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Sources of innovation and industry–university interaction: Evidence from Spanish firms

Agustí Segarra-Blasco*, Josep-Maria Arauzo-Carod

Department of Economics, Universitat Rovira i Virgili, Av. Universitat 1, 43204 Reus, Spain

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ABSTRACT

In this paper we use a sample of Spanish innovative firms to identify the determinants of R&D cooperation agreements between five types of partners: firms that belong to the same group; customers and suppliers; competitors; universities; public research centres. We focus on the determinants of R&D cooperation between innovative firms and universities. We used the Spanish version of the Community Innovation Survey (CIS-3) to obtain data about the R&D cooperation of 4150 innovative firms in Spain. To obtain empirical evidence about the determinants of this cooperation, we adopted an integrated approach that enables us to compare the effects of sectorial and individual determinants on the choice of partners. Our results show that a firm's cooperation activities are closely linked to the characteristics of the industry and the characteristics of the firm. These include R&D intensity, size, whether the firm belongs to a group, product and process innovation, and access to public funds for R&D activities. Internal R&D and agreements with customers, suppliers and competitor partners also increase firm's propensity for R&D cooperation with universities.

1. Introduction

Innovation is increasingly related to a firm's ability to absorb external information, knowledge and technologies. A recent trend in the innovative performance of a firm is increasing R&D cooperation with customers and suppliers, competitors, universities, and public research organizations (Veugelers, 1997; Fritsch and Lukas, 2001; Arora et al., 2001; Tether, 2002).

In this paper we investigate the determinants of a firm's cooperative R&D agreements with different partners, paying special attention to cooperative R&D projects between firms and universities. In recent years the determinants and effects of R&D cooperation have become an important research topic and theoretical and empirical literature has increasingly focused on R&D cooperation by innovative firms. This literature assumes that cooperative R&D agreements involve relationships between organizations that aim to carry out R&D projects in order to enhance their innovation.

We believe the Spanish case is interesting because Spain has fewer R&D activities than other European countries and because Spanish firms have a traditionally low absorptive capacity, with a large number of small firms and weak links between public and private actors (Eurostat, 2007). A good way to enhance R&D activities is to encourage cooperation agreements with other private firms and/or public research organizations.

Because of the complexity of cooperation agreements, the literature usually distinguishes between formal agreements and informal ones. Formal agreements are based on stable relationships that can become R&D consortia, joint research ventures or information exchange agreements. Informal agreements are more difficult to identify because they involve sporadic relations between the agents. Most empirical studies concern formal R&D cooperation (Cassiman and Veugelers, 2002; Miotti and Sachwald,

* Corresponding author. Tel.: +34 977 759 800; fax: +34 977 759 810.
E-mail addresses: agusti.segarra@urv.cat (A. Segarra-Blasco), josepmaria.arauzo@urv.cat (J.-M. Arauzo-Carod).

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2003) but informal R&D cooperation also has an important role (Bönte and Keilbach, 2005).

In the last few years R&D cooperation with other firms and institutions has been analysed using three approaches. The first one is the transaction cost approach, which considers that cooperative R&D projects enable the costs and risks of R&D activities to be shared and the dissemination of the results to be protected (Williamson, 1985). The second one is the strategic management approach, which consider that cooperative behaviour is a way of accessing additional resources and that this leads to competitive advantages (Teece, 1986). The third one is the industrial organization approach, which focuses on knowledge spillovers between partners. This approach considers that the more knowledge spillovers there are, the greater are the incentives to cooperate and limit access to the results of the process (Petit and Tolwinski, 1999).

To protect the results of R&D activities firms can invest in appropriation instruments. Cohen and Levinthal (1989) introduced the term "firm absorptive capacity" and pointed out the dual role of R&D as both a producer of new information and a tool of a firm's ability to learn from existing information. More recently, Cassiman and Veugelers (2002) distinguished between incoming spillovers, which affect a firm's innovation rate, and appropriability, which affects a firm's ability to appropriate the returns from innovation. López (2006) used Cassiman and Veugelers' framework to find empirical evidence in Spanish manufacturing firms that incoming spillovers and appropriability affect the probability of R&D cooperation.

In this paper we propose an integrated framework to analyse a firm's motivation for cooperating in R&D projects. We follow transaction cost theory, which states that the propensity to cooperate increases when the cost and risk associated with R&D activities are considerable and the technological complexity in the sector is high. Moreover, according to strategic management theory, a firm's cooperative R&D behaviour is linked to its access to complementary resources and ability to internalize the knowledge generated by the cooperative project. In this respect, the notion of absorptive capacity introduced by Cohen and Levinthal (1989) highlights the importance of previous R&D undertaken by cooperative firms and the complementarities between internal and external R&D sources with R&D cooperation behaviour (Veugelers, 1997). Empirical evidence shows that cooperation with universities and public research centres complements other innovation activities and cooperation with other partners (Veugelers and Cassiman, 2005), and firm's adsorptive capacity has a relevant impact on the ability of firms to cooperate with external organizations (Muscio, 2007). Additionally, industrial organization highlights the importance of spillovers related to knowledge flows and the capacity of the firm to assimilate the external results generated in cooperative R&D activities.

In this paper we provide empirical evidence on the determinants of R&D cooperation in a sample of Spanish firms from manufacturing and services industries. Our data set comes from Technological Innovation Survey of Spanish firms. This survey is part of the Community Innovation Survey (CIS-3) for the period 1998–2000 and includes firms in both the manufacturing and service industries. The Spanish CIS-3 provides data on 11778 firms. This sample is representative of the population with 10 employees or more.[1] For our empirical work on analysis of the determinants of R&D cooperation, like other authors (Cassiman and Veugelers, 2002; Arbussà and Coenders, 2007) we restricted our sample to innovative firms. Between 1998 and 2000, 4150 firms carried out at least one innovation (2837 in the manufacturing sector and 1313 in the service sector).

In this paper we analyse both manufacturing and service industries. This is extremely rare in the literature on R&D cooperation (except, for example, Belderbos et al., 2004a,b, for the Netherlands).[2] Despite the increasing prominence of services in European economies, few studies have analysed firms' R&D cooperation in both manufacturing and services industries.[3] This point is relevant because the sources of innovation and R&D cooperation strategies are very different between manufacturing and service firms. We also differentiate between several types of cooperation partners. This approach was rare in this literature until a few years ago: see, for example, Belderbos et al. (2004a), Veugelers and Cassiman (2005), Kaiser (2002), Becker and Dietz (2004), Bönte and Keilbach (2005), Schmidt (2005), López (2006) and Negassi (2004). Our empirical framework explores the determinants of R&D cooperation in manufacturing and service firms with various partners: other firms from the same group; customers and suppliers; competitors; universities; public research centres. We pay special attention to the R&D agreements between Spanish firms and universities.

This paper is organised as follows: in the second section we review several contributions on the external sources of the innovation process. In the third section we analyse the characteristics of the cooperation and innovation process. In the fourth section we present the model and the variables. In the fifth section we discuss our results and in the sixth section we summarise our main conclusions.

2. Sources of innovation

Sources of innovation and the ability of a firm to cooperate with partners differ between firms and industries. Firms that maintain different forms of R&D cooperation with customers, suppliers, competitors and public research institutions tend to have a high share of intramural R&D. Complementary to internal R&D activities, firms also carry out external sources of innovation, particularly the acquisition of external R&D, machinery, equipment and software, and cooperative R&D projects. Moreover, the increasing role of innovation in market competition and increasingly

[1] These data were for a stratified random sample whose strata were defined by a combination of the branch variables of activity, size (number of employees) and R&D activity. The information was collected using a mixed system that included questionnaires and interviews backed up by phone calls.

[2] Most empirical research is for manufacturing activities: for example, Becker and Dietz (2004), Bönte and Keilbach (2005) and Schmidt (2005) for Germany; Negassi (2004) for France and López (2006) for Spain.

[3] The innovation patterns at firm level in both the manufacturing and services sectors are analysed in Cainelli et al. (2006), Tether (2002), Lööf (2004) and Miles (2005).

complex technology mean that cooperation agreements are becoming more and more common (Cohen and Levinthal, 1990; Fritsch and Lukas, 2001; Baumol, 2002).

Firms can undertake R&D cooperation projects with many partners: firms that belong to the same group, competitors, suppliers and customers (vertical cooperation), universities, and public centres. Universities are a special case because of their research potential and the diversity of their research groups (Santoro and Chakrabarti, 2002). At the university level there are formal and informal relations between institutions, firms and individuals, and new scientific knowledge is transmitted to innovative firms.

The role of R&D cooperation within the innovation process has recently increased (Busom and Fernández-Ribas, 2008) because the technological level has increased, because costs are higher and because economic activities are hazardous. The role of universities in the innovation system is particularly important in countries specialized in low-technological industries. Spain invests less in R&D than the EU average. Moreover, the weight of public funds is higher and the number of innovative firms is lower. Several statistics (Eurostat, 2007) can provide a clear picture of the scenario: in 2003 Spanish investment in R&D was only 1.05% of GDP (GERD) (EU: 1.95%), while public R&D expenditure was 40.1% (EU: 34.7%). Business sectors were responsible for 54.2% of Spanish R&D investments (EU: 64.6%), while university expenditures were responsible for 30.4% (EU: 21.5%). These figures show that in Spain the business sector played a smaller role in R&D activities than in other EU countries, while universities carried out more R&D activities in Spain than in the EU.

In Spain academic research and university–industry relationships play an important role. Spanish universities are modifying the traditional roles of a Humboldt-style university (i.e. higher education and research) in order to generate and disseminate knowledge directly connected with economic development. This connection is partially due to university–industry links such as technology transfer centres, research institutes, science parks and technology springboards. Spain is also interesting because university policy depends on the regional government, and public support for promoting firm innovation and cooperative projects with universities and public research centres, especially between SME firms, has increased considerably in recent years.

Moreover, the commercialisation of university knowledge (especially knowledge from university-based technologies) has increased considerably due to patenting, joint ventures in research and firm creation (spin-offs from universities). Several factors explain this phenomenon. First is the creation of structures that promote relations between the universities and business, such as science parks and other property-based institutions (Link et al., 2003). Second is the development of laws on intellectual property, while researchers' increasing interest in patenting their discoveries has helped to commercialise the results of university research. Third, Spanish public subsidy programs that promote R&D cooperation between SME firms and universities have increased in the last few years. Finally, closer R&D cooperation between firms and universities and public funding for the creation of joint ventures have directed universities' research activities towards the demands of business.

The decentralized system of university funding created strong incentives for public universities to pursue research that was interesting for local firms (Mowery and Sampat, 2001). However, the recent rise in university–industry partnerships has stimulated an important public-policy debate on how these relationships affect fundamental research (Poyago-Theotoky et al., 2002), given that firms' relationships with other agents involved in the innovation system play a key role in their innovation processes.

To analyse the external relations of Spanish firms linked to their innovative behaviour, an interesting data source is available at the firm level. The Spanish version of the CIS-3 contains much information on firms' R&D and innovation activities. This survey asks firms which sources they have used in their innovation process. The sources of innovation include collaboration agreements with other firms and public institutions between 1998 and 2000 for manufacturing and services firms.

The Spanish CIS-3 asks about the nature and sources of innovations by Spanish firms and their performance in various innovative fields. Between 1998 and 2000 the firms indicated whether they carried out product and process innovations (radical or incremental innovations). The survey paid special attention to conventional sources of innovation (R&D activities, R&D expenditure, patent registration), external sources of innovation (the purchase of external services related to innovative activity, the acquisition of incorporated technology and technical assistance), and cooperation agreements with other agents. It defined three types of innovations depending on the intensity and nature of the change:

- *Total product innovations* refer to the development of an entirely new product based on new technology or new uses of existing technology.
- *Progressive product innovations* refer to marginal improvements to the components or subsystems of a product.
- *Process innovations* refer to the adoption of new or appreciably improved methods of production.

Of the 4150 innovative firms, 2697 carried out at least one product or process innovation (radical product innovation: 1523 firms; incremental product innovation: 1174 firms), 2738 firms carried out at least one process innovation, and 1616 firms carried out both product and process innovations.

These technological innovations comprise R&D activities, industrial design, manufacturing equipment and manufacturing engineering, the commercialisation of new products, and the acquisition of material and immaterial technologies. A firm's R&D activities are developed at their own facilities or through agreements with other agents.[4] Internal R&D expenses include current and capital

[4] Cooperation in R&D includes R&D projects with other institutions and a company's own projects officially linked to the projects of other institutions. A special form of cooperation in R&D is participation in national and international programmes designed to encourage research.

Table 1
Main indicators of innovation by sector

	High-tech manufacturing	Low-tech manufacturing	High-tech services	Low-tech services
Product innovation	313 (76.2)	1583 (65.3)	289 (78.7)	512 (54.1)
Radical	190 (46.2)	865 (35.7)	212 (57.8)	256 (27.0)
Incremental	123 (29.9)	718 (29.6)	77 (21.0)	256 (27.0)
Process innovation	237 (57.7)	1668 (68.8)	195 (53.1)	638 (67.4)
Product and process innovation	177 (43.1)	998 (41.1)	149 (40.6)	292 (30.8)
Innovative activities in progress	302 (73.5)	1328 (54.7)	273 (74.4)	441 (46.6)
Frustrated innovative activities	144 (35.0)	561 (23.1)	84 (22.9)	110 (11.6)
Internal R&D activities	310 (75.4)	1176 (48.5)	264 (71.9)	209 (22.1)
The company has acquired external services of R&D	123 (29.9)	517 (21.3)	68 (18.5)	169 (17.8)
Cooperation with other companies or institutions in R&D activities	130 (31.6)	401 (16.5)	131 (35.7)	117 (12.4)
The company has requested a patent	122 (29.7)	402 (16.6)	66 (18.0)	33 (3.5)
The company has some current patent at the end of 2000	152 (37.0)	533 (22.0)	64 (17.4)	54 (5.7)
Number of firms	411	2426	367	946

Notes: All data refer to the period 1998–2000. Figures in brackets are firms related to total number of firms. *Source*: Survey of Technological Innovation, 2000, INE.

expenses linked to research and technological development within the firm as well as expenses incurred outside the firm to support these activities.[5] External R&D expenses include contracts for acquiring the R&D services of other firms, universities or public research centres.

The main features of innovation-related activities are shown in Table 1. In accordance with the OECD classification for the technological intensity of industries, the firms are divided into four groups according to sector (manufacturing and services) and technological intensity (high-technology sectors and medium- and low-technology sectors).[6] To facilitate the presentation, we have grouped these sectors into four categories: high-tech manufacturing (high and medium–high technologies), low-tech manufacturing (low and medium–low technologies), high-tech services (R&D services, financial activities and other business activities), and low-tech services.

Here we can see that the innovative processes and performances of manufacturing industries are different from those of service industries. Also different are the innovative processes and performances of industries with a low–medium technological level and industries with a high technological level.

Several stylised facts emerge from Table 1. Between 1998 and 2000, firms in high-technology industries carried out intensive innovative activity aimed at totally or partially incorporating related innovations into their products or services. In high-technology manufacturing industries, 46.2% of firms carried out at least one radical product innovation and 29.9% of the firms carried out at least one incremental product innovation. In high-technology services, 57.8% of the firms carried out at least one radical product innovation and 21.0% carried out at least one incremental product innovation. The innovative activity of the industries of average and below-average technological intensity was much more moderate and more orientated to partial changes in the products or services.

Low-tech manufacturing industries were more active in process innovations. Between 1998 and 2000, 68.8% of low-tech manufacturing firms carried out at least one process innovation. This was higher than the 57.7% for high-tech firms. We also found this pattern among services: 67.4% of low-tech service firms carried out at least one process innovation, while only 53.1% of high-tech firms did.

The differences in the intensity and nature of the innovations carried out by Spanish firms reflect their different innovating strategies. Firms operating in markets with intense competition, fast technological change and a short product life cycle, are forced to continuously introduce new technological knowledge and product or process innovations. On the other hand, firms operating in mature markets, where prices and distribution channels are determinants of market-share, dedicate more resources to making organizational and technological changes that reduce distribution and production costs. We must also highlight an important group of firms that make process and product innovations simultaneously. In fact, between 30% and 40% of innovating firms make as many process innovations as product innovations, both in the manufacturing industry and in the high- or low- technology services industry.

There are great differences in the origins of business innovation, both in the external acquisition of services related to innovation and in cooperation to develop innovations with other firms or with public institutions. These differences depend on the technological intensity of the industry. Predominant in high-technology industries are innovative firms that develop internal R&D activities and cooperate with other firms, universities and public research

[5] These expenses include the amount of expenditure on innovation activity in 2000 that affects intramural (in-house) R&D activities, the acquisition of R&D (extramural R&D), the acquisition of machinery, equipment and software, the acquisition of external knowledge and training, and marketing expenditures related to innovation.

[6] The OECD initially defined technology intensity in manufacturing sectors on the basis of the ratio of R&D expenditure to added value. This method was later extended to take into account the technology embodied in intermediate and capital goods. This new measure could also be applied to service industries, which tend to use technology rather than produce it (OECD, 2006).

institutions. Such activities are less frequent in other industries, particularly service industries.

Patenting, as an instrument for protecting innovations, is not very deep-rooted in Spanish firms. This aspect of the innovation process is critical because firms need to be able to appropriate the results of their innovations in order to create innovation incentives (Cohen et al., 2002). The level of appropriability in Spain is low and unpatented products and processes are common among Spanish firms. This poor tradition in patenting the results of innovations is particularly apparent in services, especially low-technology services (Abramovsky et al., 2005). Between 1998 and 2000, only 3.5% of these firms requested a patent and by the end of 2000 only 5.7% had a registered patent.

3. Cooperation and the innovation process

In recent years more empirical studies have provided 'stylized facts' about inter-firm cooperative R&D agreements. In this section we provide an integrated framework for analysing the determinants of a firm's cooperative agreements. We distinguish between several partners and focus on cooperation with universities and public research centres.[7]

The literature on the motives behind R&D cooperative relationships discusses a wide range of factors related to the firm's characteristics, the market structure, the firm's absorptive capacity and the effect of positive and negative spillovers of R&D activities. Several theoretical models that study a firm's R&D cooperation strategies and the role of spillovers have related sectorial and individual characteristics (De Bondt, 1997; Veugelers, 1997; Veugelers and Cassiman, 1999). Cassiman and Veugelers (2002) presented an analytical framework for analysing how information flows or spillovers affect the propensity of innovative firms to cooperate in R&D. They found that a firm's external information sources (incoming spillovers) and the ability of firms to appropriate the returns from innovation (appropriability) have a positive effect on the probability of R&D cooperation. In accordance with recent literature (Fritsch and Lukas, 2001; Bayona et al., 2001; Miotti and Sachwald, 2003; Cassiman and Veugelers, 2002), we explore the determinants of Spanish firms' R&D cooperation agreements with several types of partners aimed at benefiting from information flows. Our empirical framework tests the hypotheses in Table 2 in accordance with recent models of R&D cooperation.

These hypotheses describe the motivations behind cooperative R&D projects between firms. Here we take into account both manufacturing and service activities, whereas most empirical studies have focused only on manufacturing activities. The propensity to cooperate is higher for firms in high-technological sectors in both manufacturing and services (Hypothesis 1). In high-tech sectors, universities and public research centres are important sources of

Table 2
Summary of hypotheses

Hypothesis	R&D cooperation with other partners
H1	The propensity to engage in R&D cooperation is higher for firms from sectors with high R&D intensity, especially in services.
H2	Cooperation increases with firm size
H3	Intramural R&D activities increase the propensity to engage in cooperation R&D agreements
H4	Firms that perform both product and process innovation have a high propensity to engage in R&D cooperation agreements
H5	Public funding programs affect the propensity to engage in R&D cooperation agreements
H6	Firms that belong to a group tend to establish R&D cooperation agreements with other partners
	R&D cooperation with universities and public research centres
H7	Firms that establish cooperation agreements with other partners also tend to establish cooperation agreements with Spanish and foreign universities.
H8	Firms belonging to Spanish groups are more predisposed to establish cooperation R&D agreements with Spanish universities

Source: own elaboration.

open science and R&D cooperative activities (Cohen et al., 2002). The positive effect of sectorial R&D intensity on the propensity to engage in R&D cooperation has been confirmed for manufacturing industries in several European countries (Fritsch and Lukas, 2001; Bayona et al., 2001; Miotti and Sachwald, 2003). In a sample of French firms Negassi (2004) found that R&D cooperation increases with both size and R&D intensity but not with market share and highlighted the important role of the absorptive capacity of innovating firms.

One of the most recursive topics in R&D cooperation is the role of firm size in influencing the propensity of firms to cooperate with partners. Large firms are generally more likely to collaborate with other firms, and especially with public institutions (Mohnen and Hoareau, 2003) (Hypothesis 2). The positive link between firm size and R&D cooperation has recently been demonstrated for several European countries (Miotti and Sachwald, 2003; Negassi, 2004; López, 2006). Tether (2002) found that large firms might be more attractive to partners than smaller firms. Segarra et al. (2008) observed that small and innovative firms in Spanish manufacturing and service industries find it very difficult to find R&D partners.

Cohen and Levinthal (1989) emphasised the dual role of R&D as a source of new information and a tool that facilitates a firm's absorptive capacity to absorb existing information. Firms that invest in R&D are likely to absorb the information developed outside the firm. We hypothesize that a firm's absorptive capacity is especially related to intramural R&D (Veugelers, 1997; Veugelers and Cassiman, 1999). If a firm's absorptive capacity increases when it invests in internal R&D, its probability of establishing cooperative R&D projects increases (Hypothesis 3). Other studies have observed the capacity of the firm to do both product and process innovation and its propensity to cooperate. The empirical results are diverse (Mohnen and Hoareau, 2003; Fontana et al., 2006). These studies generally found that firms involved in both product and

[7] In this paper we measured industry–university cooperation with data from the Technological Innovation Survey. There are, of course, other forms of cooperation, such as informal cooperative agreements but it is extremely difficult to include such situations in our data set.

process innovation are more likely to cooperate in R&D projects. Moreover, the number of partners cooperating in R&D projects positively affects the firm's innovation capacity (Becker and Dietz, 2004). We expect a firm involved in both product and process innovation to have a high propensity to engage in cooperative R&D agreements (Hypothesis 4).

Many empirical studies have estimated the effect of public R&D subsidies aimed at promoting R&D activities and cooperation (Negassi, 2004). According to these studies, firms with access to public subsidies aimed at promoting R&D activities or that belong to a group tend to cooperate more (Bayona et al., 2001; Miotti and Sachwald, 2003; Cassiman and Veugelers, 2002; Becker and Dietz, 2004). We expect public subsidies to help firms find new partners and reach R&D cooperation agreements (Hypothesis 5). In agreement with existing literature (Arbussà and Coenders, 2007), we also expect firms belonging to a group to be more likely to perform R&D cooperative projects (Hypothesis 6).

In addition to these stylized facts, since 1980s the literature has increasingly analysed the determinants of R&D cooperation between firms and universities and public research institutions (Feller, 1990; Cohen et al., 2002; Mora-Valentin et al., 2004; Fontana et al., 2006). Empirical research found that, for example, a firm's size, R&D intensity and absorptive capacity, as well as access to public subsidies, positively affect a firm's capacity to cooperate with universities and other public research institutions. In agreement with recent studies, we expect that firms with other R&D partners to be more likely to carry out R&D cooperative agreements with other firms and public research organizations (Hypothesis 7).

Whether the fact that a firm belongs to a group affects R&D cooperation agreements with universities is ambiguous. When a firm belongs to a group, the incentive to exploit knowledge by entering into R&D agreements with local universities increases. Its propensity to cooperate with foreign universities is ambiguous, however. In this area, the empirical literature differs. Tether (2002) found that foreign groups are more likely to have at least one R&D relationship, especially with customers and universities. Miotti and Sachwald (2003) found that belonging to a group increases a firm's propensity to cooperate in R&D, especially with foreign firms. Belderbos et al. (2004b) found that belonging to a group increases R&D cooperation with customers and suppliers but not with universities or research institutions. In line with these ambiguous results, we expect a firm that belongs to a group to cooperate more with universities, and especially with Spanish universities (Hypothesis 8).

The above hypotheses are supported by several empirical studies on the relationship between R&D cooperation between firms and universities in various European countries. Spain, for example, has been analysed by several authors. Bayona et al. (2001) studied the reasons behind cooperation agreements and profiled the cooperating firms as large firms belonging to high-technology industries that carry out intramural R&D. Acosta and Modrego (2001) analysed how public policies affect the precompetitive research projects carried out by Spanish firms in collaboration with universities and public research centres. Abramovsky et al. (2005) found a positive link between the likelihood of undertaking cooperative R&D agreements and incoming knowledge. Specifically, they concluded that Spanish firms choose cooperative ways of trying to overcome perceived high risks and financial constraints. López (2006) found that cost-risk sharing is the most important determinant of R&D cooperation in Spanish firms and that the level of legal protection in the industry has a negative effect on R&D cooperation. Finally, Arbussà and Coenders (2007) showed that for Spanish manufacturing industries the effects of incoming spillovers on innovation, measured by absorptive capacity, are stronger for firms that invest in appropriation instruments. In general these works mainly studied R&D agreements with firms and public research organization in manufacturing industries.

Before analysing the model used in our econometric analysis, we should provide a descriptive view of the data set and of the characteristics of the survey. As we have mentioned, the CIS-3 contains interesting information about cooperative strategies with other agents and institutions between 1998 and 2000.

In those years, of the 4150 innovative firms in our sample only 819 had a formal cooperation agreement with other firms or institutions. About 19% of Spanish innovative firms had external channels of collaboration on R&D activities. Collaboration with external agents depends on the industry to which the firm belongs. In high-technology services, 35.7% of innovative firms cooperated with other agents and in high-technology manufacturing the cooperation rate was 31.6%. In the other manufacturing and services industries, there are fewer cooperation agreements.

Table 3 shows several interesting facts. Firstly, cooperation agreements with other firms or public institutions are still rare among Spanish innovative firms. Internal R&D activities and external R&D services related to innovation activities are still the main sources for the innovative process of Spanish firms. However, it appears that collaboration with other agents is beginning to become part of the innovation strategy of certain firms, especially those in high-technology markets.[8] About 31.6% of high-technology manufacturing firms and 35.7% of high-technology service firms set up relations for technological cooperation with other firms or public institutions between 1998 and 2000. Agreements with universities and public research organizations predominated over collaboration with other firms, customers or suppliers. There is less vertical cooperation (customers and suppliers) and horizontal cooperation (competitors) than in other European countries.[9]

Firms at the low-technology level are less likely to cooperate with external partners. Relationships between these firms and universities and public research organizations are very scarce: 9.8% of manufacturing firms and 5.1% of ser-

[8] R&D cooperation agreements with customers and suppliers are an example of the importance of these new innovation strategies (Gemünden et al., 1992; Mason and Wagner, 1999). Through this kind of collaboration, firms can develop new products that can be tested by their customers. At the same time they can test their suppliers' new products and work with their suppliers to improve quality.

[9] See Abramovsky et al. (2005) for the French, German and UK cases.

Table 3
Share of firms with a cooperative relationship in R&D activities by industries

	All firms		High-technology manufacturing		Low-technology manufacturing		High-technology services		Low-technology services	
	Firms	%	Firms	%	Firms	%	Firms	%	Firms	%
Total firms with R&D agreements	779	18.8	130	31.6	401	16.5	131	35.7	117	12.4
Cooperative partners										
Other firms of the group	366	8.8	63	15.3	197	8.1	56	15.3	50	5.3
Customers	337	8.1	62	15.1	157	6.5	81	22.1	37	3.9
Suppliers of components, equipment and software	440	10.6	65	15.8	221	9.1	82	22.3	72	7.6
Competitors and other firms	276	6.7	51	12.4	134	5.5	59	16.1	32	3.4
Experts and consultancy firms	362	8.7	53	12.9	178	7.3	69	18.8	62	6.5
R&D firms or laboratories	301	7.3	60	14.6	157	6.5	54	14.7	30	3.2
Universities or centres of higher education	479	11.5	93	22.6	237	9.8	101	27.5	48	5.1
Public and non-profit research organizations	439	10.6	83	20.2	237	9.8	85	23.2	34	3.6
Number of firms	4150	–	411	–	2426	–	367	–	946	–

Sources: Survey of Technological Innovation, 2000, INE.

Table 4
Share of firms with cooperative relationships in R&D activities with universities

Country of partners	All firms		High-technology manufacturing		Low-technology manufacturing		High-technology services		Low-technology services	
	Firms	%	Firms	%	Firms	%	Firms	%	Firms	%
Universities or centres of higher education	479	11.5	93	22.6	237	9.8	101	27.5	48	5.1
Spain	431	10.4	89	21.7	211	8.7	89	24.3	42	4.4
EU countries	98	2.3	17	4.1	42	1.7	38	10.4	1	0.1
USA	10	0.2	2	0.5	2	0.1	6	1.6	0	0.0
Japan	2	0.0	0	0.0	1	0.0	1	0.3	0	0.0
Other countries	34	0.8	2	0.5	15	0.6	12	3.3	5	0.5
Total firms	4150	–	411	–	2426	–	367	–	946	–

Sources: Survey of Technological Innovation, 2000. INE.

vice companies established cooperation agreements with universities, and 9.8% of manufacturing firms and 3.6% of service firms cooperated with public research organizations.

We can further analyse cooperation by studying cooperation with universities. Table 4 shows how cooperation patterns depend on the industry and technological level, i.e. high-technology firms (both manufacturing and services) have a higher degree of cooperation with universities, though mainly with Spanish universities: 430 of the 479 firms that were involved in cooperative R&D activities with universities worked with Spanish universities, 98 firms had agreements with other universities from the European Union, and 46 had agreements with universities from other countries. Only 10 Spanish firms entered into collaboration agreements with U.S. institutions.

4. The model

Cooperation agreements between firms and other firms or public institutions are important for the innovative process. In this section we use a logistic model to profile the Spanish innovative firms that use formal agreements with other agents as key elements of their innovation strategy. Formal collaboration with other agents is an important source for a firm's innovative output. Spanish firms tend to enter into few formal agreements with others agents in innovative fields, but external cooperation is increasing between the more innovative industries.

4.1. The determinants of cooperation

Collaboration with external agents is included in our model through a dichotomous variable whose value is 1 when the firm cooperates with other agents and 0 otherwise. We consider four types of firms: firms that carry out vertical cooperation with customers and suppliers, firms that carry out horizontal cooperation with their competitors, firms that have cooperation agreements with universities, and firms that cooperate with public research centres.

In our logistic model we define the dependent binary variable $y_n = 1$ if the firm cooperates with agent "j" and 0 otherwise. The collaborative strategies of the innovative firm can be modelled by four different vectors of explanatory variables: x_1, x_2, x_3 and x_4. These sets of explanatory variables define the profile of the innovative Spanish firms. As is usual in this literature (see Veugelers and Cassiman (2005), among others), we assume that cooperation agree-

Table 5
Definitions of the independent variables

Industry variables	
High-tech manufacturing	Dummy variable that takes the value 1 if the firm is in the high or medium–high tech manufacturing industries and 0 otherwise
High-tech services	Dummy variable that takes the value 1 if the firm is in knowledge-intensive services or business services industries and 0 otherwise
Industry R&D investment	Mean expenditure on innovation by firm in the SIC-2 digits sector
Firm variables	
Size	Categorical variable: 1, if firm employees in 2000 less than first quartile; 2, if firm employees in 2000 less than median; 3, if firm employees in 2000 less than third quartile; 4, if firm employees in 2000 more than third quartile
Domestic group	Dummy variable that takes the value 1 if the firm is part of a domestic firm grouping and 0 otherwise
Foreign multinational	Dummy variable that takes the value 1 if the firm is part of a foreign multinational and 0 otherwise
Product and process innovation	Takes the value 1 if the firm made both product and process innovations in the period 1998–2000 and 0 otherwise
Innovation sources	
Intramural R&D	Takes the value 1 if the firm carried out internal R&D activities related to innovations made in the period1998–2000 and 0 otherwise
External R&D	Takes the value 1 if the firm acquired external R&D services depending on innovative activities carried out in the period 1998–2000 and 0 otherwise
Public funds	
Regional public funds	Takes the value 1 if the firm accessed public resources of the local or autonomous administrations for innovative activities in the period 1998–2000 and 0 otherwise
Spanish public funds	Takes the value 1 if the firm accessed public resources of the state administration for innovative activities in the period 1998–2000 and 0 otherwise
European public funds	Takes the value 1 if the firm accessed public resources of the EU for innovative activities in the period 1998–2000 and 0 otherwise
Cooperation partners	
Vertical cooperation	Takes the value 1 if the firm cooperated with clients and suppliers; 0 otherwise
Competitor firms	Takes the value 1 if the firm cooperated with competitors; 0 otherwise
Universities	Takes the value 1 if the firm cooperated with universities; 0 otherwise
Public research centres	Takes the value 1 if the firm cooperated with public research centres; 0 otherwise

ments depend on some industry variables, on some firm characteristics, on the type of R&D activities, and on the origin of funds used in those activities.

Vector x_1 includes three explanatory variables related to the firm's industrial characteristics. Vector x_2 includes four variables related to the firm's individual characteristics. Vector x_3 includes two variables that show the firm's innovation sources. Finally, vector x_4 includes three variables that represent access to public funds for the innovative activities. The econometric specification is the following:

$$y_{j,i} = X_{1,j,i}\beta_{j,1} + X_{2,j,i}\beta_{j,2} + X_{3,j,i}\beta_{j,3} + X_{4,j,i}\beta_{j,4} + \varepsilon_{j,i}$$

where $X_{1,j,i}, X_{2,j,i}, X_{3,j,i}$ and $X_{4,j,i}$ are the matrices of explanatory variables of dimension k_0, k_1, k_2, k_3 and k_4; $\beta_{j,1}$, $\beta_{j,2}$, $\beta_{j,3}$ and $\beta_{j,4}$ are the vectors of the parameters, and $\varepsilon_{j,i}$ is the vector of stochastic error term.

We also analyse firms' cooperation behaviour with Spanish and foreign universities using five different vectors of explanatory variables: x_1, x_2, x_3, x_4 and x_5. Vector x_1 includes two explanatory variables related to the firm's industrial characteristics. Vector x_2 includes five variables related to the firm's individual characteristics. Vector x_3 includes four variables that show the innovation sources of the firm. Vector x_4 includes three variables that show the origin of the public funds for the innovative activities. Finally, vector x_5 shows cooperation with other firms and public institutions. The econometric specification is the following:

$$y_{j,i}=X_{1,j,i}\beta_{j,1}+X_{2,j,i}\beta_{j,2}+X_{3,j,i}\beta_{j,3}+X_{4,j,i}\beta_{j,4}+X_{5,j,i}\beta_{j,5}+\varepsilon_{j,i}$$

4.2. Explanatory variables

We have divided the explanatory variables into five categories: industry variables, firm variables, innovation sources, public funds and cooperation partnerships. Industry variables involve characteristics shared by all firms in the same industry. Firm variables involve specific characteristics. Innovation sources involve whether innovation activity came from internal or external R&D activities. Public funds involve the origin of public funds used for innovative activities. Finally, cooperation involves cooperation relationships with other partners (customers and suppliers, competitors or firms in the same group) or public research centres (Table 5).

5. Results

In this section, we profile the innovative firms that cooperate with other firms, universities or public research centres. We analyse a firm's R&D cooperation by differentiating between five types of partners (group firms, suppliers and customers, competitors, universities and research institutes) and pay special attention to the complementarities between R&D cooperation with universities and other partners. We start with the results of the logit

Table 6
Propensity to cooperate with other firms and public institutions (logit model)

	All partners	Group firms	Customers and suppliers	Competitors	Universities	Public centres
Industry variables						
High-tech manufacturing	0.409 (0.150)*	0.290 (0.185)	0.231 (0.171)	0.337 (0.199)***	0.557 (0.168)*	0.351 (0.177)**
High-tech services	0.632 (0.157)*	0.434 (0.195)**	0.857 (0.168)*	0.538 (0.202)*	0.877 (0.174)*	0.434 (0.190)**
Industry R&D Investment	0.354 (0.056)*	0.229 (0.069)*	0.259 (0.063)*	0.308 (0.076)*	0.325 (0.066)*	0.314 (0.069)*
Firm variables						
Size	0.376 (0.053)*	0.294 (0.074)*	0.308 (0.063)*	0.213 (0.078)*	0.358 (0.067)*	0.322 (0.070)*
Domestic group	0.641 (0.111)*	1.370 (0.150)*	0.479 (0.130)*	0.496 (0.161)*	0.679 (0.134)*	0.574 (0.140)*
Foreign multinational	0.127 (0.136)	1.203 (0.174)*	0.263 (0.156)***	0.367 (0.194)**	0.186 (0.165)	−0.017 (0.178)
Product and process innovation	0.274 (0.096)*	0.552 (0.124)*	0.434 (0.111)*	0.373 (0.139)*	0.290 (0.116)*	0.286 (0.121)*
Innovation sources						
Intramural R&D	0.493 (0.100)*	0.473 (0.139)*	0.618 (0.124)*	0.740 (0.166)*	0.929 (0.140)*	1.153 (0.155)*
External R&D	1.025 (0.092)*	0.803 (0.116)*	0.844 (0.106)*	0.536 (0.131)*	0.942 (0.110)*	0.790 (0.114)*
Public funds						
Regional public funds	0.401 (0.108)*	−0.113 (0.148)	0.150 (0.126)	−0.121 (0.160)	0.281 (0.129)**	0.568 (0.130)*
Spanish public funds	0.818 (0.111)*	0.427 (0.146)*	0.593 (0.126)*	0.491 (0.159)*	0.713 (0.129)*	0.956 (0.130)*
European public funds	1.346 (0.153)*	0.916 (0.177)*	1.564 (0.153)*	1.509 (0.172)*	1.244 (0.160)*	1.418 (0.160)*
Constant	−12.983 (0.816)*	−10.746 (0.982)*	−11.795 (0.904)*	−12.173 (1.086)*	−13.640 (0.960)*	−14.428 (1.019)*
Model summary						
Chi-square for covariates	1131.73	594.35	798.06	448.14	910.67	936.92
Pseudo R^2	0.270	0.230	0.249	0.209	0.293	0.318
Number of cases	4150	4150	4150	4150	4150	4150

Notes: Standard error in parentheses. *Significance at 1%; **significance at 5%; ***significance at 10%.

model on the propensity to cooperate with other partners and finally by analysing the results of the logit model on cooperation with Spanish and foreign universities.

Table 6 shows that specific industrial characteristics affect the propensity of innovative firms to collaborate with other agents in their innovative activity.[10] We expect firms in the manufacturing and service industries with a high technological level to be more likely to enter into formal cooperation agreements with external agents. This is the case for service firms with cooperation agreements with other firms from the same group, for service firms that cooperate with customers and suppliers, and for both service and manufacturing firms that cooperate with competitors, universities and public centres. These results are in line with those of Bayona et al. (2001), Hagedoorn (1993), Robertson and Gatignon (1998) and Wang (1994). Firm size is positively related to cooperation strategies with other partners. For instance, Bayona et al. (2003, 2001), Veugelers and Cassiman (2005), Colombo and Garrone (1998) and Hagedoorn and Schakenraad (1994) found that size has a positive influence on cooperation. Specifically, in a CIS sample with Belgian firms, Veugelers and Cassiman (1999, p. 63) found that “small firms are more likely to restrict their innovation strategy to an exclusive make or buy strategy, while large firms are more likely to combine both internal and external knowledge acquisition in their innovation strategy”. Other scholars, such as Pisano (1990) and Robertson and Gatignon (1998), found no relationship. Our results show not only that firm size affects external cooperation, but also that an innovative firm that belongs to a corporate group carries out product and process innovations simultaneously, and enters into more formal cooperation agreements with other agents. Our results also show that firm size and a firm’s own R&D activities and R&D acquisition are significant and positive determinants of R&D cooperation, especially when the firms choose to cooperate with Spanish universities.

The individual characteristics of innovative firms are more ambiguous than the industrial determinants. If we consider characteristics such as innovation sources, our results show that the propensity to cooperate with other firms depends positively on the firm’s internal R&D activities and the acquisition of external R&D. Specifically, a firm’s internal R&D activities increased a firm’s probability of cooperating with private and public partners, as Veugelers (1997) also showed. A firm’s R&D performance complements cooperation on R&D activities with external agents (Bayona et al., 2003; Bönte and Keilbach, 2005).

The effect of public funding on cooperation, especially from the European Union, has a positive influence on the propensity to cooperate in R&D. Public funds have a twofold effect on the R&D behaviour of firms, since they increase internal R&D investment and facilitate R&D cooperation (Cassiman and Veugelers, 2002). Our detailed results show that only Spanish and European public funds increase cooperation with firms from the same group, with customers and suppliers and with competitors. Cooperation with universities and public centres, on the other hand, benefits from public funds at regional, Spanish, and European levels. Regional funds play a different role in cooperation with private firms and with public research centres because the Spanish research system has a high degree of decentralization.

Table 7 shows the determinants of an individual firm’s cooperation with universities. Generally speaking, these are fairly similar for all partners. However, we believe that cooperation is not the same with Spanish universities as it is with non-Spanish universities. Cooperation with Spanish universities seems to be linked to a higher degree of innovation activities. For example, firms in the high-tech manufacturing industries are positively influenced to cooperate with Spanish universities, but this variable is not significant for cooperation with foreign universities. Several firm characteristics also affect cooperation: belonging to a group of firms enhances cooperation with Spanish universities and decreases cooperation with foreign universities. Internal R&D activities and the acquisition of external R&D services also favour cooperation with Spanish universities.

Cooperation agreements with other firms can also help to explain cooperation with universities. Cooperation with competitors or with public research centres, for instance, increases cooperation with foreign universities.

Our preliminary results are not conclusive but they show that cooperation with Spanish universities is greater than with foreign universities. The main exceptions are firms that receive public resources from the European Union: these firms show a greater level of cooperation with foreign universities. At the same time, regional and national funds have a greater influence on cooperation with Spanish universities than with foreign universities.

To sum up, our results show that most of our main hypotheses have been satisfied (see above):

H1. The propensity to engage in R&D cooperation is higher for firms from sectors with high R&D intensity, especially in services.

This hypothesis is satisfied in all types of cooperation agreements for service activities and in most cooperation agreements for manufacturing activities (cooperation with competitors, universities and public centres).

H2. Cooperation increases with firm size.

This hypothesis is satisfied in all types of cooperation agreements, but the effect is higher for cooperation with universities, public centres and customers and suppliers. We assume that a bigger size allows firms to start more complicated strategies and cooperation is one of those strategies.

H3. Intramural R&D activities increase the propensity to engage in cooperation R&D agreements.

This hypothesis is satisfied in all types of cooperation agreements, mainly for cooperation with public centres and universities.

[10] The propensity to cooperate in R&D projects can be correlated with some of the explanatory variables. Cooperation and innovation decisions involve a potential endogeneity problem. To address this shortcoming, some endogeneity tests can be applied in our logit estimation of a set of exogenous variables along the lines of Veugelers and Cassiman (2005).

Table 7
Cooperation with Spanish and foreign universities (logit model)

	Spanish universities		Foreign universities	
	Model 1	Model 2	Model 1	Model 2
Industry variables				
High-tech manufacturing	0.628 (0.171)*	0.754 (0.222)*	0.048 (0.314)	−0.018 (0.358)
High-tech services	0.813 (0.181)*	0.669 (0.231)*	0.856 (0.276)*	0.900 (0.340)*
Industry R&D investment	0.305 (0.068)*	0.166 (0.087)*	0.377 (0.114)*	0.161 (0.132)
Firm variables				
Size	0.354 (0.070)*	0.287 (0.087)*	0.471 (0.129)*	0.470 (0.155)*
Domestic group	0.724 (0.139)*	0.556 (0.174)*	0.063 (0.242)	−0.387 (0.283)
Foreign multinational	0.232 (0.172)	0.249 (0.217)	0.104 (0.300)	−0.170 (0.356)
Product and process innovation	0.267 (0.120)**	0.090 (0.151)	0.166 (0.211)	−0.026 (0.246)
Innovation sources				
Intramural R&D	0.938 (0.149)*	0.506 (0.172)*	1.312 (0.324)*	0.407 (0.351)
External R&D	0.946 (0.114)*	0.632 (0.140)*	0.282 (0.199)	−0.137 (0.217)
Public funds				
Regional public funds	0.339 (0.133)*	0.158 (0.173)	0.021 (0.230)	−0.120 (0.268)
Spanish public funds	0.759 (0.133)*	0.346 (0.176)**	0.609 (0.238)*	−0.067 (0.282)
European public funds	1.049 (0.164)*	−0.194 (0.225)	2.256 (0.222)*	1.461 (0.262)*
Cooperation				
Vertical cooperation		2.028 (0.183)*		1.275 (0.402)*
Competitor firms		0.179 (0.227)		1.230 (0.281)*
Public research centres		2.189 (0.184)*		2.803 (0.445)*
Constant	−13.439 (0.989)*	−9.141 (1.231)*	−16.779 (1.688)*	−11.851 (1.918)*
Model summary				
Chi-square for covariates	841.01	1502.48	403.51	679.83
Pseudo R^2	0.290	0.518	0.336	0.566
Number of cases	4150	4150	4150	4150

Notes: Standard error in parentheses. *Significance at 1%; **significance at 5%; ***significance at 10%.

H4. Firms that perform both product and process innovation have a high propensity to engage in R&D cooperation agreements.

This hypothesis is satisfied in all types of cooperation agreements, but the effect is greater for cooperation with firms from the same group and with customers and suppliers.

H5. Public funding programs affect the propensity to engage in R&D cooperation agreements.

This hypothesis is partially satisfied (especially for Spanish and European public funds) but some additional explanations are needed. In our estimations we are testing the use of public funds from several public administrations. However, the amount of these funds differs considerably: regional program funds provide little budgetary support while Spanish funds and (mainly) European funds are of great importance. Our results therefore seem to show that regional funds are not large enough to start a process (as our results show) of cooperation with all types of partners.

H6. Firms that belong to a group tend to establish R&D cooperation agreements with other partners.

This hypothesis is satisfied for firms belonging to Spanish groups, which have higher cooperation rates (mainly with firms from the same group). However, firms belonging to foreign groups tend to cooperate only with other firms (group firms, competitors and customers and suppliers) and not with local universities or Spanish public centres. We assume that cooperation with this type of public institution exists only in the multinational group's country of origin.

H7. Firms that establish cooperation agreements with other partners also tend to establish cooperation agreements with Spanish and foreign universities.

This hypothesis is largely satisfied except for cooperation agreements with competitors (within cooperation with Spanish universities). This implies that cooperation with universities also means cooperation with clients and suppliers and, mainly, with other public research centres. The latter result was expected since there are some complementarities in cooperation agreements with public research centres and universities.

H8. Firms belonging to Spanish groups are more predisposed to establish R&D cooperation agreements with Spanish universities.

This hypothesis is satisfied and is explained in similar terms to Hypothesis 6, since firms cooperate largely with universities of their own country. It seems logical that cooperation decisions are usually taken at the headquarters of the firm. As these are located in the group's country of origin, cooperation agreements are more likely to be reached with universities located close to the group.

6. Conclusions

This paper uses an integrated framework to analyse R&D cooperation agreements in both the manufacturing and services sectors. Unlike most previous studies, which focused on industries, we focus mainly on technological intensity. We also analyse a country that is quickly converging with OECD countries in terms of GDP and R&D activities. This is a distinctive approach since most contributions have focused on more well-developed countries.

Our results show that a firm's cooperation activities are closely linked to the characteristics of both the industry and the firm as well as to the origin of public funds for R&D activities. In line with the results of other studies, we show that the industry has a strong effect on a firm's capacity to innovate in R&D. In Spain, firms that operate in the high-tech manufacturing and service sectors with high R&D investments at a sectorial level cooperate more with external partners. Firm size and innovation activities are related to the propensity of the firm to establish R&D agreements. This means that a firm's cooperation behaviour can be explained by certain characteristics of the firm's innovative activity.

We believe that public administrations have a key role in promoting cooperation and innovation activities by offering public funds to innovative firms, especially SME firms with important internal R&D activities. This appears to be one of the most effective ways of stimulating innovation. If public policies are not heavily R&D oriented, as is the case in Spain, innovative firms suffer from a lack of support that is an important barrier to innovation.

Our results also indicate that cooperation with Spanish universities is more intense than cooperation with other universities. This limits a firm's competitive capacity because it is prevented from cooperating with major universities and acquiring potential benefits from this cooperation. This is partially due to the origin of the innovation: when the funding is domestic the cooperation is also domestic and when the funding is from the European Union, the cooperation may be more international. This means that firms must follow a strategy for joining EU research programs in order to benefit from participating in superior innovation networks, where the expectations for innovation are also greater.

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