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The Impact of Cooperation on R&D, Innovation and Productivity: an Analysis of Spanish Manufacturing and Services Firms.

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Abstract

This paper investigates relationships between cooperation, R&D, innovation and productivity in Spanish firms. It uses a large sample of firm-level micro-data and applies an extended structural model that aims to explain the effects of cooperation on R&D investment, of R&D investment on output innovation, and of innovation on firms' productivity levels. It also analyses the determinants of R&D cooperation. Firms' technology level is taken into account in order to analyse the differences between high-tech and low-tech firms, both in the industrial and service sectors. The database used was the Technological Innovation Panel (PITEC) for the period 2004-2010. Empirical results show that firms which cooperate in innovative activities are more likely to invest in R&D in subsequent years. As expected, R&D investment has a positive impact on the probability of generating an innovation, in terms of both product and process, for manufacturing firms. Finally, innovation output has a positive impact on firms' productivity, being greater in process innovations.

Keywords: innovation sources; productivity; R&D Cooperation

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1 Introduction

In recent years it has been concluded that innovation is a key element of productivity growth. The seminal contribution was provided by Griliches (1979), who showed that a single equation model was too simple for the analysis of innovation processes. This type of literature focuses on analysing the impact of technological innovations. The recent literature on industrial organizations concentrates more on strategic interactions between firms rather than on transaction costs and policy strategies. It focuses on the effects that come with business strategies. The main purpose of firms when innovating is to develop new products and processes which will enable them to increase their business share and thus be more competitive. Recently, there has been a third alternative for generating technology improvements: in addition to being able to develop through R&D activities conducted by the company itself and external R&D generated by external entities, firms are able to generate technological improvements through R&D cooperation. This R&D cooperation can develop between firms or between firms and institutions. According to the Oslo Manual (2005), cooperation in innovation involves active participation in joint innovation projects with other organizations. As shown by the OECD (2002), technological cooperation has been one of the main instruments used by companies when conducting R&D in the last 20 years.

Many articles investigating R&D cooperation try to explain the factors that affect the decision to cooperate, showing that the main determinants are spillovers (Cassiman and Veugelers, 2002), size (Dutta and Weiss, 1997), or the technological or commercial objectives of the firm (Bayona et. al 2001; Tether, 2002; Miotti and Schwald, 2003 and Becker and Dietz, 2004). However, few studies analysed the impact of technological cooperation on R&D intensity, innovation and business development.

When measuring the impact of technological cooperation on innovative output, the literature relates R&D cooperation with the role of knowledge sharing between R&D cooperation partners. Many empirical studies of existing side effects have focused mainly on the impact of involuntary knowledge flows on performance, which are caused by lack of cooperation, which increases competitors' stock of knowledge and can weaken the firm's position in the market in question. The existence of this kind of involuntary leakage reduces the efficiency of firms' R&D

efforts as they cannot appropriate all the benefits, and this results in lower R&D investment levels. However, R&D cooperation enables firms to internalize knowledge externalities and eliminate the deterrent effect of spillovers on R&D (e.g. Amir, 2003; De Bondt, 1996; Kamien et al. 1992, and Suzumura, 1992). Firms have incentives to manage the flow of surplus and from competitors, trying to maximize the incoming spillovers through R&D collaboration, while minimizing side effects projections through investment in protecting knowledge (Cassiman et al. 2002 and Amir et al. 2003).

The work undertaken by Cassiman and Veugelers (2002) distinguishes two kinds of externalities: firstly, the indirect entry effect, which affects the rate of a firm's innovation, generally in the public domain, and its use for the firm, depends on the firm's capacity to create information flows from this public knowledge; and secondly, appropriation, which affects the firm's ability to appropriate the benefits of innovations. With regard to the issue of the appropriation of R&D cooperation, Cassiman and Veugelers (2002) found that the firms which were better able to appropriate the results of innovation were more likely to cooperate with clients or suppliers, but this did not affect cooperation agreements with research institutes. In the case of Spanish firms, López (2008) confirms that the main determinants of cooperation include publicly-accessible information that is introduced by side effects and the efficacy of the protection of intellectual property rights. This type of study is mainly characterized by the heterogeneity of existing models. Therefore, cooperation produces complementarities between a firm's internal and external resources which can help the partners to obtain innovative results (Miotti and Schwald, 2003 and Cassiman and Veugelers, 2002).

Another relevant factor for cooperative strategies in R&D is the absorption capacity. This notion was introduced by Cohen and Levinthal (1989). The concept was defined as technological opportunities, and was subsequently developed theoretically by Kamien and Zang (2000), in which they stressed the importance of a prior stock of knowledge for effectively absorbing spillovers while cooperating. As a result, by Bayonne et al. (2001), Fritsch and Lukas (2001), Schwald and Miotti (2003) and Belderbos et al. (2004), a firm's absorption capacity is listed as one of the main features of firms that cooperate. These authors concluded that firms in sectors with high technological opportunities are more willing to cooperate.

In general, the literature confirms the existence of a positive relationship between R&D cooperation and innovative results, but the effect on economic performance is not so evident. Therefore, the main objective of this paper is to analyse the impact of cooperation projects on the input and output innovations of Spanish firms. Innovation input is measured by the intensity of R&D expenditure, while innovation output is measured by the knowledge function; finally, the impact of innovation output on the production function can be observed. This paper aims to show the effect of having to make a cooperation agreement on future investment in R&D on the generation of knowledge and hence the firm's productivity level.

This study used the structural model developed by Crépon, Duguet and Mairesse (1998), referred to henceforth as the CDM model, involving four stages: (i) the determinants of cooperation projects, (ii) the firm's decision to engage in sufficient effort to result in observable R&D investment and the intensity with which the firm undertakes R&D, (iii) the innovation or knowledge production function, where the knowledge takes two different forms - process and product innovations, and (iv) the output production function, where knowledge is an input.

Due to the increasing availability of micro-level innovation survey data, many authors rely on the CDM model to analyse the impact of innovation on the productivity of firms, e.g. Janz et al., 2004 in the case of Germany and Sweden; Lööf and Heshmati, 2006 for Sweden; Benavente, 2006 for Chile; Jefferson et al., 2006 for China; Mohen et al., 2006 for seven European countries; Griffith et al., 2006, which makes a comparative study of four countries; and, more recently, Segarra-Blasco, 2010 and Segarra-Blasco and Teruel, 2011 for Catalonia and Mairesse et al, 2012 for China.

This paper aims to cover at least two key aspects. Firstly, it analyses the reasons that drive firms to reach cooperation agreements. In this respect it answers questions such as what kind of companies decide to reach a cooperation agreement, whether it affects the operating sector, whether the technological intensity of the firm is an important factor, if it is relevant that the company operates internationally or exports, or whether the company has already cooperated in the past or not. Secondly, it analyses what impact this decision has on the firm's future strategies. In this case, it aims to answer questions such as: How does a cooperation agreement affect the firm's behaviour in terms of its R&D decisions? What is the relationship between cooperation and innovation? What impact does innovation have on a firm's productivity?

The study was conducted using the Technological Innovation Panel (PITEC) database for the period 2004-2010. In order to avoid endogeneity problems, all the variables were lagged by one period when estimating the cooperation equation.

The rest of the paper is structured as follows: Section 2 presents the theoretical mode; Section 3 describes the database; Section 4 presents the empirical implementation and the results obtained; and finally, Section 5 sets out the conclusions.

2 Model

This paper used a structural model whereby firms first decided whether to cooperate in innovation activities; it was then observed how these cooperation agreements affected R&D, innovation and productivity. This model is based on five equations: (i) the determinants of cooperation projects, (ii) the firm's decision to engage in sufficient effort to result in observable R&D investment and the intensity with which the firm undertakes R&D, (iii) the innovation or knowledge production function where the knowledge takes two different forms - process and product innovations, and (iv) the output production function, where knowledge is an input. This model is a modified version of the model by Crépon, Duguet and Mairesse (CDM, 1998). The original model was also extended by introducing measures of the cooperation agreements as a first stage of the firm's decision to cooperate or not in R&D.

2.1 R&D Cooperation

In formal terms, the model can be expressed as follows. Let i=1,...,N index firms. The equation explains the determinants of cooperating in innovative activities:

$$coop = \begin{cases} 1 & \text{if } c_i^* = \delta X_i + \mu_i \\ 0 & \text{in other case,} \end{cases} \tag{1}$$

where *coop* is a latent dependent variable corresponding to firms that decide to reach a cooperation agreement, X_i is a vector of explanatory variables of participation in cooperation projects on innovative activities, δ represents the parameters of interest to estimate and μ_i is the error term.

2.2 The research equation

The second step concerns a firm's research activities, modelling the process that leads the firm to decide whether or not to undertake these research projects and how much to invest in them. However, the intensity of R&D investment can be observed if, and only if, firms actually choose to spend on R&D. Therefore the second equation is a selection equation indicating whether the firm performs R&D activities or not, and can be specified as:

$$rd_i = \begin{cases} 1 & \text{if } rd_i^* = \alpha coop_i + \beta W_i^{'} + \varepsilon_i > b \\ 0 & \text{if } rd_i^* = \alpha coop_i + \beta W_i^{'} + \varepsilon_i \leq b, \end{cases} \tag{2}$$

where rd_i is the observed binary endogenous variable that takes the value 1 if firm i has positive R&D expenditures, rd_i^* is a corresponding latent variable whereby firms decide to do (and/or report) R&D if it is above a certain threshold level, b, where $coop_i$ is the predicted explanatory variable of cooperation, $W_i^{'}$ is a set of explanatory variables and ε_i is the error term.

The third equation represents innovation intensity, specified as:

$$r_i = \begin{cases} r_i^* = \theta_i coop_i + \beta Z_i^{'} + e_i & \text{if } rd_i^* = 1 \\ 0 & \text{if } rd_i^* = 0, \end{cases} \tag{3}$$

where r_i^* is the unobserved latent variable accounting for a firm's innovative effort measured as the logarithm of R&D expenditure per employee, $coop_i$ is the predicted explanatory variable of cooperation, $Z_i^{'}$ is a set of explanatory variables and e_i is the error term.

2.3 The innovation equation

The third stage links the research activities above to innovation output measures. Thus, the fourth equation is the innovation production function:

$$g_i = \gamma_i r_i^* + \delta X'_i + \mu_i, \tag{4}$$

where g_i is innovation output proxied by both product and process innovation indicators,and where the latent innovation effort r_i^* is an explanatory variable, $X_i^{'}$ is a vector of other determinants of knowledge production and μ_i is the error term.

2.4 The productivity equation

Finally, the last step is modelled by an augmented Cobb-Douglas production function:

$$y_i = \pi_1 k_i + \pi_2 g_i + \pi_3 h_i + \pi_4 X_i + v_i, \tag{5}$$

where y_i is labour productivity, k_i is physical capital per employee, g_i is innovation output, h_i is human capital, X_i is a vector of additional control variables and v_i is the error term.

This analysis includes the human capital factor because as workers become more highly trained and acquire more skills they are able to carry out their tasks more efficiently.

3 Data

The data used is from the Spanish Technological Innovation Panel (henceforth, PITEC), which provides information on the technological innovation activities of Spanish firms for the period 2003-2011. PITEC was set up by the Spanish Foundation for Science and Technology (FECYT), the National Institute of Statistics (INE) and the COTEC Foundation with the purpose of providing data from the Community Innovation Survey (CIS). CIS is formed by the European Commission, the OECD and the European Economic Area (EEA) Member States and one of its objectives is to create a database on technological innovation.

The PITEC panel's data is based on a representative selection of firms which allows more accurate estimates and analyses to be made through repeated observations of economic units. It allows researchers to observe the evolution of R&D, determine the impact of innovation, and analyse the different strategies adopted by firms in the introduction of innovations in their business. The panel consists of four essential samples: (i) firms with 200 or more employees, (ii) firms with internal expenditure on R&D, (iii) firms with fewer than 200 employees with external R&D expenditures but no internal R&D, and (iv) firms with fewer than 200 workers with no innovation expenditures.

The filtering process [1] only considered the industrial and service sectors and firms with twenty or more employees. Thus the final sample consisted of 37,991 observations for the period 2004 - 2010.

In order to determine whether the effects of cooperation on innovation and productivity vary with the technology level, we used the Eurostat classification to separate firms by the technology level in the sector in which each firm operates. This classification grouped the firms by sectors as follows: (i) High and medium-high-tech industries (HTI), (ii) Medium-low and low-tech industries (LTI), (iii) Knowledge-intensive services (KIS) and (iv) Non knowledge-intensive services (Non-KIS).

4 Empirical Implementation

4.1 Empirical model

In the first stage, the cooperation equation was estimated using a Probit model of the maximum likelihood, using delayed explanatory variables for one time period. The estimated predicted value was then taken to estimate the research equations.

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[1] This filtering process also involved eliminating observations that included some kind of incident (problems of confidentiality or takeovers and mergers, etc.) and those with an obvious anomaly (such as null sales).

The determinants of a firm's cooperation in innovative activities are: firm size, belonging to a group, R&D expenditure, a dummy variable indicating whether the firm received public funding for R&D activities, a dummy variable for foreign firms, a dummy variable indicating whether the firm protected its innovations, a dummy variable indicating whether the firm exports, a dummy variable indicating whether the firm has cooperated in the past, and a set of dummy variables.

In the second stage, the system of research equations was estimated as a generalized Tobit model in a two-step process using the Heckman procedure; thus it is assumed that the correlated error e_i and ε_i are jointly normally distributed.

The determinants of a firm's engagement in R&D activities are: firm size, belonging to a group, investment intensity per employee, dummy variables indicating whether the firm received public funding for R&D activities, a dummy variable for foreign firms, a dummy variable indicating whether the firm protected its innovations, a dummy variable indicating whether the firm exports, and market share. The explanatory variables of R&D intensity are the same as for the engagement in R&D equation and also add a set of dummy variables for factors hampering innovations, a set of dummy variables for the different sources of information, and the predicted value of cooperation [2] obtained in equation (1) as a proxy of the probability of cooperating in innovative activities.

In the third stage, two kinds of innovation output were distinguished: process and product innovation. Each was measured by a dummy variable equal to 1 if the firm introduced at least one process (product) innovation. Thus, the innovation production function was estimated using a bivariate probit [3] by maximum likelihood, assuming both variables to be highly correlated. The determinants included the predicted value of R&D intensity obtained in equation (3) as a proxy for innovative effort (r_i^*) and a set of variables (X_i): firm size, belonging to a group, protection methods used, export activity, a dummy variable indicating whether the firm received public funding for R&D activities, investment intensity, market share, sources of

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[2] The cooperation variable is only available for innovative firms, which is why it could not be included in the equation (2).

[3] In this regard, the process followed recent literature such as Hall et al. (2009), Masso and Valther (2008) and Piga and Vivarelli (2002).

information, and factors hampering innovations.

In the final stage, the labour production function was estimated using a fixed effect model for panel data. Labour productivity depends on the innovation output (process and product innovation) predicted in equation (4), investment intensity, human capital and firm size.A control was also established for unobserved manufacturing characteristics and for firm size in all the equations.

In the econometric analysis, the CDM model provides a solution for the problems of biases of selectivity and endogeneity. In the case of selectivity, it would be inappropriate to consider innovative firms alone because the firms are not randomly drawn from the population and a selection bias may thus arise. The CDM model takes this situation into account by including a selection equation in the second step. In the case of endogeneity, using predicted values instead of the realized values is a way of dealing with this potential bias in the various stages of the process. It is possible that unobservable firm characteristics can affect both their innovative effort (R&D expenditure) and their efficiency in producing innovations.

4.2 Descriptive statistics

Table 1 shows the descriptive statistics for the main variables in the model across the different technology sectors.

Firstly, it can be seen that the proportion of firms which decide to cooperate in innovative activities is higher in high-tech firms than it is in low-tech firms, both in the manufacturing and service sectors, especially in knowledge-intensive services (52%) and in high-tech industries (approximately 40%). It is also noticeable that firms continuous cooperation in R&D activities for at least in four years is greater in the more advanced firms in both sectors. In both variables, service sector firms show more cooperation and persistence than manufacturing firms.

Productivity is similar among high-tech and low-tech manufacturers, and is the same for the service sector. Investment intensity is higher in high-tech firms than it is in low-tech firms for both the manufacturing and service sectors. In the case of human capital, the average percent-

Table 1: Descriptive statistics

	High tech Industries	Low tech Industries	KIS	Non-KIS
Collaborative Projects				
Cooperation	0.389	0.334	0.520	0.396
Persistence Cooperation	0.137	0.112	0.197	0.114
Innovation				
R&D Engagement	0.842	0.755	0.900	0.713
R&D Intensity[1]	8.221	7.385	9.272	6.742
Process Innovation	0.715	0.787	0.640	0.801
Product Innovation	0.810	0.681	0.789	0.593
Basic				
Productivity[2]	12.114	12.071	11.112	11.760
Investment Intensity[3]	8.009	7.159	9.067	6.523
Market Share[4]	0.007	0.008	0.008	0.009
Human Capital[5]	44.323	29.210	58.858	22.305
Factors hampering innovations				
Cost factors	0.461	0.447	0.544	0.323
Knowledge factors	0.232	0.225	0.257	0.141
Market factors	0.333	0.290	0.318	0.171
Reasons no to innovate	0.037	0.063	0.037	0.091
Sources of information				
Internal sources	0.643	0.547	0.682	0.593
Market sources	0.499	0.455	0.526	0.482
Institutional sources	0.150	0.143	0.260	0.108
Other sources	0.181	0.147	0.281	0.138
Appropriability/Public Funds				
Protection	0.379	0.335	0.437	0.214
Public Funds	0.469	0.396	0.642	0.203
Firm Size				
Size: <50	0.361	0.304	0.439	0.132
Size: 50-99	0.219	0.243	0.204	0.088
Size: 100-249	0.214	0.246	0.205	0.171
Size: 250-999	0.165	0.177	0.096	0.406
Size: >999	0.036	0.026	0.051	0.201
Others				
Foreign	0.204	0.142	0.117	0.152
Exports	0.753	0.648	0.342	0.072
Group	0.502	0.441	0.390	0.583

Note: 1)R&D expenditure per employee (in logs). 2)Sales per employee (in logs). 3)Gross investment in tangible goods per employee (in logs). 4)Sales divided by total sales in 3-digit subsector (in logs). 5)Percentatge of employees with higher education.

age of employees with higher education is much higher in high-tech firms than it is in low-tech firms in both manufacturing and service sectors. Specifically, in knowledge-intensive services (high-tech industries), approximately 59% (44%) of employees have higher education.

The decision to engage in R&D activities is higher in high-tech firms than it is in low-tech firms. In particular, in knowledge-intensive services 90% of firms decide to engage in R&D activities. The R&D intensity is also greater in high-tech than it is in low-tech firms. It can be seen that the firms with more product innovations are the more advanced firms; however, in the case of process innovations the figure is highest for low-tech firms.

With regard to the protection methods used, it seems that this factor is similar across all technology levels, with the exception of the knowledge-intensive service sector where it is higher. In terms of public funding, the number of firms that receive public support is much higher in high-tech sectors. Internal and market sources of information are the most important sources of information for innovation activities across all technology levels. Among the factors that hamper innovation, the most important are cost and market factors.

With regard to firm size, it can be seen that the manufacturing and knowledge-intensive service sectors are dominated by small firms (firms with fewer than 50 employees), followed by firms with between 100 and 249 employees.

4.3 Results

4.3.1 Cooperation

Table 2 presents the results of the estimated equations of cooperation in innovative activities. The results are presented for each technology sector in order to observe any differences. The numbers reported are the marginal effects of the variables considered as determinants of cooperation agreements. Almost all the variables are dummies except for R&D intensity. Thus they take the value 1 when the factor is important to the firm and the value zero if it is unimportant. Therefore, the marginal effect is that of changing the dummy variable from 0 to 1.

Firstly, the cooperation equation shows that firms' R&D intensity, group and public funds are significantly positive with regard to engagement in cooperation projects for all levels of technology. Receiving public financial support, as expected, increased the probability of engaging in cooperation projects, above all among firms in the knowledge-intensive service and low-tech manufacturing sectors.

Table 2: Determinants of the probability of cooperating in innovative activities

	High tech Industries	Low tech Industries	KIS	Non-KIS
R&D Intensity$_{t-1}$	0.222***	0.0718***	0.166***	0.104**
	(0.0280)	(0.0229)	(0.0519)	(0.0490)
Cooperation Persistence$_{t-1}$	0.383***	0.400***	0.550***	0.278
	(0.0746)	(0.0760)	(0.155)	(0.192)
Group$_{t-1}$	0.263***	0.284***	0.291*	0.526***
	(0.0844)	(0.0762)	(0.169)	(0.193)
Public Funds$_{t-1}$	0.425***	0.513***	0.803***	0.291*
	(0.0575)	(0.0539)	(0.137)	(0.156)
Exports$_{t-1}$	0.256***	0.179***	-0.0366	-0.370
	(0.0696)	(0.0605)	(0.129)	(0.255)
Foreign$_{t-1}$	0.0625	-0.0808	-0.502**	-0.0943
	(0.0826)	(0.0986)	(0.253)	(0.274)
Protection$_{t-1}$	0.263***	0.110*	0.137	0.410***
	(0.0583)	(0.0569)	(0.120)	(0.157)
Size:50	-0.0954	-0.105	-0.819	-5.909
	(0.337)	(0.365)	(0.730)	(1,045)
Size:50-99	0.0657	0.0737	-0.810	-5.307
	(0.330)	(0.361)	(0.724)	(1,045)
Size:100-249	0.330	0.109	-0.485	-5.360
	(0.332)	(0.359)	(0.727)	(1,045)
Size:250-1000	0.748**	0.446	-0.403	-5.284
	(0.341)	(0.367)	(0.760)	(1,045)
Size: 1000	1.168***	0.768*	0.488	-5.045
	(0.394)	(0.424)	(0.841)	(1,045)
Log-Likelihood	-3609.7076	-3940.6708	-919.5911	-565.4854
Observations	7818	8234	2221	1027
Number of firms	1733	2071	569	333

Reported marginal effects (at the sample means). Standard errors in parentheses are robust. Dependent variable is a dummy variables. Industry dummies are included. ***Significant at 1%, **Significant at 5%, *Significant at 10%.

These results show that protecting innovative output is associated with a higher probability of cooperation, except in the case of knowledge-intensive service sectors. Also, the effect of prior experience in cooperation projects in the last three years is positive in all levels of technology, except in non-knowledge-intensive service sectors. To define the competitive position of a firm, the fact of having a foreign market is taken into account, which has a significantly positive effect on engagement in cooperation projects for knowledge-intensive service firms only.

The effect on participation in cooperation projects depends on the size of firm to which they belong. Being a high-tech manufacturing firm with 250 or more employees or being a low-tech manufacturing firm with 1,000 or more employees has a significantly positive effect on cooperation.

4.3.2 Research

Table 3 presents the results for equations (2) and (3). This table show the estimates of the determinants of whether a firm engages in R&D activities and the intensity of R&D investment, conditional upon a firm engaging in R&D. The results are presented for each technology sector in order to observe any differences.

The numbers reported in table 3 are marginal effects. Almost all the variables are dummies except for capital intensity and market share. Thus they take the value 1 when the factor is important to the firm and the value zero if it is unimportant. Therefore the marginal effect is that of changing the dummy variable from 0 to 1.
Considering the coefficient of the predicted value of cooperation, it shows that fifty per cent of the manufacturing firms which cooperate are more likely to report engaging in R&D than firms which do not cooperate. Group membership does not seem to influence the decision to engage in R&D activities, but it is a significant factor in terms of R&D intensity, especially in manufacturing firms.

Public funding for innovation activities only shows an impact on the decision to engage in R&D activities for knowledge-intensive service firms, with a positive impact. For instance,

Table 3: Research equation

	High tech Industries		Low tech Industries		KIS		Non-KIS	
	Engage in R&D	R&D Intensity	Engage in R&D	R&D Intensity	Engage in R&D	R&D Intensity	Engage in R&D	R&D Intensity
Predicted Cooperation	0.521**	0.520***	0.583***	0.539***	0.602	0.221***	0.895	0.666
	(0.208)	(0.0490)	(0.179)	(0.0971)	(0.469)	(0.0828)	(0.607)	(0.898)
Group	-0.0236	-0.0534***	-0.0910	-0.0895***	-0.0900	-0.0174	-0.335**	0.201
	(0.0657)	(0.0148)	(0.0559)	(0.0285)	(0.139)	(0.0225)	(0.168)	(0.309)
Public Funds	-0.0436	0.0929***	0.0165	0.147***	0.275**	0.0472**	-0.0197	-0.114
	(0.0475)	(0.0110)	(0.0405)	(0.0207)	(0.108)	(0.0232)	(0.135)	(0.154)
Exports	0.203***	0.0424***	0.146***	0.0535**	0.125	0.0117	0.499**	-0.0273
	(0.0499)	(0.0127)	(0.0416)	(0.0235)	(0.116)	(0.0183)	(0.236)	(0.372)
Foreign	-0.106	0.00208	0.0148	-0.00348	-0.0586	-0.00967	-0.0204	-0.156
	(0.0672)	(0.0134)	(0.0608)	(0.0282)	(0.190)	(0.0288)	(0.180)	(0.192)
Protection	0.248***	-0.00933	0.144***	0.0296	0.253**	-0.0250	-0.0253	-0.0372
	(0.0496)	(0.0114)	(0.0423)	(0.0226)	(0.113)	(0.0186)	(0.147)	(0.159)
Capital Intensity	0.416***	0.931***	0.347***	0.990***	0.294***	0.953***	0.117**	0.797***
	(0.0228)	(0.00798)	(0.0194)	(0.0241)	(0.0463)	(0.00952)	(0.0494)	(0.0993)
Market Share	1.588	0.320	-1.964*	-0.740*	82.17**	1.213***	11.68***	-1.968
	(2.012)	(0.235)	(1.163)	(0.443)	(34.63)	(0.435)	(3.661)	(6.956)
Cost factors		-0.00350		-0.0167		-0.0279*		-0.0199
		(0.00987)		(0.0162)		(0.0160)		(0.120)
Knowledge factors		-0.00429		-0.0286		0.0300*		0.0262
		(0.0119)		(0.0196)		(0.0176)		(0.156)
Market factors		0.0156		0.00949		-0.0320*		-0.154
		(0.0104)		(0.0179)		(0.0169)		(0.146)
Non-innovative reason		-0.0766**		0.00914		0.0411		0.0793
		(0.0318)		(0.0478)		(0.0525)		(0.338)
Internal sources		0.00676		-0.0108		0.0208		0.00908
		(0.0105)		(0.0165)		(0.0183)		(0.117)
Market sources		-0.0140		0.0409**		0.0324**		0.000134
		(0.00988)		(0.0161)		(0.0161)		(0.109)
Institutional sources		0.0960***		0.0535**		0.0330*		0.124
		(0.0128)		(0.0211)		(0.0189)		(0.144)
Other sources		-0.0102		0.0492**		-0.0610***		-0.123
		(0.0117)		(0.0207)		(0.0177)		(0.131)
Size:50	-0.527	0.352***	-0.0144	0.424***	0.158	0.113	-4.490***	1.109
	(0.452)	(0.0725)	(0.277)	(0.145)	(0.698)	(0.128)	(0.582)	(1.663)
Size:50-99	-0.574	0.217***	0.0799	0.297**	-0.0634	0.0469	-4.486***	0.851
	(0.441)	(0.0693)	(0.264)	(0.139)	(0.662)	(0.124)	(0.610)	(1.634)
Size:100-249	0.00812	0.207***	0.432	0.386***	0.177	0.0387	-4.375***	0.511
	(0.442)	(0.0691)	(0.265)	(0.141)	(0.668)	(0.124)	(0.578)	(1.617)
Size:250-1000	0.340	0.218***	0.799***	0.443***	0.168	-0.0545	-4.492***	0.790
	(0.444)	(0.0693)	(0.265)	(0.146)	(0.684)	(0.126)	(0.560)	(1.634)
Size: 1000	1.006**	0.194***	1.163***	0.390**	0.846	-0.103	-4.278***	0.215
	(0.493)	(0.0740)	(0.301)	(0.159)	(0.886)	(0.134)	(0.583)	(1.597)
Mills' ratio		0.152***		0.701***		-0.271**		-1.535
		(0.0575)		(0.165)		(0.107)		(1.728)
Observations	6985	6985	6668	6668	2096	2096	701	701

Reported marginal effects (at the sample means). Standard errors in parentheses are robust.

Dependent variable ”engaging in R&D activities” is a dummy variables. Industry dummies are included.

***Significant at 1%, **Significant at 5%, *Significant at 10%.

knowledge-intensive service firms that received public funding were approximately 30% more likely to engage in R&D than firms that did not receive public subsidies. Public funding, in manufacturing and knowledge-intensive service firms, also has a positive impact on R&D intensity. It shows that low-tech industries spend more on R&D if they receive public funding.

Manufacturing firms that operate in international markets are more likely to engage in R&D, with a positive impact on R&D intensity. Also, manufacturing firms that export are more likely to engage and invest in R&D.

All firms, except non-knowledge-intensive service firms, that use methods to protect innovations are more likely to engage in R&D, but it does not seem to influence their R&D intensity.

The most important sources of information on R&D intensity are universities, public research organizations and technology centres. Their impact is more positive for manufacturing firms than for service firms. Market and other sources also show a positive impact on R&D intensity for low-tech industries and knowledge-intensive service firms.

The results in relation to investment intensity show a positive impact on the decision to engage in R&D, and a very positive impact on R&D intensity. The size of manufacturing firms also has a positive effect on participation in R&D, with larger firms being more likely to engage and invest in R&D.

4.3.3 Innovation

Table 4 shows the estimates of the knowledge production function. The first four columns show the results for product innovation and the last four columns those for process innovation. The numbers reported are again marginal effects evaluated at the sample means.

All of the variables, except predicted R&D intensity, capital intensity and market share, are dummies; thus the coefficients show the effect of changing the dummy variable from 0 to 1.

Table 4: Innovation equation

	Product Innovation				Process Innovation			
	High tech Industries	Low tech Industries	KIS	Non-KIS	High tech Industries	Low tech Industries	KIS	Non-KIS
Predicted R&D	0.117***	0.0848***	0.119	0.341	0.140***	0.0562	0.0775	-0.242
Intensity	(0.02547)	(0.03029)	(0.47945)	(0.23357)	(0.03637)	(0.0414)	(0.07256)	(0.30442)
Group	-0.0295***	-0.0332**	-0.0303	0.0291	-0.0183	-0.00609	-0.0217	0.00627
	(0.01039)	(0.01351)	(0.12111)	(0.05685)	(0.01505)	(0.01316)	(0.02803)	(0.03779)
Public Funds	0.0134*	0.0380***	0.0249	0.0117	0.00902	0.0270	0.0271	-0.00583
	(0.00801)	(0.0105)	(0.09964)	(0.04545)	(0.01157)	(0.01703)	(0.02711)	(0.03285)
Exports	-0.0387***	-0.00773	0.00512	0.0776	-0.0558***	-0.0142	-0.0390	0.0698
	(0.01006)	(0.01409)	(0.02943)	(0.08235)	(0.01591)	(0.0153)	(0.02933)	(0.09942)
Foreign	0.0212**	0.0632***	-0.00809	0.0563	0.0367**	0.0395	0.0572	-0.0519
	(0.01071)	(0.01444)	(0.04424)	(0.06876)	(0.01633)	(0.02594)	(0.03847)	(0.07808)
Protection	0.0664***	0.117***	0.0821	0.164	0.0673***	0.0154	0.0534**	-0.0126
	(0.00773)	(0.00999)	(0.32766)	(0.10953)	(0.01118)	(0.01272)	(0.02247)	(0.03716)
Capital Intensity	-0.0778***	-0.0555*	-0.0885	-0.288	-0.129***	-0.0479	-0.0626	0.210
	(0.02423)	(0.02908)	(0.35867)	(0.2047)	(0.03459)	(0.03755)	(0.0683)	(0.26598)
Market Share	0.380	-0.400	0.0428	0.294	-0.143	0.590	-0.530	5.0585
	(0.2601)	(0.24297)	(0.5484)	(1.15151)	(0.28761)	(0.40836)	(0.62549)	(6.1235)
Cost factors	0.00985	-0.00734	-0.0280	0.0282	-0.00920	-0.00121	0.0163	-0.0241
	(0.00788)	(0.01044)	(0.1141)	(0.04434)	(0.01127)	(0.00978)	(0.02233)	(0.04085)
Knowledge factors	-0.0269**	0.00656	0.0277	0.0234	-0.00322	0.00571	0.00655	0.112
	(0.01039)	(0.0125)	(0.11505)	(0.05781)	(0.01344)	(0.01196)	(0.02469)	(0.15577)
Market factors	0.05607***	0.0635***	0.0173	0.0542	0.0242*	0.00960	-0.0181	-0.0859
	(0.00833)	(0.01158)	(0.07251)	(0.05882)	(0.01301)	(0.01254)	(0.02588)	(0.10203)
Non-innovative	-0.00177	-0.123***	-0.153	0.0796	-0.0224	-0.0925*	-0.116	-0.00390
reason	(0.02524)	(0.03494)	(0.46146)	(0.10138)	(0.0363)	(0.05144)	(0.07944)	(0.07299)
Internal sources	0.0428***	0.0468***	0.0937	0.0436	0.0614***	0.0357*	0.101***	0.0170
	(0.00862)	(0.01066)	(0.3383)	(0.04734)	(0.01193)	(0.02061)	(0.02582)	(0.03576)
Market sources	0.0393***	0.0495***	0.0361	0.0372	0.0491***	0.0546*	0.0974***	0.0486
	(0.00787)	(0.01031)	(0.14371)	(0.04278)	(0.01121)	(0.02968)	(0.02249)	(0.06281)
Institutional	-0.0341***	-0.0466***	-0.00443	-0.188**	-0.0336**	-0.0147	-0.0723**	-0.0420
sources	(0.01307)	(0.01563)	(0.02729)	(0.09301)	(0.01679)	(0.01612)	(0.02947)	(0.06223)
Other sources	0.0366***	0.0385***	0.0363	0.261	0.0536***	0.0537*	0.0690***	-0.0393
	(0.009)	(0.01339)	(0.15009)	(0.18679)	(0.01354)	(0.032)	(0.02546)	(0.05922)
Size:50	-0.00480	-0.0145	-0.962	-0.890	-0.123	0.0622	-0.183	-0.970
	(0.06048)	(0.076)	(39.903)	(17.619)	(0.09293)	(0.0668)	(0.18193)	(7.52168)
Size:50-99	-0.0203	0.0393	-0.983	-0.852	-0.158	0.0536	-0.142	-0.946
	(0.06418)	(0.06929)	(14.464)	(15.837)	(0.09834)	(0.06529)	(0.19139)	(10.53)
Size:100-249	0.0205	0.0723	-0.982	-0.889	-0.0621	0.101	-0.0732	-0.974
	(0.05586)	(0.06694)	(13.774)	(20.686)	(0.09412)	(0.07824)	(0.19169)	(7.46835)
Size:250-1000	0.0471	0.0824	-0.936	-0.965	-0.0303	0.108	-0.0447	-0.990
	(0.04695)	(0.06093)	(11.348)	(23.314)	(0.09138)	(0.07866)	(0.19099)	(11.673)
Size: 1000	0.0679	0.103**	-0.910	-0.9318	0.0299	0.0966	-0.0157	-0.985
	(0.03391)	(0.05129)	(7.04066)	(35.929)	(0.08973)	(0.0738)	(0.20003)	(15.206)
Observations	6985	6668	2069	701	6985	6668	2069	701

Reported marginal effects (at the sample means) are for bivariate probit. Standard errors in parentheses are robust.
Both dependent variable are dummies. Industry dummies are included.
***Significant at 1%, **Significant at 5%, *Significant at 10%.

On analysing the results, it can be observed that the R&D intensity predicted by the previous equation has a positive and significant impact for high-tech manufacturing firms on product and process innovations and for low-tech manufacturing firms on product innovations only. If the differences between product and process innovations are analysed, it can be seen that the effect is higher for process innovations in high-tech industries. If a comparison is made between technology levels, it can be seen that, in the manufacturing sector, high-tech firms are more likely than low-tech firms to report an innovation, given their R&D intensity. In the case of the service sector, the results have a positive impact but are not significant for knowledge-intensive service firms.

Manufacturing firms that operate in international markets are likely to generate product innovations. Group membership and firms that export have a negative and significant impact for manufacturing firms, and protection methods and subsidies are influential in obtaining a product innovation for manufacturing firms.

As expected, the most important sources of information for both types of innovation are internal (i.e. within the firm or group). Market and other information sources also have a positive and significant impact, but less so than internal sources. Sources of information from universities, public research organizations and technology centres have a negative and significant impact on both kinds of innovation.

4.3.4 Productivity

Table 5 shows the estimates of the production function equation. This analysed the effect of innovation on a firm's productivity. In this case, the coefficients are elasticities, because the dependent variable being analysed is the logarithm of sales per employee. The first four columns report the results when the predicted values of product are included, while the last four columns show the result for process innovations.

The findings show that both types of innovation have a positive effect on productivity for all technology levels, except the non-knowledge-intensive service sectors. It was also observed that process innovation increases productivity much more than product innovation, especially in high-tech manufacturing firms. More specifically, a high-tech manufacturing firm that generates a process innovation reports an increase in productivity of 72% compared to one of 0.7% for a product innovation.

Table 5: Productivity equation

	Labour Productivity							
	High tech Industries	Low tech Industries	KIS	Non-KIS	High tech Industries	Low tech Industries	KIS	Non-KIS
Product	0.0713**	0.0675**	0.246***	-0.0745				
Innovation$_{hat}$	(0.0362)	(0.0326)	(0.0856)	(0.277)				
Process					0.717***	0.376***	1.294***	0.485
Innovation$_{hat}$					(0.120)	(0.132)	(0.223)	(0.455)
Investment	0.0352***	0.0238***	0.0241	0.111***	0.0390***	0.0269***	0.0382**	0.110***
Intensity	(0.00733)	(0.00640)	(0.0174)	(0.0363)	(0.00728)	(0.00641)	(0.0172)	(0.0362)
Human	0.00112**	0.000555	-0.0004	0.00188	0.00110**	0.000580	-0.0005	0.00189
Capital	(0.000523)	(0.000511)	(0.00117)	(0.00266)	(0.000522)	(0.000510)	(0.00116)	(0.00265)
Size:50	0.181***	0.0901	0.0212	0.290	0.224***	0.0954	0.0914	0.541
	(0.0628)	(0.0641)	(0.160)	(0.713)	(0.0627)	(0.0638)	(0.158)	(0.733)
Size:50-99	0.108*	0.0698	-0.0844	-0.110	0.109*	0.0571	-0.119	0.0419
	(0.0578)	(0.0587)	(0.154)	(0.683)	(0.0571)	(0.0577)	(0.150)	(0.686)
Size:100-249	0.0815	-0.0184	-0.0507	0.0826	0.107*	-0.0230	-0.0234	0.273
	(0.0588)	(0.0579)	(0.146)	(0.637)	(0.0585)	(0.0572)	(0.144)	(0.647)
Size:250-1000	-0.0117	-0.167***	-0.0188	-0.173	0.0286	-0.163***	0.0420	0.0134
	(0.0638)	(0.0630)	(0.160)	(0.650)	(0.0639)	(0.0629)	(0.158)	(0.663)
Size: 1000	-0.261***	-0.469***	-0.337	-0.921	-0.248***	-0.474***	-0.333	-0.851
	(0.0823)	(0.0867)	(0.226)	(0.695)	(0.0820)	(0.0865)	(0.224)	(0.694)
Constant	11.78***	12.09***	10.61***	11.34***	11.09***	11.75***	9.458***	10.69***
	(0.108)	(0.173)	(0.251)	(0.739)	(0.163)	(0.220)	(0.334)	(0.885)
Observations	6985	6668	2067	701	6985	6668	2067	701
R-Squared	0.017	0.032	0.020	0.056	0.022	0.033	0.035	0.058
Number of firms	1567	1677	524	214	1567	1677	524	214

Reported coeficients are elasticities from fixed effects estimation. Standard errors in parentheses are robust. Industry dummies are included. ***Significant at 1%, **Significant at 5%, *Significant at 10%.

Investment intensity has a positive effect on productivity across all sectors except the knowledge-intensive service sector for product innovations. It was also observed that human capital has a positive impact on productivity in high-tech manufacturing firms. It was shown that non-knowledge-intensive service firms generate higher profits than other sectors. Finally, size has a negative impact on productivity for large firms.

5 Conclusions

This paper has investigated the causes of innovation and how they affect productivity at a corporate level using the extended CDM model. The first goal was to determine the factors that affect a firm's decision to engage in cooperation projects and how this cooperation affects future R&D expenditure. The second goal was to determine the relationship between innovation and its productivity, comparing the technology level of the firm. For this paper, the PITEC database for the period 2004-2010 was used and the sample was divided into four subsamples depending on the technology level of the firm.

The structural model describes the link between the determinants of probability of participation in cooperation agreements, R&D expenditure, innovation output (product and process) and productivity. In this particular case, it can be demonstrated that firms which decided to cooperate spent more on R&D, that this investment in R&D affected innovation output and that, in turn, this output had a positive impact on the firm's productivity.

The results are consistent with other studies and show that the main determinants of cooperation in innovative activities are public funding, whether the firm has already cooperated in the last four years, and the use of protection methods.

Cooperation has a clearly positive effect on the decision to engage in R&D activities for manufacturing and knowledge-intensive service firms; therefore, collaboration projects increase the probability of participating in R&D activities. These findings answer the main question of the paper, the conclusion being that cooperation agreements generate continuous investments in R&D. The main determinants that have a positive impact on engagement in R&D activities are the use of protection methods, export activities by manufacturing firms, and investment intensity. After a firm decides to participate in R&D projects, the intensity of these activities has a positive impact on investment intensity for all sectors, subsidies for all sectors except non-knowledge-intensive service sectors, and exports for all sectors apart from knowledge-intensive service sectors. Additionally, market share has a positive impact on R&D expenditure for low-tech manufacturing and knowledge-intensive service sectors.

As expected, manufacturing firms that spend more on R&D per employee are more likely to generate innovations. However, in contrast to previous studies, the impact is greater in relation to process innovation than it is to product innovation.

In the case of productivity, the results show that generating a product or process innovation has a positive effect on productivity for all technology levels except for the non-knowledge-intensive service sector. Specifically, process innovation increases productivity much more than product innovation, especially in high-tech manufacturing firms.

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Appendix 1: Classification of manufacturing and service industries

In this paper we will consider the sector classification of technological and knowledge intensities developed by Eurostat, which was based on the methodoloy developed by the OECD. This classification is show in the following table differentiating between manufacturing and services.

	NACE
High-tech manufacturing industries (HTM)	
Aircraft and spacecraft	353
Pharmaceuticals	244
Office, accounting and computing machinery	30
Radio, TV and communications equipment	32
Medical, precision and optical instruments	33
Electrical machinery and aparatus, n.e.c	31
Motor vehicles, trailers and semi-trailers	34
Chemical products	24 exclusive 24.4
Railroad equipment and transport equipment, n.e.c	35 exclusive 353
Machinery and equipment, n.e.c	29
Low-tech manufacturing industries (LTM)	
Coke, refined petroleum products and nuclear fuel	23
Rubber and plastic products	25
Other non-metallic mineral products	26
Metallurgy	27
Metal products	28
Food products, beverages and tobacco	15-16
Textile manufacturing	17
Clothing and furriers	18
Leather articles and footwear	19
Wood and cork	20
Paper industries	21
Printing industries	22
Furniture and other manufactures	36
Knowledge-intensive services (KIS)	
Post and Telecommunications	64
Computer and related activities	72
Research and development	73
Non knowledge-intensive services (NKIS)	
Financial intermediation	65+66+67
Real estate	70+71
Health and social work	85
Recreational, cultural and sportig activities	92

Appendix 2: Variables Definitions

Variable Name	**Explanation**
Collaborative Projects	
Cooperation	Dummy variable which takes the value 1 if the enterprise had some cooperative arrangements in innovation activities during t-2 to t.
Persistence Cooperation	Dummy variable which takes the value 1 if the firm cooperates continuously in R&D activities for at least four years.
Innovation	
R&D Engagement	Dummy variable which takes the value 1 if the firm has positive R&D expenditure.
R&D Intensity	R&D expenditure per employee in t-2 to t (in logs).
Process innovation	Dummy variable which takes the value 1 if the enterprise reports having introduced new or significantly improved production processes during t-2 to t.
Product innovation	Dummy variable which takes the value 1 if the enterprise reports having introduced new or significantly improved products during t-2 to t (new to the market or only new to the firm).
Basic	
Productivity	Sales per employee (in logs).
Investment intensity	Gross investments in tangible goods per employee (in logs).
Market Share	Sales divided by total sales in 3-digit subsector (in logs).
Human Capital	Percentage of employees with higher education.
Factors hampering innovations	
Cost factors	Dummy variable which takes the value 1 if the lack of funding (internal and external is an important factor or innovation costs are too high during t-2 to t.
Knowledge factors	Dummy variable which takes the value 1 if the lack of qualified personnel, lack of information on markets or difficulty in finding a cooperation partner for innovation has high importance during t-2 to t.
Market factors	Dummy variable which takes the value 1 if market rigidities or uncertain demand levels have high importance during t-2 to t.
Non-innovative reason	Dummy variable which takes the value 1 if innovation is not necessary due to previous innovations or there is no demand during t-2 to t.
Sources of information	
Internal sources	Dummy variable which takes the value 1 if information from sources within the enterprise or group has high importance during t-2 to t.
Market sources	Dummy variable which takes the value 1 if information from suppliers, clients, competitors or private R&D institutions has high importance during t-2 to t.
Institutional sources	Dummy variable which takes the value 1 if information from universities, public research organizations or technology centres has high importance during t-2 to t.
Other sources	Dummy variable which takes the value 1 if information from conferences, scientific reviews or professional associations has high importance during t-2 to t.
Appropriability/Public Funds	
Protection	Dummy variable which takes the value 1 if the enterprise uses patents, a design pattern, trademarks, or copyright to protect inventions or innovations during t-2 to t.
Subsidy	Dummy variable which takes the value 1 if the enterprise received central, local or EU funding for innovation projects during t-2 to t.
Firm Size	
Size:50	Dummy equals 1 if employees 50 (for reference)
Size:50-99	Dummy equals 1 if employees $\geq 50 and < 100$
Size:100-249	Dummy equals 1 if employees $\geq 100 and < 250$
Size:250-999	Dummy equals 1 if employees $\geq 250 and < 1.000$
Size:1000	Dummy equals 1 if employees ≥ 1.000
Other	
Foreign	Dummy variable which take the value 1 if the firm trades in an international market during t-2 to t.
Exportations	Dummy variable which takes the value 1 if the firm exports.
Manufacturing	Set of manufacturing dummies according to the main branch of business activity