CÀTEDRA INNOVACIÓ EMPRESA

WORKING PAPERS

Innovation and absorptive capacity: What is the role of technological frontier?

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ABSTRACT

This paper explores how absorptive capacity affects the innovative performance and productivity dynamics of Spanish firms. A firm's efficiency levels are measured using two variables: the labour productivity and the Total Factor Productivity (TFP). The theoretical framework is based on the seminal contributions of Cohen and Levinthal (1989, 1990) regarding absorptive capacity; and the applied framework is based on the four-stage structural model proposed by Crépon, Duguet and Mairesse (1998) for setting the determinants of R&D, the effects of R&D activities on innovation outputs, and the impacts of innovation on firm productivity. The present study uses a two-stage structural model. In the first stage, a probit estimation is used to investigate how the sources of R&D, the absorptive capacity and a vector of the firm's individual features influence the firm's likelihood of developing innovations in products or processes. In the second phase, a quantile regression is used to analyze the effect of R&D sources, absorptive capacity and firm characteristics on productivity. This method shows the elasticity of each exogenous variable on productivity according to the firms' levels of efficiency, and thus allows us to distinguish between firms that are close to the technological frontier and those that are further away from it. We used extensive firm-level panel data from 5,575 firms for the 2004-2009 period. The results show that the internal absorptive capacity has a strong impact on the productivity of firms, whereas the role of external absorptive capacity differs according to nature of the each industry and according the distance of firms from the technological frontier.

Key words: R&D sources, innovation strategies, absorptive capacity, technological distance, quantile regression

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Acknowledgements
This research was partially funded by the Spanish Ministry of Innovation and Science (project ECO2009-08735) and the Consolidated Group of Research 2009-SGR-907. An earlier version of this paper was presented at the XIV Encuentro de Economía Aplicada held in Huelva, June, 2011. We are grateful to participants for their useful comments. Any errors are, of course, our own.

1. Introduction

Innovation has been a major topic in the literatures on growth, productivity and industrial organization for many decades. The ability to create economic value by introducing new products to the market, redesigning production processes, or creating new organizational practices is critical to competitive advantage and growth for firms, industries and countries. Joseph Schumpeter (1934) carried out the first rigorous studies of the determinants of innovation performance at firm level, and these studies were followed by contributions from Schmookler (1962), Scherer (1982), and Griliches (1979, 1994), among others, who prepared the ground for subsequent theoretical and applied advances.

These approaches have provided the most innovative studies into important aspects of these new analytical perspectives. In the last thirty years, the studies by Cohen and Levinthal (1989, 1990) on absorptive capacity and the complementarity of R&D sources at firm level have greatly stimulated research interest in the nature and complexity of these issues.

It is well known that Cohen and Levinthal (1989) define absorptive capacity as a firm's ability to recognize and assimilate external knowledge. The absorptive capacity of the firm does not take on a static dimension, but rather is dynamic and depends on the knowledge previously amassed by the firm, which in turn becomes a key factor in future innovation. These authors also highlighted the complex nature of the sources and processes that characterize any innovative process, which means that the complementarity of innovation manifests itself in various ways between the internal and external knowledge of the firm, between the absorptive capacity of individuals and organizations, and between internal and external R&D, to mention only the most important aspects.

A firm's incentives to innovate are also conditioned by the nature of new knowledge, as was shown by Nelson (1959) and Arrow (1962). Nelson (1959) demonstrated that scientific knowledge was a public asset (especially from the perspective of basic research) and that this characteristic limits the knowledge generator's ability to appropriate its own knowledge and generates positive externalities (or knowledge spillovers) that benefit others. Meanwhile, Arrow (1962) showed that the knowledge resulting from R&D activities is a non-rival and non-exclusive good with three characteristics that limit private markets' capacity to optimally allocate resources in accordance with social demands; these characteristics are: the indivisibility of the information, the knowledge generator's problems of appropriability, and uncertainty. In this scenario, the incentives of the innovating firm, in terms of supply, are limited by knowledge spillovers and the increased risk that the firm must take on; whereas in terms of demand, the firm's acquisition of R&D, participation in cooperative projects and ability to benefit exclusively from internal R&D activities are closely related to its absorptive capacity.

Despite the limitations that firms face when trying to ensure that they benefit exclusively from their R&D activities, many invest in large sums of money in scientific and technological development. In this regard, when Rosenberg (1990) posed his question "*Why do firms do basic research (with their own money)?*" he had few doubts about the answer. As far as he was concerned, despite the low levels of appropriability regarding their own basic research, firms still invest in R&D, the principal reason being that it generates skills and abilities that facilitate the absorption of external knowledge. That is, rather than being merely an asset that realizes its value within the confines of the firm alongside the other agents, internal R&D is, for the directors of innovative firms, one of the essential ways of strengthening the firm's absorptive capacity and benefiting from the knowledge generated by others .

The complex nature of firms' R&D and innovation activities is increasingly attracting the attention of researchers, theorists and empiricists. Furthermore, governments are greatly interested in gradually reducing the barriers to R&D (making, buying and cooperating) and in developing the skills in firms and institutions to encourage creative and innovative environments, all of which means that the various effects of R&D, innovation and productivity need to be studied.

In this regard, the aim of this paper is to study the links between firms' absorptive capacity, their potential to innovate and their levels of productivity. Specifically, the paper will look at two basic questions: What are the main ways in which Spanish firms amass skills and improve their capacity to gather and incorporate external knowledge?; and how does a firm's distance from the technological frontier affect the differences between its sources of innovation and the improvements in its production?

The paper will use a two-stage structural model. First it will use a probit estimation to investigate how R&D sources, absorptive capacity and a vector of a firm's individual features influence the firm's ability to carry out product or process innovations. Second, a quantile regression is used to analyze the effect of R&D sources, absorptive capacity and firm characteristics on productivity. This method allows us to observe the elasticity of each determinant of productivity according to a given firm's productivity.

This paper uses an exhaustive data source from the Spanish Technological Innovation Panel (henceforth PITEC), which brings together in a collaborative venture the Spanish National Institute of Statistics (INE) and the Foundation for Technological Innovation (COTEC). The panel obtains firm-level data and uses a collection methodology that is relatively consistent over a good number of periods. The data are taken from the *Community Innovation Survey* (CIS) and include information regarding innovation activities that is comparable with microdata on innovation from many other European countries. PITEC covers a broad range of sectors, and includes the activities of both manufacturing and services firms. Its principal advantage is that it allows longitudinal data to be obtained for more than 12,000 firms for the 2004-2009 period.

This paper makes five main contributions. First, we look at empirical development in four groups of sectors in terms of the technological intensity of their manufacturing processes (high and low technological intensity) and the knowledge intensity of services (knowledge-intense services and other services). Second, we analyze the labour productivity, in accordance with most other studies on this area, but also go a step further and analyze the Total Factor Productivity (TFP). Third, we adopt a dual econometric methodology where we start by applying an OLS followed by quantile regression in order to observe in detail the elasticity of the R&D sources and the determinants of absorptive capacity according to the firms' different productivity levels. In this way, we can deal explicitly with the subject of the firms' distance from the technological frontier, something which has hardly been touched upon in the micro-economics literature. Fourth, we analyze absorptive capacity from various perspectives, and distinguish between those firms that are close to the technological frontier and those that are lagging behind at a distance, another area that to date has not been explicitly dealt with in the literature. Finally, we use a panel of data that allows us to make a more in-depth analysis of cross section data than those carried out thus far.

The results show that although all firms' internal absorptive capacity behaves in the same way, their external absorptive capacity is conditioned by the characteristics of the sector to which each firm belongs and by its distance from the technological frontier.

The remainder of this paper is organized as follows. In section 2 we review the literature regarding the role of innovation sources, the factors related to absorptive capacity and the distance from the technological frontier. In section 3 we present a two-stage model which uses a probit and a quantile regression to study how the determinant factors of absorptive capacity and a vector of a firm's individual characteristics affect the likelihood of the firm carrying out innovations of its products, processes or productivity. Section 4 describes the steps followed during the data cleansing process and the most important features of the 5,575 firms that make up the definitive sample of innovating firms for the 2004-2009 period. Finally, section 5 details the empirical results and section 6 summarizes the main conclusions and discusses innovation policies.

2. Conceptual framework: the effect of R&D on productivity

Despite the proliferation of studies on the nature and effects of innovation activities at both an individual and aggregate level, we still do not have a general framework that can provide a comprehensive answer to various questions raised by economists, agents and policy makers. Consequently, this paper aims to show the main advances made in the analytical interpretation of the nature of R&D activities and the effect of these activities on the efficiency levels of innovative firms.

The nature of R&D

If we are to understand the role played by a given economic factor, we need to identify the particular features that distinguish it from other factors. When investigating research activity and technological development, studying in depth the nature and peculiarities of knowledge is not just advisable, it is essential. This is the main contribution made by Richard Nelson and Kenneth Arrow. Nelson (1959) pointed out that science, and in particular basic research, was a public asset, which causes considerable problems for the knowledge generator regarding appropriability and gives rise to positive externalities, or spillovers, that benefit others.

In addition, Arrow (1962) studied in detail how the market assigns resources in the ambit of R&D and innovation. For Arrow, the resulting output of R&D activities is a non-rival and non-exclusive asset with three characteristics that limit the market's capacity to optimally allocate resources in accordance with social demands, these being: the indivisibility of the information, the knowledge generator's problems of appropriability, and uncertainty, which only serves to increase the risks assumed by the actors involved. The indivisibility of information generates economies of scale in the production of knowledge; the problems of appropriability reduce the incentives of innovative firms to invest in R&D, resulting in suboptimum R&D investment; and high levels of uncertainty increase the risks and expenses associated with R&D activities and cause problems in the relations between agents participating in the same cooperative project.

The presence of knowledge spillovers reduces the incentives of innovative firms to invest and cooperate in R&D projects, and generate social externalities that affect broad groups of agents (Heijs, 2001). Romer (1986, 1987, 1990) and Lucas (1988) showed that spillovers occur because of the problems that the innovator encounters when trying to appropriate his own invention.

The effects of technological externalities were analyzed by Zvi Griliches in his study in 1979. He highlighted the magnitude of the external economies linked to R&D, and the lack of private investment from innovative firms. Innovative firms compensate for the lack of incentives to carry out internal R&D by adopting external sources that range from the acquisition of external knowledge to collaboration agreements. Although these external sources (acquisition and cooperation) may be a good option for mitigating the failings of the market and making up for the shortfall in internal R&D, they also bring a series of relational problems. According to Nooteboom (2002), the external sources generate some relational problems (adverse selection, moral risk, information flows and revenue extraction) because of the information asymmetries and the difficulties in determining the value of the invention and the effort invested by the agents involved.

Sources of innovation in firms

Firms have different ways of engaging in R&D activities. The first is to do it internally, a strategy known as the decision to *make*. The second is to acquire external technology through transactions on the open market. In this instance, firms basically have two options: to acquire technological knowledge incorporated into goods or assets, or to acquire technological knowledge that is not incorporated into any tangible material, whether this is by subcontracting R&D activities, purchasing patents, etc. In the literature, this strategy is known as the decision to *buy* (Veugelers and Cassiman, 1999). The third strategy consists of establishing agreements to collaborate in R&D projects with other agents (universities, firms, suppliers, customers or even competitors, etc.). In cooperative R&D projects, firms share resources and risks with the aim of reducing costs and effort (Mowery et al., 1996).[1]

Since the last decade of the twentieth century, new developments have made clear the dual nature of R&D (i.e. it generates knowledge and improves the ability of organizations to absorb external knowledge) and the interrelations between the various sources of R&D. For this reason, in addition to the three

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[1] The fundamental difference between buying and cooperating is that in buying there is a unilateral relationship (money is exchanged for R&D results), whereas in cooperation each partner contributes a proportional part to the project (Croisier, 1998).

R&D sources of *making, buying* and *cooperating*, this text will look at a fourth dimension linked to the dual nature of R&D and to the capacity of firms to absorb external technological knowledge (Veugelers y Cassiman, 1999).

Mowery (1983) was the first author to suggest the existence of possible relations between the strategies of *making, buying* and *cooperating*. His study of the factors that influence the externalization of R&D activities shows that the greater a firm's technological capacity (which is derived from its internal R&D activities), the greater its likelihood of acquiring technology externally. In a subsequent study, Mowery and Rosenberg (1989) posited again a similar relation between cooperation and the internal development of R&D activities; on this occasion, they demonstrated that firms acquire more knowledge as the complementarity between sources increases.

This area of research received was boosted by the seminal work of Cohen and Levinthal (1990) on absorptive capacity. These authors pointed out that internal R&D activities play a double role: on the one hand, they are an important source of knowledge that generates innovative ideas; and on the other hand, they increase a firm's capacity to identify, assimilate and exploit externally available knowledge; that is, they increase its absorptive capacity. On the basis of this concept, various studies have analyzed the relations between internal and external know-how, or in strategic terms, the relations between the decisions to *make*, *buy* and *cooperate*. For example, Arora and Gambardella (1990, 1994) state that large firms with a larger knowledge base are more active in searching for and acquiring external technology. In this regard, Lowe and Taylor (1998) found a similar relation between internal R&D and the acquisition of technology through licences, etc., whereas Freeman (1991) indicated that firms that possess an R&D department tend to make more intensive use of external knowledge sources.

However, innovation strategies are not only related in the manner that has just been outlined. To efficiently exploit the acquired technology, a firm must assimilate and integrate it into its productive processes, and this requires the firm to be in possession of a good knowledge and technological skills base. In this regard, the acquisition of external know-how may incentivize rather than substitute internal R&D activity. Veugelers (1997) offers empirical evidence supporting this relationship. He found that both buying technology and cooperating encourage the firm to carry out internal R&D, especially when it possesses its own technological infrastructure (i.e. an R&D department with full time staff). Kaiser (2002) and Becker and Dietz (2004) also arrive at similar results, and find that firms that cooperate invest more in R&D activities than those that do not.

Usually, there is empirical evidence demonstrating the role played by internal knowledge in identifying and acquiring external knowledge and, conversely, the role played by the external acquisition of technology in stimulating the developing of internal R&D activities. These findings corroborate the likelihood of a firm jointly adopting various mechanisms aimed at obtaining technology; in other words, they confirm that the strategies of *making, buying* and *cooperating* coexist in the overall business strategy.

The previous results led to a new research line focused on the analysis of complementarities between the different innovation strategies. Nevertheless it is important to point out that research in this area is still in its infancy and faces considerable methodological difficulties (Athey and Stern, 1998).

An important aspect arising from the research of Milgrom and Roberts (1990)[2] is that an evaluation of complementarity should include a production function, something which has been overlooked in many of the empirical studies on complementarity between innovation strategies. A common practice in this area of research has been to evaluate complementarity by focusing on "correlation", a proposal originally put forward by Arora and Gambardella (1990). By adopting such an approach, rather than producing evidence of complementarity, those authors demonstrated the coexistence of strategies.

The studies of Cassiman and Veugelers (2006) and Laursen and Salter (2006) provide empirical results of the complementarity between the internal generation and external acquisition of the knowledge. However, these two studies produced contradictory results. Cassiman and Veugelers (2006) found that internal R&D activities and the external acquisition of knowledge have complementary effects on firms' innovative activities, whereas Laursen and Salter (2006) found that substitution effects between the intensity of R&D and the use of external knowledge sources predominate.

The absorptive capacity of innovative firms

Since the 1980s the interest in analyzing absorptive capacity in innovative firms has continued to grow. Cohen and Levinthal (1989, 1990) introduced the concept of absorptive capacity and highlighted the dual nature of R&D in that it both generates new information and improves the ability of a firm to calibrate and incorporate external information. Rosenberg (1990) was the first to argue that internal R&D is necessary to understand how scientific and

[2] Milgrom and Roberts (1990) were the first to introduce and formally develop the concept of "complementarity". According to their theory of supermodularity, two activities are complementary if the change in the production function that is obtained when they are carried out separately is less than when they are carried out together.

technological information flows from external sources into a firm. These studies emphasize the potential synergies between internal and external knowledge. Nevertheless, Rosenberg's discussion does not deal with the multi-dimensional nature of knowledge and therefore does not fully explore the sources of these synergies.

For this reason, Arora and Gambardella (1994) proposed distinguishing between two types of knowledge. The first type looks at the capacity or ability of a firm to *evaluate* external information, whereas the second type looks at a firm's ability to *use* externally generated information. Several years later, Cassiman and Veugelers (2000) and Arbussà and Coenders (2007), among others, carried out further research along these lines. The first type of knowledge does not entail complex scientific or technological knowledge, but rather knowledge regarding the technology at user level and knowledge regarding business trends. The second type allows a firm to not only to discover technological developments and business trends, but also to integrate complex and abstract external knowledge into its activities.

Distance of firms from the technological frontier

In recent years the concept of distance from the technological frontier has been widely employed in the macro, sectorial and individual literatures. In Industrial Economics, this concept has been very useful for studying firms' innovation strategies (Griffith et al., 2004). Research has shown that a firm's position in relation to the technological frontier is an important factor when determining the intensity and nature of innovation in manufacturing and services firms. Nevertheless, there are certain differences among analyses carried out at country and firm level. For example, life cycle and entrance and exit strategies are less important at country level than at firm level. Likewise, firm mergers or takeovers have no equivalent at country level.

One of the first contributions to this literature regarding country level was made by Gerschenkron (1962). He argued that lagging economies find it easier to shorten the distance that separates them from the technological frontier because they can imitate and absorb external technology. This phenomenon was originally known as the "*advantage of backwardness*". Years later, Abramovitz (1986) qualified Gerschenkron's proposal by stating that underdeveloped countries need to have a certain amount of physical, human and technological capital to be able to use foreign technology and to benefit from international technological externalities. And more recently Griffith et al. (2004) and Cameron et al. (2005) defined the distance from the technological frontier as the TFP of the country on the frontier divided by the TFP of the country under study.

One of the first contributions regarding firm level came from Coad (2008), who showed that the highest quantiles corresponded to leading firms near to the technological frontier, whereas the lowest quantiles corresponded to backward firms, that is, those furthest away from the frontier.

3. Empirical model

In this section we present a method for analysing in depth the role played by a set of factors that determine the absorptive capacity of firms. The two objectives of this study were outlined in the introductory pages and are: 1) to study the mechanisms by which the sources of R&D (*making*, *buying* and *cooperating*) affect innovation and productivity; and 2) to analyze the role of factors linked to absorptive capacity. To meet these two objectives, we use a two-stage econometric strategy that follows, in part, the analytical framework proposed by Crépon, Duguet and Mairesse (1998) (CDM), which has been improved in successive revisions by Mairesse and Mohen, 2004; Kremp et al., 2004; Griffith et al., 2006 and Mohnen et al., 2006.

The structural model of CDM links productivity with the input from innovation, and this in turn with the firm's investment in R&D, thus optimizing the information available in the different versions of the *Community Innovation Survey* (CIS). The CDM structural model has four equations: the first deals with whether firms decide to carry out innovation activities; the second deals with the factors that determine investment in innovation activities; the third estimates the elements that determine the outputs of a firm's innovation; and the fourth uses a Cobb Douglas production function to study the effects of innovation activities on productivity.

This paper covers two stages of the CMD structural model. In the first stage, we apply a probit model to estimate how the R&D sources, the determinants of absorptive capacity and a vector of the firm's individual characteristics condition the firm's likelihood of carrying out product or process innovations. The empirical work classifies the firms into four groups (manufacturing firms versus services firms, high knowledge intensity versus low knowledge intensity) and applies fixed effects per sector (CNAE-2009 divisions) and per financial year (2004-2009). We can express a firm's likelihood of developing an innovation with the following expression:

$$\mathrm{inn}_i^* = \beta X_i + \mu_i \qquad [1]$$

where X_i is a vector of the determinant factors of innovation, β is a vector of the parameters that are estimated and μ is a random error term. In this binary model, the dependent variable —the likelihood of innovating— is a latent variable (Greene, 2003). Using inn_i to denote the binary that indicates that the firm "i" carries out innovation, we get:

$$\text{inn}_i = \begin{cases} =1 & \text{if } \text{inn}_i^* > 0 \\ =0 & \text{if } \text{inn}_i^* \leq 0 \end{cases} \quad [2]$$

where *inn* is binary observable that is equal to 1 if the firm carries out product or process innovations and equal to 0 if it does not. The vector X_i includes a series of variables related to the sources that firms use in their innovation processes (internal R&D, external acquisition of R&D and cooperation in R&D projects), as well as the determinants of absorptive capacity and a series of factors that bring together the individual characteristics related to the firm's productivity. We also introduce a vector with sectorial dummy variables to capture the heterogeneity across the sectors.

In the second stage, we use quantile regressions to estimate the impact of innovation sources, absorptive capacity and several of the firm's characteristics on its productivity.

Originally many researchers interpreted R&D activities as a new kind of capital that is accumulated after R&D investment, but continued research then led many to observe that knowledge stock is not only the result of each firm's investment, but also that knowledge is a non-rival good that allows firms to learn from the efforts and innovation carried out by their competitors and the firms with whom they share their surroundings. For this reason, we adopt a series of assumptions based on the seminal contribution by Arrow (1962) regarding the limitations faced by an innovative firm when trying to appropriate all the benefits, the accumulated experience potential, and the learning and externalities. This contribution opened up a new horizon for interpreting the barriers and incentives that prevent firms from investing R&D, and several years later would result in endogenous growth models that support the growth trajectories sustained by the presence of growing incomes and external effects in the production functions (Romer, 1986; Lucas, 1988).

In particular, we are interested in adopting a series of factors first proposed by Griliches in 1979. His study has become a reference work for all those interested in analysing the nature and effect of R&D activities on the productivity of innovative firms. A Cobb-Douglas production function, broadened to include R&D activities, would be as follows:

$$Y_{it} = AK_{it}^{\alpha} L_{it}^{\beta} R_{it}^{\gamma} e^{\lambda_{it} + \mu} \quad [3]$$

where the firm's product i in each period of time t, Y, is obtained by means of the 'conventional factors' of work, L, and physical capital, K, from the knowledge or technological capital of the firm, R, and, finally, from the rate of technical progress related to the profile of the sector, the technological spillovers and the individual characteristics of the firm, A. The parameters α ,β,γ are the elasticities of the product in terms of physical capital, work and knowledge, respectively. Following on from Griliches (1979), the parameter λ captures the firm's characteristics that affect the level of productivity, and μ stands for any limitations regarding the quality of the data; that is, it is an indicator of our lack of certainty about their quality. By applying logarithms to the production function [3] we can rewrite the equation thus:

$$\ln(\frac{Y_{i,t}}{L_{i,t}}) = \ln(A_{it}) + \alpha \ln(\frac{K_{i,t}}{L_{i,t}}) + \gamma \ln(R_{i,t}) \qquad [4]$$

Where the parameters α and γ correspond to the elasticities of the product for each of the factors. When we incorporate a series of variables related to knowledge, absorptive capacity and the firm's characteristics, we obtain the following expression:

$$\ln(y_{i,t}) = \delta_0 + \delta_1 \ln(RD\mathrm{int}_{i,t}) + \delta_2 \ln(RDext_{i,t}) + \delta_3 (Coop_{i,t}) + \delta_4 AC_{i,t} + \\ + \delta_5 \ln(Size_{i,t}) + \delta_6 \ln(\frac{K_{i,t}}{L_{i,t}}) + \delta_7 Group_{i,t} + \delta_8 \ln(MarketShare_{i,t}) + \delta_9 Age_{i,t} + \varepsilon_{i,t} \qquad [5]$$

Where for each individual firm i in each period of the time t, y is the firm's productivity; $RD\mathrm{int}$ is the intensity of the internal R&D expenditure; $RDext$ is the intensity of the external R&D expenditure; $Coop$ is the cooperation with other partners; AC is the absorptive capacity; $Size$ is the size of the firm; K/L is the investment in terms of physical capital per employee; $Group$ refers to membership of a group; $MarketShare$ is the share of the market; and Age refers to age. Furthermore, $\delta_1, \delta_2, \delta_3, \delta_4, \delta_5, \delta_6, \delta_7, \delta_8, \delta_9$ are elasticities referring to the intensity of internal R&D expenditure, the intensity of external R&D expenditure, cooperation, absorptive capacity, size, the intensity of the investment, membership of a group, the market share and age, respectively.

Despite our efforts to give the empirical work a rich vector of variables to explain firm level productivity, it should not be forgotten that the results obtained present the endogenous or simultaneous biases that are common to this type of estimation. To guarantee the robustness of our results, we have followed the proposals of Coad (2008) and Raymond et al. (2010), among others, and have moved the product determinants back one period with regard to the dependent variable, thus adopting the following model:

$$\ln(y_{i,t}) = \delta_0 + \delta_1 \ln(RD\text{int}_{i,t-1}) + \delta_2 \ln(RDext_{i,t-1}) + \delta_3 (Coop_{i,t-1}) +$$

$$\delta_4 AC_{i,t-1} + +\delta_5 \ln(Size_{i,t-1}) + \delta_6 \ln(\frac{K_{i,t-1}}{L_{i,t-1}}) + \delta_7 Group_{i,t-1} + \quad [6]$$

$$\delta_8 \ln(MarketShare_{i,t-1}) + \delta_9 Age_{i,t-1} + \varepsilon_{i,t}$$

In the following section we present the most important aspects of the PITEC that is made up of the Spanish National Institute of Statistics and the Foundation for Technical Innovation and which provided most of our empirical data. We also used data from the Instituto Valenciano de Investigaciones Económicas (Valencian Economics Research Institute) to determine the stock of physical capital in each sector, data from the Spanish National Institute of Statistics to determine sales in each sector, and the Industrial Prices Index to deflate various variables.

4. Data

4.1 Sample

The PITEC collates a large amount of information regarding the most important aspects of a considerable number of manufacturing and services firms. One of the advantages of the PITEC over transversal data sources from technical innovation surveys is the PITEC's temporal nature, which allows it to obtain much more accurate estimations of the progress of firms and to obtain much more robust data that better reflect the heterogeneous nature of the firms.

Nevertheless, we should highlight certain limitations (such as subjectivity) to some of the questions. In this regard, how the innovative character of a particular activity is evaluated depends in part on the point of view of the person answering the survey. Nevertheless, the evidence offered by Mairesse and Mohnen (2004) suggests that subjective evaluations of innovation tend to be consistent with more objective evaluations. For the present study, it is also essential to cleanse the primary data source and to cleanse the database (treat missing values, remove excessively disparate ratios regarding the average sectorial values, etc.). After cleansing the database, the sample was reduced from 12,813 firms to 5,575 firms.

The most important operations that were taken into account throughout the cleansing process were that: *a)* the survey data should cover the 2004-2009 period; *b)* the chosen sectors should be manufacturing and services, with a distinction made between sectors with high technological intensity and sectors with low technological intensity; *c)* the sample should only include firms that have appeared in the database for at least four years; d) firms that have not undergone a merger or takeover and e) firms with ten or more employees.

4.2 Variables and descriptive statistics

We measured the productivity variable, y, in two different ways. First, we defined it as the number of sales per employee, in keeping with most studies that have dealt with this subject, and secondly, we measured it as the Total Factor Productivity (TFP), because we think that this form of measurement is much broader and covers different aspects of productivity. Even so, we should clarify that our study of the TFP only looked at manufacturing firms because we did not have the corresponding information for services firms.

Table 1.a: Descriptive statistics (average values) in 2004-2009 (Labour Productivity) by quantiles

High-tech industries (11,220 Obs.)					
	10%	**25%**	**50%**	**75%**	**90%**
Labour Productivity	52,084.19	86,484.15	127,836.00	189,254.90	291,085.20
Factors related to knowledge					
Internal R&D	4,161.66	4,157.69	4,797.06	5,149.90	5,859.00
External R&D	1,171.40	401.09	675.18	1,010.12	1,908.92
Cooperation (%)	24.35	26.43	30.09	36.19	38.80
Absorptive capacity I (External factors)					
MARKET	2.55	2.48	2.43	2.38	2.32
PUBLIC	3.39	3.36	3.32	3.22	3.15
OTHERS	3.02	2.97	2.91	2.86	2.78
Absorptive capacity II (Internal factors)					
INTERNAL	2.84	2.73	2.80	2.83	2.91
Firm characteristics					
Size	68.60	79.89	105.15	158.38	225.11
Investment	5,720.46	5,015.78	8,670.19	9,144.47	13,955.90
Group (%)	17.40	21.08	30.90	42.89	59.06
Share Market (%)	0.03	0.05	0.08	0.14	0.32
Age	19.82	24.74	25.56	29.32	32.21
Low-tech industries (14,204 Obs.)					
	10%	**25%**	**50%**	**75%**	**90%**
Labour Productivity	44,878.43	78,096.54	117,043.50	183,802.10	305,071.40
Factors related to knowledge					
Internal R&D	1,013.14	1,503.37	1,841.37	1,869.57	2,282.46
External R&D	228.21	359.23	382.98	425.31	510.09
Cooperation (%)	16.90	22.34	26.56	30.00	31.41
Absorptive capacity I (External factors)					
MARKET	2.82	2.73	2.68	2.66	2.59
PUBLIC	3.51	3.44	3.37	3.32	3.27
OTHERS	3.11	3.08	3.05	3.01	2.94
Absorptive capacity II (Internal factors)					
INTERNAL	2.79	2.81	2.81	2.86	2.89
Firm characteristics					
Size	98.29	97.26	113.78	175.49	205.11
Investment	3,029.15	5,611.11	13,225.45	14,726.60	20,074.63
Group (%)	11.41	17.46	26.92	39.62	50.28
Share Market (%)	0.02	0.04	0.06	0.15	0.22
Age	21.83	25.64	27.81	28.83	29.73

Source: PITEC
Notes: Productivity in euros, Internal R&D, External R&D and Investment in euros per employee and size in employees.

We defined the intensity variable for internal R&D, *RD int*, as the internal R&D expenditure per employee, and then we defined the intensity variable for external R&D, *RDext*, as the external R&D expenditure per employee. The cooperation variable, *Coop*, is a binary variable that differentiates between firms that do not cooperate (represented by 0) and those that do cooperate (represented by 1).

Table 1.b: Descriptive statistics (average values) in 2004-2009 (TFP) by quantiles					
High-tech industries (11,220 Obs.)					
	10%	**25%**	**50%**	**75%**	**90%**
TFP	8,603.20	14,561.44	21,286.94	31,299.58	47,292.11
Factors related to knowledge					
Internal R&D	4,530.44	4,463.24	4,727.54	5,065.23	5,338.72
External R&D	1,156.28	440.96	728.94	1,065.86	1,676.16
Cooperation (%)	25.86	27.44	31.62	36.35	38.59
Absorptive capacity I (External factors)					
MARKET	2.50	2.48	2.44	2.35	2.34
PUBLIC	3.34	3.35	3.24	3.22	3.20
OTHERS	2.97	2.92	2.88	2.87	2.81
Absorptive capacity II (Internal factors)					
INTERNAL	2.82	2.74	2.79	2.83	2.93
Firm characteristics					
Size	79.73	85.96	109.01	170.78	236.81
Investment	10,060.59	6,796.44	8,148.97	9,955.69	12,110.07
Group (%)	20.82	23.26	33.14	44.37	56.84
Share Market (%)	0.04	0.05	0.08	0.16	0.32
Age	20.60	25.19	26.34	30.44	31.75
Low-tech industries (14,204 Obs.)					
	10%	**25%**	**50%**	**75%**	**90%**
TFP	7,071.02	12,230.05	18,194.34	28,133.60	46,396.41
Factors related to knowledge					
Internal R&D	869.02	1,477.36	1,698.42	1,841.97	2,219.87
External R&D	202.39	334.96	363.42	370.92	486.81
Cooperation (%)	16.94	22.87	27.73	30.22	32.10
Absorptive capacity I (External factors)					
MARKET	2.84	2.75	2.67	2.65	2.61
PUBLIC	3.50	3.42	3.38	3.30	3.27
OTHERS	3.12	3.08	3.05	3.00	2.94
Absorptive capacity II (Internal factors)					
INTERNAL	2.78	2.80	2.83	2.85	2.88
Firm characteristics					
Size	111.14	104.64	127.19	185.83	208.83
Investment	14,104.76	9,890.43	11,239.35	13,125.56	16,644.05
Group (%)	13.63	19.08	28.56	41.27	50.97
Share Market (%)	0.02	0.04	0.07	0.16	0.22
Age	22,33	26.51	28.50	29.29	30.66
Source: PITEC *Notes: Productivity in euros, Internal R&D, External R&D and Investment in euros per employee and size in employees.*					

We considered the two types of absorptive capacity described previously: the first allows a firm to scan its immediate environment for knowledge and the second allows it to integrate knowledge generated anywhere into its own activities. Given that knowledge spillovers cannot be measured directly, we used the variables that are best suited to defining these two types of absorptive capacity.

Table 2: Descriptive statistics (average values) in 2004-2009 (Labour Productivity) by quantiles					
Knowledge-intensive services (3,837 Obs.)					
	10%	**25%**	**50%**	**75%**	**90%**
Labour Productivity	18,860.50	36,268.54	50,432.48	72,527.29	115,148.60
Factors related to knowledge					
Internal R&D	12,452.95	14,446.14	12,661.80	18,058.86	19,262.59
External R&D	1,624.36	1,115.27	1,224.23	1,361.38	2,155.52
Cooperation (%)	50.13	40.97	37.43	43.59	40.97
Absorptive capacity I (External factors)					
MARKET	2.50	2.45	2.46	2.31	2.36
PUBLIC	2.71	2.99	3.09	3.09	3.14
OTHERS	2.59	2.78	2.79	2.78	2.82
Absorptive capacity II (Internal factors)					
INTERNAL	2.80	2.78	2.82	2.74	2.82
Firm characteristics					
Size	116.85	211.63	140.06	77.97	103.72
Investment	5,951.37	9,079.29	4,987.04	5,550.41	12,831.16
Group (%)	16.71	19.79	22.21	27.32	41.31
Share Market (%)	0.09	0.10	0.09	0.14	0.35
Age	12.24	12.51	12.78	13.15	13.63
Other Services (2,951 Obs.)					
	10%	**25%**	**50%**	**75%**	**90%**
Labour Productivity	16,025.12	36,884.13	66,058.97	139,496.70	314,079.20
Factors related to knowledge					
Internal R&D	305.91	1,691.35	845.12	1,779.94	1,009.83
External R&D	41.51	125.07	104.42	254.22	856.25
Cooperation (%)	14.24	20.14	26.83	26.69	39.37
Absorptive capacity I (External factors)					
MARKET	3.11	3.03	3.14	2.96	2.68
PUBLIC	3.46	3.48	3.39	3.49	3.62
OTHERS	3.18	3.07	3.03	3.08	3.14
Absorptive capacity II (Internal factors)					
INTERNAL	3.14	3.09	3.17	3.23	3.19
Firm characteristics					
Size	485.67	272.10	502.80	429.94	979.11
Investment	1,419.14	10,799.13	9,097.10	15,672.07	38,242.48
Group (%)	14.58	29.86	38.21	51.76	64.48
Share Market (%)	0.01	0.01	0.03	0.12	0.45
Age	17.04	24.17	32.39	32.57	53.52
Source: PITEC					
Notes: Productivity in euros, Internal R&D, External R&D and Investment in euros per employee and size in employees.					

Following the paper by Arbussà and Coenders (2007), to study the first type of absorptive capacity, we used the responses regarding the importance of external sources of information to innovation; these sources range from market sources of information (MARKET), which include customers and competitors, to public institutions (PUBLIC), which include universities, technological centres and other public research institutions, to other sources (OTHERS), which include conferences, scientific journals, technical publications, fairs, exhibitions, etc. Given that firms' responses to these questions were subjective, we believe that they reflect not only the degree to which knowledge is available in the sector but also the degree of use and absorption by the firm. Again following on from Arbussà and Coenders (2007), as a proxy for the second type of absorptive capacity, we used the responses to the questions regarding the internal barriers that impede innovation in a firm (INTERNAL), these being: a) the lack of qualified people, b) the lack of technological information and c) the lack of market information. On the basis of this, we used a summated scale to construct these variables, which have a value of 1 to 4. In other words, this method adds the information from various categorical responses and provides an aggregate value that is more in line with the purpose of the study, and in doing so reduces the limitations inherent in the use of individual indicators that offer a partial dimension of a complex phenomenon, in our case the absorptive capacity.

We defined the size variable, *Size*, as the number of employees. The investment variable, K/L, measures the gross investment of material assets per employee. The group variable, *Group*, is a binary variable that differentiates between independent firms, (represented by 0) and those that belong to a group (represented by 1). We defined the market share variable, *MarketShare*, as the firm's sales divided by the value of the sales in its sector. We obtained the sectorial sales from the Spanish National Institute of Statistics. The age variable, *Age*, covers the years between the current financial year t and the financial year in which the firm was created.

Tables 1.a, 1.b and 2 show the descriptive statistics of the variables used throughout the study. Tables 1.a and 1.b show that for manufacturing firms, information from the market, the public institutions and other sources is more important for firms that are close to the technological frontier. Furthermore, these firms also have less difficulty in finding qualified staff, etc. Table 2 shows that for firms providing knowledge intense services, information from the market is more important to those firms that are closer to the technological frontier, whereas information from other sources is more important to those firms that are further from the technological frontier. The latter also have more difficulty in finding qualified staff, etc. If we look at firms that provide other services, we can see that information from the market and from other sources is more important for firms that are nearer to the technological frontier. On the other hand, information from public institutions is more important for firms that are further away from it, and these firms also have more difficulty in finding qualified staff, etc.

5. Results

In this section we discuss the most important results from our empirical study. In the first stage, we used a probit estimation to determine how R&D sources and absorptive capacity affect a firm's likelihood of carrying out innovations of products, processes or both. In the second stage, we use a quantile regression to estimate the elasticity of productivity regarding a series of sources that determine the innovative potential of Spanish firms. The results obtained from the quantile regressions provide the value of each parameter for the hundred distribution percentiles, and thus provide detailed information regarding the changes that occur in a firm's elasticity of productivity as a result of its position in relation to the technological frontier.

The empirical evidence obtained contributes greatly to the existing body of knowledge. Some authors have estimated the causal relation between R&D and innovation and have obtained ambiguous results. For example, Benavente (2006) found that intense R&D in Chilean manufacturing firms had a negative impact on innovation; on the other hand, Ebersberger et al. (2010) found that intense R&D in Finnish manufacturing firms had a positive impact on innovation and that the closer firms get to the technological frontier, the greater this impact. In addition, Segarra (2010) showed that intense R&D in Spanish manufacturing firms with high technological intensity and in Spanish services firms with high knowledge intensity had a positive effect on productivity, whereas the impact was negative for Spanish manufacturing firms with low technological intensity.

The results in Table 3 indicate that, for manufacturing firms with either high or low technological intensity, if a firm cooperates with other firms and there is an increase in the importance given to information from the market and other sources such as conferences, etc., that consequently there is a significant increase in the likelihood of the firm carrying out innovation.

Table 3: Probit estimation on the determinants of innovations

	High-tech industries	**Low-tech industries**	**Knowledge-intensive services**	**Other Services**
Factors related to knowledge				
Internal R&D	0.0045 (0.0029)	-0.0023 (0.0024)	-0.0123 (0.0051)**	-0.0282 (0.0059)***
External R&D	0.0026 (0.0029)	-0.0070 (0.0026)***	0.0079 (0.0047)*	(0.0084 (0.0069)
Cooperation	0.4424 (0.0510)***	0.4186 (0.0457)***	0.5570 (0.0817)***	0.4496 (0.1055***)
Absorptive capacity I (External factors)				
MARKET	-0.1699 (0.0241)***	-0.1116 (0.0222)***	-0.2877 (0.0403)***	0.0769 (0.0583)
PUBLIC	0.1619 (0.0309)***	0.2346 (0.0278)***	0.1506 (0.0515)**	0.2615 (0.0708)***
OTHERS	-0.1967 (0.0315)***	-0.2793 (0.0293)***	-0.2399 (0.0505)***	-0.2701 (0.0701)***
Absorptive capacity II (Internal factors)				
INTERNAL	0.0263 (0.0260)	0.0290 (0.0232)	-0.0517 (0.0442)	-0.1550 (0.0630)**
Sectorial dummies	Yes	Yes	Yes	Yes
Time dummies	Yes	Yes	Yes	Yes
[pseudo]R^2	0.0761	0.0709	0.1324	0.1382
Number observations	9,821	11,200	3,253	1,832

Source: PITEC
****Significant at 1%; **significant at 5%; *significant at 10%; standard errors in parentheses*

Regarding knowledge-intensive services, the empirical results show that a firm's likelihood of innovating increases when the firm invests more in external R&D, cooperates with other firms and gives importance to information from the market and other sources (conferences, meetings, fairs, etc.). Regarding firms that provide other services, we find that their likelihood of innovating significantly increases if they cooperate with other firms and give importance to information from other sources (conferences, meetings, fairs, etc.).

The variables regarding firm characteristics (size of the firm, investment in physical assets, membership of a group, market share and age of the firm) are highly significant and as expected.

In Tables 4.a, 4.b and 5 we find empirical evidence of quantile regressions that link the sources and results of innovation activities with productivity. As such, we can see the effects of independent variables on the relative efficiency of each firm. Tables 4.a, 4.b and 5 present five estimations (quantiles 10%; 25%; 50%; 75%; 90%). It is particularly useful to contrast the least efficient firms, located far from the technological frontier (10%), with those firms that are close to the frontier (90%). The quantile regression parameters were calculated using bootstrapped standard errors (200 reproductions). The quantile regression coefficients can be interpreted as the marginal change y in the quantile θth caused by the marginal change in the particular regressor $\Delta Q_{\theta}(y_i|x_i)/\Delta x$.

Specifically, Tables 4.a and 4.b show that internal R&D expenditure has a positive impact on manufacturing firms with high technological intensity that are situated far from the technological frontier, whereas it has a negative impact on those firms nearer to the frontier. In contrast, external R&D expenditure always has a positive impact on firms that are far from the technological frontier and those that are close to it. These results indicate that internal R&D and external R&D coexist in firms that are far from the technological frontier, whereas internal R&D is substituted by external R&D in firms close to the frontier. These results coincide with those found in studies such as Segarra and Teruel (2011). Lokshin et al. (2008) found that internal R&D and external R&D have a positive impact on the productivity of manufacturing firms, but does not classify these firms either in terms of technological intensity or in terms of their position in relation to the technological frontier.

Table 4.a: Quantile regressions on the determinants of productivity (Labour productivity)						
	OLS	**Quantile Regression**				
		10%	**25%**	**50%**	**75%**	**90%**
High-tech industries (8,125 Obs.)						
Factors related to knowledge						
Internal R&D	0.0025 (0.0011)**	0.0059 (0.0019)***	0.0056 (0.0013)***	0.0037 (0.0014)***	0.0046 (0.0017)	-0.0043 (0.0021)**
External R&D	0.0066 (0.0009)***	0.0044 (0.0017)***	0.0053 (0.0011)***	0.0052 (0.0009)***	0.0060 (0.0015)***	0.0059 (0.0020)***
Cooperation	0.0111 (0.0152)	0.0027 (0.0248)	0.0014 (0.0185)	0.0147 (0.0164)	-0.0057 (0.0221)	0.0127 (0.0284)
Absorptive capacity I (External factors)						
MARKET	-0.0228 (0.0081)***	-0.0043 (0.0124)	-0.0089 (0.0098)	-0.0346 (0.0091)***	-0.0269 (0.0104)***	-0.0525 (0.0148)***
PUBLIC	0.0340 (0.0100)***	0.0164 (0.0153)	0.0143 (0.0127)	0.0379 (0.0118)***	0.0226 (0.0160)	0.0449 (0.0199)**
OTHERS	-0.0162 (0.0100)	-0.0198 (0.0133)	-0.0172 (0.0120)	-0.0067 (0.0126)	-0.0126 (0.0133)	-0.0297 (0.0194)
Absorptive capacity II (Internal factors)						
INTERNAL	0.0380 (0.0089)***	0.0247 (0.0146)*	0.0376 (0.0109)***	0.0403 (0.0105)***	0.0416 (0.0113)***	0.0475 (0.0196)**
Firm characteristics						
Size	0.0440 (0.0077)***	0.0799 (0.0132)***	0.0767 (0.0096)***	0.0617 (0.0102)***	0.0145 (0.0122)	-0.0161 (0.0194)
Investment	0.0101 (0.0011)***	0.0115 (0.0016)***	0.0106 (0.0014)***	0.0088 (0.0014)***	0.0093 (0.0015)***	0.0099 (0.0018)***
Group	0.2800 (0.0163)***	0.1990 (0.0226)***	0.2110 (0.0202)***	0.2310 (0.0197)***	0.3010 (0.0248)***	0.3420 (0.0324)***
Share Market (%)	0.1500 (0.0077)***	0.1110 (0.0069)***	0.1130 (0.0074)***	0.1150 (0.0175)***	0.2210 (0.0273)***	0.3220 (0.0843)***
Age	0.0292 (0.0094)***	0.1090 (0.0176)***	0.0425 (0.0121)***	0.0244 (0.0126)***	-0.0012 (0.0156)	-0.0450 (0.0172)***
Sectorial dummies	Yes	Yes	Yes	Yes	Yes	Yes
Time dummies	Yes	Yes	Yes	Yes	Yes	Yes
[Pseudo]-R^2	0.2572	0.1398	0.1466	0.1418	0.1488	0.1666
Low-tech industries (9,282 Obs.)						
Factors related to knowledge						
Internal R&D	0.0038 (0.0009)***	0.0043 (0.0015)***	0.0040 (0.0010)***	0.0047 (0.0010)***	0.0053 (0.0012)***	0.0019 (0.0016)
External R&D	0.0015 (0.0010)	0.0001 (0.0014)	-0.0004 (0.0011)	0.0004 (0.0011)	0.0019 (0.0014)	0.0035 (0.0018)*
Cooperation	0.0176 (0.0159)	0.0682 (0.0267)**	0.0432 (0.0153)***	0.0140 (0.0166)	-0.0231 (0.0215)	-0.0038 (0.0259)
Absorptive capacity I (External factors)						
MARKET	-0.0020 (0.0084)	-0.0169 (0.0132)	-0.0167 (0.0075)**	-0.0087 (0.0102)	-0.0039 (0.0108)	0.0170 (0.0130)
PUBLIC	-0.0269 (0.0106)**	-0.0215 (0.0187)	-0.0113 (0.0121)	-0.0141 (0.0117)	-0.0069 (0.0149)	-0.0260 (0.0192)
OTHERS	-0.0035 (0.0104)	0.0040 (0.0154)	0.0092 (0.0115)	0.0025 (0.0119)	-0.0024 (0.0137)	-0.0077 (0.0184)
Absorptive capacity II (Internal factors)						
INTERNAL	0.0620 (0.0091)***	0.0538 (0.0127)***	0.0503 (0.0097)***	0.0543 (0.0096)***	0.0464 (0.0114)***	0.0416 (0.0160)***
Firm characteristics						
Size	-0.0335 (0.0078)	0.0546 (0.0121)***	0.0232 (0.0092)**	-0.0359 (0.0099)***	-0.1130 (0.0148)***	-0.2670 (0.0219)***
Investment	0.0089 (0.0010)***	0.0081 (0.0018)***	0.0081 (0.0010)***	0.0086 (0.0011)***	0.0080 (0.0013)***	0.0104 (0.0020)***
Group	0.3300 (0.0164)***	0.2140 (0.0252)***	0.2480 (0.0188)***	0.2840 (0.0173)***	0.3130 (0.0241)***	0.3100 (0.0275)
Share Market (%)	0.4480 (0.0201)***	0.2510 (0.0245)***	0.3680 (0.0396)***	0.6700 (0.0629)***	1.0440 (0.1190)***	1.8580 (0.1720)
Age	0.0822 (0.0095)***	0.1020 (0.0130)***	0.0887 (0.0103)***	0.0742 (0.0121)***	0.0478 (0.0120)***	0.0459 (0.0173)***
Sectorial dummies	Yes	Yes	Yes	Yes	Yes	Yes
Time dummies	Yes	Yes	Yes	Yes	Yes	Yes
[Pseudo]-R^2	0.2625	0.1268	0.1304	0.1524	0.1838	0.2128

Source: PITEC

Notes: Internal R&D, External R&D, Size and Investment in logs; Cooperation and Group are dummies; MARKET, PUBLIC, OTHERS and INTERNAL take values of 1 to 4 and Market Share is in percentages. ***Significant at 1%; **significant at 5%; *significant at 10%; standard errors in parentheses

Table 4.b: Quantile regressions on the determinants of productivity (TFP)						
	OLS	**Regresión Cuantílica**				
		10%	**25%**	**50%**	**75%**	**90%**
High-tech industries (8,125 Obs.)						
Factors related to knowledge						
Internal R&D	0.0015 (0.0011)	0.0051 (0.0016)***	0.0034 (0.0014)**	0.0030 (0.0015)**	-0.0012 (0.0018)	-0.0059 (0.0021)***
External R&D	0.0059 (0.0009)***	0.0042 (0.0017)**	0.0055 (0.0012)***	0.0054 (0.0011)***	0.0051 (0.0014)***	0.0053 (0.0020)***
Cooperation	0.0141 (0.0151)	0.0088 (0.0234)	0.0037 (0.0171)	0.0092 (0.0180)	0.0164 (0.0199)	0.0057 (0.0330)
Absorptive capacity I (External factors)						
MARKET	-0.0226 (0.0080)***	0.0037 (0.0121)	-0.0111 (0.0097)	-0.0372 (0.0090)***	-0.0281 (0.0109)***	-0.0368 (0.0171)**
PUBLIC	0.0349 (0.0099)***	0.0148 (0.0152)	0.0176 (0.0113)	0.0380 (0.0116)***	0.0345 (0.0129)***	0.0367 (0.0210)*
OTHERS	-0.0105 (0.0098)	-0.0215 (0.0141)	-0.0154 (0.0122)	-0.0029 (0.0124)	-0.0141 (0.0140)	-0.0226 (0.0236)
Absorptive capacity II (Internal factors)						
INTERNAL	0.0354 (0.0088)***	0.0189 (0.0134)	0.0285 (0.0105)***	0.0368 (0.0100)***	0.0337 (0.0120)***	0.0511 (0.0175)***
Firm characteristics						
Size	0.0236 (0.0076)***	0.0620 (0.0142)***	0.0582 (0.0087)***	0.0412 (0.0095)***	-0.0111 (0.0126)	-0.0332 (0.0204)
Investment	0.0085 (0.0011)***	0.0096 (0.0017)***	0.0089 (0.0012)***	0.0070 (0.0013)***	0.0075 (0.0014)***	0.0080 (0.0019)***
Group	0.2730 (0.0162)***	0.2040 (0.0242)***	0.2070 (0.0207)***	0.2370 (0.0174)***	0.3070 (0.0244)***	0.3210 (0.0358)***
Share Market (%)	0.1460 (0.0077)***	0.1080 (0.0081)***	0.1030 (0.0067)***	0.1120 (0.0157)***	0.2140 (0.0240)***	0.3310 (0.0862)***
Age	0.0294 (0.0093)***	0.1050 (0.0178)***	0.0435 (0.0133)***	0.0242 (0.0122)***	0.0050 (0.0137)	-0.0594 (0.0180)***
Sectorial dummies	Yes	Yes	Yes	Yes	Yes	Yes
Time dummies	Yes	Yes	Yes	Yes	Yes	Yes
[Pseudo]-R^2	0.2254	0.1387	0.1361	0.1252	0.1219	0.1313
Low-tech industries (9,282 Obs.)						
Factors related to knowledge						
Internal R&D	0.0040 (0.0009)***	0.0044 (0.0015)***	0.0041 (0.0011)***	0.0051 (0.0011)***	0.0052 (0.0013)***	0.0022 (0.0017)
External R&D	0.0015 (0.0010)	0.0004 (0.0015)	-0.0004 (0.0012)	0.0005 (0.0010)	0.0025 (0.0014)*	0.0035 (0.0017)**
Cooperation	0.0150 (0.0158)	0.0576 (0.0233)**	0.0453 (0.0163)***	0.0079 (0.0160)	-0.0267 (0.0194)	-0.0131 (0.0273)
Absorptive capacity I (External factors)						
MARKET	-0.0045 (0.0083)	-0.0174 (0.0117)	-0.0160 (0.0087)*	-0.0124 (0.0103)	-0.0059 (0.0111)	0.0109 (0.0133)
PUBLIC	-0.0246 (0.0105)**	-0.0177 (0.0164)	-0.0125 (0.0108)	-0.0133 (0.0115)	-0.0012 (0.0140)	-0.0127 (0.0194)
OTHERS	-0.0027 (0.0103)	0.0013 (0.0154)	0.0070 (0.0112)	0.0026 (0.0104)	-0.0045 (0.0137)	-0.0003 (0.0167)
Absorptive capacity II (Internal factors)						
INTERNAL	0.0603 (0.0091)***	0.0465 (0.0136)***	0.0504 (0.0119)***	0.0511 (0.0104)***	0.0430 (0.0111)***	0.0337 (0.0150)**
Firm characteristics						
Size	-0.0548 (0.0079)***	0.0350 (0.0127)***	0.0054 (0.0096)	-0.0549 (0.0099)***	-0.1400 (0.0154)***	-0.0295 (0.0231)***
Investment	0.0079 (0.0010)***	0.0072 (0.0016)***	0.0072 (0.0011)***	0.0075 (0.0012)***	0.0065 (0.0011)***	0.0097 (0.0018)***
Group	0.3280 (0.0163)***	0.2050 (0.0255)***	0.2500 (000176)***	0.2790 (0.0184)***	0.3070 (0.0230)***	0.3100 (0.0269)***
Share Market (%)	0.4520 (0.0199)***	0.2540 (0.0259)***	0.3570 (0.0420)***	0.6580 (0.0594)***	1.0950 (0.1070)***	1.954 (0.1830)***
Age	0.0826 (0.0094)***	0.1060 (0.0143)***	0.0852 (0.0124)***	0.0765 (0.0119)***	0.0527 (0.0136)	0.0410 (0.0179)**
Sectorial dummies	Yes	Yes	Yes	Yes	Yes	Yes
Time dummies	Yes	Yes	Yes	Yes	Yes	Yes
[Pseudo]-R^2	0.2519	0.1164	0.1194	0.1417	0.1792	0.2168

Source: PITEC
Notes: Internal R&D, External R&D, Size and Investment in logs; Cooperation and Group are dummies; MARKET, PUBLIC, OTHERS and INTERNAL take values of 1 to 4 and Market Share is in percentages.
***Significant at 1%; **significant at 5%; *significant at 10%; standard errors in parentheses

Regarding the factors related to the absorptive capacity of firms with high technological intensity, we can see that the importance given to information from the market (MARKET) generally has a negative impact on productivity for all manufacturing firms, that is, if a firm gives less importance to market information, the firm's productivity decreases. Furthermore, this impact is greater in firms closer to the technological frontier than in those further from it. On the other hand, information from public institutions (PUBLIC) has a positive impact on productivity; that is, if a firm gives less importance to this type of information, its productivity increase. Perhaps, therefore, public institutions should consider other ways of providing their information so that firms regarded it as important. We also find that information from other sources (OTHERS) has a negative impact both on labour productivity and on TFP for all firms, regardless of whether they are far from or close to technological frontier. That is, if the importance given to information from other sources decreases, the labour productivity decreases.

We can say that internal absorptive capacity (INTERNAL) has a positive impact both on labour productivity and on TFP (see Tables 4.a and 4.b). That is, if there is decrease in the difficulties faced by a firm when recruiting qualified staff, etc., then there is a corresponding increase in productivity.

Our results cannot be compared with the existing literature because none of the research carried out to date has analyzed the impact of absorptive capacity on productivity, but rather has focused how absorptive capacity influences a firm's likelihood of carrying out R&D activities, acquiring technology, etc.

If we look at manufacturing firms with low technological intensity, we can see that in general internal R&D expenditure and external R&D expenditure have a positive impact on productivity for all firms, both in terms of labour productivity and TFP, regardless of the firm's proximity to the technological frontier. These results indicate, therefore, that internal R&D and external R&D coexist.

Regarding the factors related to the absorptive capacity of firms with low technological intensity, we can see that the importance given to market information (MARKET) has a negative impact on the labour productivity and the TFP for firms that are situated far from the technological frontier; that is, if a firm gives less importance to information from the market, its productivity decreases. In contrast, the importance given to market information has a positive impact on firms close to the technological frontier. For these firms, the act of giving less importance to market information leads them to increase their productivity levels. The opposite occurs with information from other sources (OTHERS). Information from public institutions (PUBLIC) has a negative impact on productivity; that is, if a firm gives less importance to this type of information, then its productivity decreases, which is in direct contrast to manufacturing firms with high technological intensity.

We can say that internal absorptive capacity (INTERNAL), as is the case with manufacturing firms with high technological intensity, has a positive impact both on labour productivity and on TFP (see Tables 4.a and 4.b). That is, if there is decrease in the difficulties faced by a firm when recruiting qualified staff, etc., then there is a corresponding increase in productivity.

Table 5 shows the results of the regressions for services. Specifically, in the case of knowledge-intensive services, we can see that R&D expenditure has a negative impact on firms that are either far from or close to the technological frontier. In contract, this impact is positive for firms at a medium distance from the frontier. If we look at external R&D expenditure, we can see that it has a negative impact on firms that are located far from the technological frontier. In contrast, it has a positive impact on firms close to or at an intermediate distance from the technological frontier. Segarra and Teruel (2011) found that both internal and external R&D have a positive impact on productivity, although they did not take into account firms' proximity to the technological frontier.

We can see that both information from the market (MARKET) and information from other sources (OTHERS) have a negative impact for all firms, regardless of whether they are close to or far from the technological frontier; that is, if a firm decreases the importance it gives to market information or other sources, then it decreases its productivity. We can also see that, as is the case with manufacturers with high technological intensity, information from public institutions (PUBLIC) has a positive impact on productivity; that is, if a firm decreases the importance it gives to public institutions, then it increases its productivity. Internal absorptive capacity (INTERNAL) has a positive impact on both labour productivity and TFP, as it does with manufacturing firms with high or low technological intensity (see Table 5). That is, if there is decrease in the difficulties faced by a firm when recruiting qualified staff, etc., then there is a corresponding increase in its productivity.

For firms that provide other services (Table 5), internal R&D expenditure has a positive impact on the productivity of firms that are far from the technological frontier, whereas it has a negative impact on firms that are close to the frontier. In contrast, external R&D expenditure has a positive impact on productivity, regardless of a firm's proximity to the technological frontier.

Table 5: Quantile regressions on the determinants of productivity (Labour productivity)						
	OLS	**Quantile regression**				
		10%	**25%**	**50%**	**75%**	**90%**
Knowledge-intensive services (2,686 Obs.)						
Factors related to knowledge						
Internal R&D	-0.0019 (0.0022)	-0.0030 (0.0032)	0.0003 (0.0023)	0.0036 (0.0019)*	0.0019 (0.0033)	-0.0026 (0.0048)
External R&D	0.0040 (0.0018)**	-0.0009 (0.0039)	0.0020 (0.0023)	0.0032 (0.0017)*	0.0083 (0.0026)***	0.0066 (0.0026)**
Cooperation	-0.0155 (0.0308)	0.0801 (0.0524)	0.0654 (0.0378)*	0.0364 (0.0262)	-0.0049 (0.0456)	-0.1090 (0.0480)
Absorptive capacity I (External factors)						
MARKET	-0.0459 (0.0162)***	-0.0925 (0.0326)***	-0.0602 (0.0219)***	-0.0062 (0.0171)	-0.0078 (0.0233)	-0.0280 (0.0317)
PUBLIC	0.0913 (0.0193)***	0.1380 (0.0426)***	0.0917 (0.0203)***	0.0502 (0.0188)***	0.0610 (0.0267)**	0.0898 (0.0247)***
OTHERS	0.0180 (0.0192)	-0.0036 (0.0344)	0.0208 (0.0195)	-0.0032 (0.0182)	0.0284 (0.0253)	-0.0091 (0.0327)
Absorptive capacity II (Internal factors)						
INTERNAL	0.0128 (0.0185)	0.0397 (0.0296)	0.0030 (0.0253)	0.0123 (0.0193)	-0.0026 (0.0245)	0.0003 (0.0292)
Firm characteristics						
Size	0.0078 (0.0142)	-0.0047 (0.0250)	-0.0038 (0.0139)	-0.0453 (0.0159)***	-0.0364 (0.0245)	-0.0531 (0.0325)
Investment	0.0068 (0.0022)***	0.0005 (0.0040)	0.0024 (0.0024)	0.0038 (0.0019)***	0.0067 (0.0031)**	0.0079 (0.0032)**
Group	0.3530 (0.0317)***	0.3010 (0.0676)***	0.2650 (0.0381)***	0.3150 (0.0334)***	0.4270 (0.0551)***	0.5270 (0.0650)***
Share Market (%)	0.1040 (0.0105)***	0.0974 (0.0230)***	0.0951 (0.0103)***	0.1330 (0.0322)***	0.1470 (0.0422)***	0.2540 (0.0509)***
Age	0.1420 (0.0217)	0.2230 (0.0413)***	0.1230 (0.0281)***	0.1020 (0.0205)	0.1430 (0.0357)***	0.1090 (0.0390)
Sectorial dummies	Yes	Yes	Yes	Yes	Yes	Yes
Time dummies	Yes	Yes	Yes	Yes	Yes	Yes
[Pseudo]-R^2	0.2619	0.1289	0.1041	0.1140	0.1635	0.2467
Other Services (1,517 Obs.)						
Factors related to knowledge						
Internal R&D	-0.0001 (0.0031)	0.0002 (0.0062)	0.0021 (0.0043)	0.0036 (0.0033)	-0.0043 (0.0039)	-0.0047 (0.0036)
External R&D	0.0093 (0.0034)***	0.0140 (0.0073)*	0.0083 (0.0038)**	0.0026 (0.0035)	0.0040 (0.0042)	0.0036 (0.0045)
Cooperation	0.0181 (0.0488)	-0.0555 (0.0967)	0.0966 (0.0588)	0.0203 (0.0572)	0.0244 (0.0556)	0.0482 (0.0594)
Absorptive capacity I (External factors)						
MARKET	-0.0794 (0.0282)***	-0.0002 (0.0480)	0.0133 (0.0361)	-0.0623 (0.0323)*	-0.0947 (0.0385)**	-0.0976 (0.0364)***
PUBLIC	0.0609 (0.0369)*	0.0886 (0.0744)	0.0293 (0.0450)	0.0531 (0.0383)	0.0680 (0.0455)	-0.0279 (0.0501)
OTHERS	0.0286 (0.0341)	-0.0438 (0.0577)	-0.0287 (0.0346)	0.0246 (0.0379)	-0.0072 (0.0461)	0.0217 (0.0488)
Absorptive capacity II (Internal factors)						
INTERNAL	0.0764 (0.0325)**	0.0506 (0.0492)	0.1030 (0.0367)***	0.0901 (0.0346)***	0.0790 (0.0448)*	0.0442 (0.0445)
Firm characteristics						
Size	-0.2320 (0.0185)***	-0.1570 (0.0359)***	-0.0896 (0.0269)***	-0.1740 (0.0182)***	-0.3010 (0.0246)***	-0.4070 (0.0314)***
Investment	0.0085 (0.0036)**	0.0243 (0.0085)***	0.0209 (0.0056)***	0.0079 (0.0044)*	-0.0006 (0.0052)	0.0004 (0.0049)
Group	0.5540 (0.0503)***	0.3760 (0.0886)***	0.3070 (0.0641)***	0.4040 (0.0511)***	0.4510 (0.0633)***	0.5050 (0.0574)***
Share Market (%)	0.6630 (0.0497)***	0.5040 (0.0840)***	0.4390 (0.0925)***	0.7220 (0.0957)***	1.0140 (0.1280)***	1.3090 (0.2300)***
Age	0.2030 (0.0280)***	0.2380 (0.0612)***	0.1350 (0.0317)***	0.1170 (0.0297)***	0.1220 (0.0313)***	0.1050 (0.0352)***
Sectorial dummies	Yes	Yes	Yes	Yes	Yes	Yes
Time dummies	Yes	Yes	Yes	Yes	Yes	Yes
[Pseudo]-R^2	0.4817	0.2247	0.2540	0.3160	0.3550	0.3925

Source: PITEC

Notes: Internal R&D, External R&D, Size and Investment in logs; Cooperation and Group are dummies; MARKET, PUBLIC, OTHERS and INTERNAL take values of 1 to 4 and Market Share is in percentages.

***Significant at 1%; **significant at 5%; *significant at 10%; standard errors in parentheses

Therefore, we can say that internal R&D and external R&D coexist in firms that are far from the technological frontier, and that external R&D substitutes internal R&D in firms that are close to the technological frontier.

The only significant variable regarding external absorptive capacity is information from the market (MARKET). This variable generally has a negative impact on the productivity of firms that are close to the technological frontier; that is, as firms give less importance to this information, so too does their productivity. Internal capacity (INTERNAL) is significant for almost all firms and has a positive impact on productivity; that is, if there is decrease in the difficulties faced by a firm when recruiting qualified staff, etc., then there is a corresponding increase in its productivity.

6. Conclusions

The empirical literature regarding R&D sources and innovation performance at firm level has grown continuously since the first CIS coordinated by the OECD. This increasing interest represents a significant advance in research in this field; however, the diverse nature of national systems and regional and sectorial conditions generates differences that limit the direct application of simple models. In the European Union, the Lisbon Strategy of 2000 made the mistake of treating all countries as equals, without taking into account their different starting points. In this study we have presented certain micro-economic evidence regarding the determinants of innovation and the effects of R&D sources and innovation on productivity. Specifically, we highlight the role of factors that determine absorptive capacity and their effect on productivity in firms at varying distances from the technological frontier. To do this, we have carried out an empirical analysis of 5.575 for the 2004-2009 period.

The empirical results can be summarized as follows. When the dependent variable is the firm's labour productivity, the econometric results show that information from the market and from other sources is important for practically all firms, regardless of whether firms are far from or close to the technological frontier. In contrast, information from public institutions is only important for manufacturing firms with low technological intensity, again regardless of whether they are far from or close to the technological frontier, and for firms that provide other services that are close to the technological frontier. If we look at the TFP, we can see that information from the market is only important for manufacturing firms with high technological intensity that are close to the technological frontier and for manufacturing firms with low technological intensity that are far from the frontier. In contrast, information from public institutions is important for manufacturing firms with low technological intensity, regardless of their distance from the technological frontier, but it is not important for manufacturing firms with high technological intensity. Information from other sources is important for manufacturing firms with high technological intensity, again regardless of whether they are far from or close to the technological frontier and for manufacturing firms with low technological intensity that are close to it. Furthermore, if a firm from any of the sectors analyzed experiences a decrease in the difficulties it faces when recruiting qualified staff, etc., then there is a corresponding increase in its labour productivity and in its TFP, regardless of the firm's proximity to the technological frontier.

We have therefore found that although internal absorptive capacity behaves in the same way for all types of firm, external absorptive capacity of different firms is affected by the characteristics of the sector to which they belong and by their respective distance from the technological frontier.

A surprising result among firms that belong to highly technologically or knowledge intense sectors is that they do not perceive information from public institutions as a strategic asset, whether this comes from the public administrations or from scientific or technological institutions. That is, these firms do not pay much attention to information from public institutions, which highlights the traditional separation between the academic and business worlds. This result means that public institutions, and in particular universities and their transfer structures, should to adapt their channels for transmitting knowledge to a more dynamic global environment that requires a quicker and more direct response to resolve the innumerable technological challenges that Spanish firms have to face, whether they are close to or far from the technological frontier.

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