2 the slope of the line diminishes from 0,12 to 0,04.

development of key activities for their innovation processes. This cooperation with scientific agents might be motivated more by access to funds through participation in government sponsored programmes, than to improving innovative capacities based on the integration of complementary knowledge from external agents

In addition, Figure 1 shows that when in-house R&D is continuous ($IRD=2$) and the firm cooperates with the four types of scientific agents considered in the analysis, the probability of introducing new products is less than when firms either do not engage in in-house R&D or do so only occasionally. This result indicates that the firms could be facing an 'attention allocation problem' (Ocasio, 1997). As managerial attention is a limited resource, the managers need to concentrate their efforts and energy on a restricted number of strategies. Thus, when the firm engages both internal development and external knowledge sourcing, there may be many ideas that surpass the firm's capabilities for evaluating and exploiting them (Ocasio, 1997). The effectiveness of external knowledge sourcing strategies to encourage a firm's innovative performance depends therefore not only on the acquisition of knowledge but also on the firm's capability to set priorities and concentrate resources.

Finally, we found that the *SIZE* variable was not significant in either process or product innovation; however, in the first-stage model (Appendix 1) firm size had a significant and positive effect. This suggests that the effect of firm size is limited only to the decision to implement an innovation activity. Once the firm has decided to innovate, the probability that it will introduce new products or processes does not depend on size.

4. Conclusions

This study has examined the effects of different external knowledge sourcing strategies on product and process innovation and to what extent these effects are influenced by in-

house R&D. We found that product and process innovations may be independent of each other and, even more importantly, that they are associated with different knowledge sourcing strategies. For instance, our results indicate that process innovation is largely driven by the acquisition of knowledge 'embodied' in machinery and equipment and that cooperation with external agents has no significant effect. In contrast, cooperation with scientific agents seems to be an important strategy to develop new products. Along this line, it is all the more surprising that R&D contracting was found to be not significant in enhancing firms' innovative performance.

Our results also indicate that in-house R&D activity still represents a strategic asset in the development of new products and, in addition, that developing and implementing these activities is significantly more important than employing strategies involving external partners. Moreover, our analysis reveals another more fundamental issue. When we examined the relationships between external sourcing strategies and internal R&D, we found no evidence to support the complementarity hypothesis. More importantly, our analysis indicates instead that there are possible substitution effects between these activities. Thus, the greater the firm's internal technological capability, the less important is the cooperation with scientific agents in determining product innovation. This seems to run against the increasingly dominant *open innovation model* (Chesbrough, 2003).

These results have at least two important implications. Firstly, they support the idea that product innovation is a process that largely builds on the firm's internal capabilities, and warns against the risk of overrating external knowledge sourcing. In this regard, the importance of cooperation, for instance, should be considered in relative terms. As Freel (2003, p 762.) has said: "*certain types of cooperation are associated with specific types of innovation, involving certain firms, in certain sectors*", and we would add certain

levels of internal technological capabilities. Secondly, acceptance of this heterogeneity should lead policy makers in Spain and other technology follower countries, to acknowledge the complexity of the innovation process and avoid the promotion of 'one size fits all' mechanisms, which are generally only suited to the most technologically developed countries. In the light of our results, it would appear that policy makers should concentrate on strengthening the technological capabilities of firms and should go beyond simple support to university-industry collaboration.

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Appendix 1. Logit analysis results for first-stage model (firm's decision to innovate or not)

Variables	Coefficients (standard error)
SIZE	0.19* (0.11)
EXPORT	0.00 (0.01)
GROUP	-0.24 (0.22)
FACcost	0.13 (0.18)
FACknow	0.42 (0.28)
FACmark	0.62*** (0.21)
FACneed	-1.10*** (0.19)
Industries dummies	Included
Intercept	-2.71 (1.84)
Chi-squared (d.f)	75.56*** (11)
Pseudo R^2	0.22
Observations	720
* $P < 0.1$	
** $P < 0.05$	
*** $P < 0.01$	