Productivity and R&D sources in manufacturing and service firms in Catalonia: a regional approach

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ABSTRACT
This paper draws on a sample of innovative Catalan firms to identify the effects of the two main sources of innovation —internal R&D and external R&D acquisition— on productivity in the manufacturing and service industries. The sample comprises a 3,267 firms from the CIS-4 for the years 2002-2004. We compare empirical results when applying usual OLS and quantile regression techniques. Our results suggest the different patterns attributable to the two sources of innovation as we move up from lower to higher conditional quantiles. First, the effect of the marginal effect of internal R&D on productivity in both sectors decreased as we moved up to higher productivity levels. Second, the marginal effect of external R&D acquisition increased as we moved up to higher productivity levels, especially in high-tech manufacturing industries. Our empirical results suggest that the link between internal and external R&D is complex, varying between firms' productivity levels and between industries.

JEL codes: O300, C100, O140
Keywords: Innovation sources, R&D, Productivity, Quantile Regression

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1. Introduction

The effect of innovative activity on growth and productivity at the firm level has received much attention in recent years. This can be explained in part by the increased availability of micro-level data from innovation surveys conducted in the EU. These surveys have enabled a growing number of studies on the links between R&D, innovation and productivity to be undertaken. In general, these empirical studies have found a direct link between R&D and innovation, on the one hand, and productivity, on the other, both in terms of levels and rates. But empirical evidence gathered at the firm level underlines the high degree of heterogeneity in the efficiency and productivity levels of firms within the same industry (Bartelsman and Doms, 2000; Baldwin and Gu, 2006; Haltiwanger et al., 2007). Moreover, regarding the productivity differentials between firms, evidence shows that productivity level dispersion is great and persistent over time. Thus, there is a strong likelihood that firms which are highly productive today will be highly productive tomorrow[1].

The reasons underpinning these productivity differentials are diverse. Productivity levels reflect factors such as investment in equipment, R&D activities, use of new technologies and the skill of the workforce (Caselli, 1999). In addition, Bresnahan et al. (2002) argue in favour of the complementary effects of practices related to the use of technologies of information and organizational changes in a firm's structure in the production function. Furthermore, these authors claim that such a synergy, or complementarity, exists between such innovations and the percentage of skilled workers in the firm[2]. The complementarity between technology, skilled workers and a firm's characteristics –market share, export activities, innovation performance, etc.- can also shed light on the complementarity between internal and external sources of knowledge generation and absorption.

The aim of this paper is to analyse the effects of internal and external R&D on the productivity of manufacturing and service firms in Catalonia depending on the level of firm productivity. The hypothesis we seek to test is the following: firms with low levels of productivity invest less in external R&D and enjoy greater returns on internal R&D, whereas in firms with

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[1] For a large sample of Spanish firms during the period 1998-2006, Segarra et al. (2008) observe that productivity per worker and wages are positively related to age and size, the heterogeneity of productivity level decreases with firm age and size, but the differences between firms persist during years.

[2] These hypotheses have been confirmed for British and French firms, where complementarity between technological and organizational changes facilitates the appearance of a more decentralized hierarchical structure (Caroli and Van Reenen, 2001).

high productivity levels these returns on internal R&D fall, while the importance of external R&D increases and marginal returns rise.

Here, we argue that innovative firms tend to invest in internal and external R&D at the same time. This positive relationship between both sources of R&D suggests that these activities are complementary, i.e., the marginal returns to one activity increase as the intensity of the other increases (Cassiman and Veugelers, 2006). There is evidence to indicate that internal R&D activities have both direct and indirect effects on a firm's productivity: a direct effect in that these activities increase innovation and an indirect effect in that they increase a firm's ability to absorb external R&D (Cohen and Levinthal, 1989).

However, our hypothesis is that low and high productive firms differ in the marginal returns of R&D. Our hypothesis is based on the fact that low productive firms that make the effort to increase their investment in internal R&D obtain greater returns. The reason is because their absorptive capacity is larger because they are lagging behind the most productive firms. This hypothesis can be justified in two ways. First, laggards can benefit from the strategies that their competitors have already adopted. Veugelers and Cassiman (1999) point out that "competitors are an important source of information for the innovation process". Second, firms with low levels of productivity may obtain a higher return because they adopt more risky R&D strategies. Cabral (2003) and Anderson and Cabral (2007) analysed the behavior of leaders and laggards and observed that leaders may fail to perform as well as laggards in terms of radical innovation. They gave two reasons for this: incumbents invest relatively less in radical innovation and leaders' research aiming to exploit radical innovation is significantly less productive than that of laggards.

Adopting the analytical framework described by Crépon, Duguet and Mairesse (1998), we can establish a sequence that ranges from those factors that determine a firm's R&D activities to their effect on its productivity. Thus, in line with Lokshin, Belderbos and Carree (2008), we aim to analyse the direct link between R&D activities and the effect on firm productivity. Despite the considerable heterogeneity associated with firm innovation, the literature still tends to use the regression methodology based on standard OLS. However, the usual assumption of normally distributed error terms is not warranted here as the distribution of innovation expenditure is highly skewed, yet despite this potential bias, few empirical studies have dealt with the problem. In this framework, therefore, conditional regression techniques constitute a suitable instrument for taking into consideration non-normally distributed error terms. Our results confirm our hypothesis:

those firms with low productivity levels obtain higher returns on internal R&D investment, while firms with high productivity levels obtain higher returns on external R&D investment.

The paper makes three contributions to the analysis of the link between internal and external R&D and the productivity of the firm. First, we observe the effects of the two main sources of innovation—internal and external R&D investment—on the productivity of manufacturing and service industries. Despite the increasing weight of the service sector in innovation activities and the overall economy, very few studies have linked innovation sources and productivity at the firm level in both the manufacturing and service sectors (Miles, 2005). Second, we seek to analyse the complementarity between both sources of innovation depending on productivity. Third, we use quantile regression to observe the effects of internal and external R&D across different productivity levels. This paper compares OLS and quantile regression parameters and provides a rich view of R&D-productivity relationships over a broad spectrum of productivity levels.

The remainder of this paper is organized as follows. Section 2 reviews the literature that discusses the relationship between internal and external R&D. Section 3 presents the data set and describes the variables used in our analysis. Section 4 sets out our empirical results, and section 5 highlights our main conclusions.

2. Internal and external R&D

Complementarity between a firm's activities appears when the carrying out of one activity increases both the firm's propensity to adopt other activities and the marginal returns of its other activities. Such complementarities are an important part of a firm's strategy since they are crucial for its survival. First, they prevent imitation by rivals since the success of innovation depends on the internal strategies of the other firms (Dierickx and Cool, 1989). Second, complementary assets raise the value of a firm's technological innovations (Teece, 1986). Third, they allow the firm to reap the benefits of innovative activities. This section discusses the literature that has analysed the complementarities between internal and external R&D.

The internal R&D activities performed by firms affect their capacity to generate and assimilate knowledge in a variety of ways. Typically the literature distinguishes two "faces" to internal R&D. The first is the direct effect of R&D in promoting innovation. Over the last decade, there has been an increasing attention in the empirical literature to the effects of R&D on the innovative performance of firms (Griliches, 1995; Crépon et al., 1998; Mairesse and Mohnen, 2004; Hall and Mairesse, 2006; Mohnen et al., 2006). In general, their results show that the probability of an innovative firm increases with internal R&D input.

The other face to internal R&D is its indirect effect that can facilitate the impact of R&D spillovers or the imitation of cutting-edge innovation in a particular technological or scientific field. This aspect of the role of internal R&D is related to the interaction that exists between the internal capacity to generate knowledge and the absorptive capacity to capture external knowledge generated by others. This second face to internal R&D originates from the tacit dimension of knowledge and can be perceived in different ways, including technology transfer flows, R&D spillovers and the capacity of the firm to imitate the innovation generated by others.

The significance of the indirect effects of R&D has been stressed in a number of studies. For example, Arrow (1962) stresses the role of tacit knowledge in the generation of technological innovation and the relevance of learning-by-doing in adaptation to new technologies. Similarly, Teece (1986) shows that innovative firms have a vector of complementary assets which determine their capacity for appropriating returns on innovation. At the same time, firms may invest in appropriation instruments to reduce outgoing spillovers (Arrow, 1962). In general, appropriation instruments fall within two categories: legal and strategic. The former include patents, trademarks and copyrights, while strategic instruments include investments in complementary assets, secrecy and lead time, and the relative complexity of products and services (Mansfield, 1986). However, the effectiveness of appropriation barriers varies across industries, so when the effects are low and the cost is high the firm's incentives to invest in R&D and innovation fall[3].

Adopting an alternative analytical approach, Cohen and Levinthal (1989) introduced the term of a firm's 'absorptive capacity' in describing the dual role of R&D both as a producer of new information and as a firm's ability to learn from existing information. The notion of 'absorptive capacity' highlights the importance of the R&D undertaken by a firm and the complementarities between internal and external R&D sources (Veugelers, 1997). Arora and Gambardella (1994) and Cassiman and Veugelers (2000) propose two dimensions to this absorptive capacity. The first one is related to the firm's ability to scan the market and to evaluate external information,

[3] Stieglitz and Heine (2007) analyse the role of complementarities to appropriate innovative rents depending on the stage of the industry.

and the second one is related to the firm's ability to utilize information and to absorb the technology acquired. Additionally, Cassiman and Veugelers (2002) distinguish between incoming spillovers related to a firm's absorptive capacity, which affects the innovation rate of the firms, and appropriability, which affects the ability of the firm to reduce outgoing spillovers and to appropriate the returns from innovation.

Empirical evidence describing the two faces of R&D - the direct effect of inducing innovation and the indirect effect of facilitating absorptive capacity- presents several stylized facts at the sectoral and firm level. At the sectoral level, Griffith et al. (2003) offer a single model that integrates the theoretical literature on Schumpeterian endogenous growth and the empirical literature on R&D and productivity. Their model identifies three sources of productivity growth: R&D-induced innovation, technology transfer and R&D-based absorptive capacity. Using industry level data for a panel of OECD countries these authors find evidence that R&D raises the rate at which technology is transferred from frontier to non-frontier countries. With a similar panel of 12 OECD countries, Griffith et al. (2004) report how human capital and R&D increase the adsorptive capacity to adopt efficient technologies in countries that lie far behind the technological frontier. Finally, for nine industries in 12 OECD members, Kneller and Stevens (2006) find that the differences in absorptive capacity explain cross-country differences in the level of productivity[4]. In this line, Bonte (2003) shows that external R&D has a positive impact on the increase of productivity which is non-linear for high-tech manufacturing firms.

In short, the empirical evidence indicates that a firm's innovation activities are related to its ability to absorb external information, knowledge and technologies. In this sense a recent trend in the analysis of innovative performance at the firm level involves observing whether internal and external R&D are complementary or not. When firms carry out internal and external R&D activities simultaneously, it can be assumed that the marginal return to one activity increases as the intensity of the other increases. In this case internal and external R&D activities are complementary (Cassiman and Veugelers, 2006).

However, there is not evidence on the differences between the level of complementarity of R&D sources between high an low productive firms. Here we are interested in measuring the marginal effects of internal and

[4] Empirical evidence about the complementarity between internal and external R&D is extensive. For example, for Spain Arbussà and Coenders (2007); for Holland, Lokshin et al. (2008); for Belgium, Cassiman and Veugelers (2006); for Japan, Nakamura and Odagiri (2005); and for UK, Love and Roper (2002).

external R&D when a firm's labour productivity levels vary. We assume that internal and external R&D are complementary and that marginal effects are correlated at the cross-sectional level, but that when we apply different estimations across the productivity level distribution our empirical results will be more ambiguous.

The importance is that the return of internal and external R&D may be different depending on the productivity level. Beneito (2006) points out that previous models neglect the different returns to R&D sources. She shows that internal R&D activities in isolation may succeed in terms of incremental and radical innovations but external R&D does not create radical innovations, unless they are combined with internal capabilities (the 'absorptive capacity' hypothesis). But for firms with high and low productivity levels, their returns from R&D sources may differ. We expect higher marginal returns from internal R&D in the lower productivity quantiles, but as we move up to higher productivity quantiles we expect a fall in the marginal returns from internal R&D and a rise in the marginal returns from external R&D.

3. Data and statistics

The data used in this study were provided by a sample of Catalan firms which had previously responded to the fourth version of the Community Innovation Survey (CIS-4) during the period 2002-2004 (Table 1). Catalonia is an interesting case to study for various reasons. First, Catalan firms are much more committed to R&D activities than the other Spanish regions. Second, the urban system is dominated by the Barcelona metropolitan area, but there is also a network of medium-sized cities with considerable economic and social vitality. Third, the region's industrial tradition is based on medium and low technological manufacturing industries and is undergoing increasing specialization in services.[5] Fourth, in Catalonia, KIS services play an important role in spreading knowledge and in firm innovation projects.

Our database contains CIS questionnaires completed by 3,267 Catalan firms, of which 1,130 operate in high-tech manufacturing industries, 1,443

[5] In recent years Catalonia has undergone an intense process of economic opening and had its comparative advantages in traditional industries eroded, which has given rise to significant changes in its industrial mix. In 2006, the services sector accounted for 63.7% of total employment, while the manufacturing sector was responsible for only 22.7% of total employment. In Catalonia, between 1996 and 2006, employment in the manufacturing sector increased at an annual rate of 3.0%, while employment in total services increased at an annual rate of 5.8% and KIS increased by 8.1%. The Catalan economy had 540,175 employees in KIS industries in 1996 and 979,788 employees in 2006.

in low-tech manufacturing industries and 694 in knowledge-intensive services (KIS). This industrial classification based on technology and knowledge intensity in manufacturing and service industries follows OECD criteria.

The CIS survey provides exhaustive information about innovation expenditure. The questionnaire asked firms to: "*Estimate the amount of expenditure in each innovation activity in 2004, either from management accounting information or using informed estimates*", with the following options: Internal R&D; Acquisition of R&D; Acquisition of machinery, equipment and software; Acquisition of external knowledge; Training; All forms of Design; and Marketing expenditure. In this way, the CIS survey allows us to study a firm's R&D strategies as it provides information about the R&D decision process.

Internal R&D projects are carried out by 1,503 firms, accounting for 54.1% of the total innovation expenditure of our sample. A group of 679 firms acquires external R&D, accounting for 21.7% of total innovation expenditure. Internal R&D plays an important role in the absorptive capacity of knowledge produced by others while the acquisition of external knowledge only is scarce, especially in manufacturing industries. Furthermore, the two main innovation sources related to internal and external R&D account for three of every four euros that Catalan firms spend on their innovation projects. The remaining sources of innovation register more moderate amounts[6].

As in other economies, R&D and innovation in Catalonia also differ across industries and firms. Our database shows that the one per cent of firms that made the largest investments in innovation concentrated 48.6% of the total, while five per cent of firms made 70.1% of the total investment. This skewed distribution of innovation expenditure at the firm level can be explained by a variety of factors. Firstly, R&D and innovation activities are uncertain and risky, and the returns for success are extremely variable. Secondly, few firms have the required financial capacity to engage in innovation projects, which usually need to be carried out over long periods of time. And thirdly, not all firms can effectively protect their innovations in the market and enjoy the innovation returns.

[6] In a sample of CIS-3 Spanish firms operating in the manufacturing and service industries, Segarra and Arauzo (2008) find large differences in the sources of business innovation in internal R&D activities, in the external acquisition of services related to innovation and in cooperation agreements with other firms or public institutions. In high-tech industries, innovative firms that conduct internal R&D activities and cooperate with firms, universities and public research institutions predominate. Internal and external R&D and R&D cooperation is less frequent in low-tech manufacturing and service industries.

Table 1 Sources of firm innovation Year 2004	All firms	High-tech Industries	Low-tech Industries	KIS Services
Innovation expenditure per firm (1)	882.9	1,489.9	260.4	1,189.0
R&D expenditure per firm (1)	669.4	1,157.7	148.3	957.9
Other innovation sources (1)	213.5	332.2	112.1	231.1
Innovation expenditures by sources				
Internal R&D	(54.1)	(47.3)	(50.6)	(69.5)
External R&D	(21.7)	(30.4)	(6.3)	(11.0)
Machinery and software	(15.4)	(17.6)	(25.5)	(6.3)
External knowledge	(1.2)	(0.9)	(0.7)	(2.2)
Training	(0.7)	(0.4)	(0.6)	(1.4)
All forms of design	(2.2)	(2.1)	(4.4)	(1.5)
Marketing expenditures	(4.6)	(1.3)	(11.7)	(8.0)
Firms with permanent R&D	1,295 (39.6)	608 (53.8)	414 (28.7)	273 (39.3)
Firms with innovation expenditures	1,156 (58.1)	559 (71.5)	374 (49.7)	223 (53.3)
Number of firms	3,267	1,130	1,443	694

Note: (1) average firm amounts in thousands of euros, percentage in parentheses
Source: Catalan Innovation Survey

This heterogeneity can be observed when comparing new firms and incumbents. In general, R&D investment and labour productivity differ between firms. On the one hand, new firms invest more in R&D per employee but their productivity is lower and they are smaller than incumbents. On the other hand, small firms present larger internal R&D and innovation investment per worker than larger firms. However, small firms invest less in external R&D and obtain lower productivity per employee (see Table A.1 in the Annex).

When firms engage in R&D activities, they have first had to adopt two important decisions. First, they must choose how to implement R&D projects internally or externally. Second, they have to decide how much to invest in their R&D projects. A considerable body of empirical research has focused on this second question (Geroski, 1990; Griliches, 1995; Crépon et al, 1998; Mairesse and Mohnen, 2004), but the evidence suggests that the first question is not trivial and responses can differ markedly between industries and firms (Love and Roper, 2002). During the process of establishing a firm's innovation strategies, the choice as to whether a firm should undertake internal R&D (*Make)* or whether it should acquire external R&D (*Buy*) is crucial.

In order to verify the adoption propensity of these R&D activities, Table 2 shows the frequency with which firms adopted each innovation strategies. Our results show how innovation strategies differ between the three sectoral groups. Firms that operate in high-tech manufacturing industries are more likely to undertake R&D (37.6%), while a high percentage of these firms carry out both internal and external R&D (25.5%). However, the percentage of firms with internal R&D and both, internal and external, R&D falls in low-tech manufacturing industries and in the service industries.

Furthermore, firms that only buy external R&D are scarce (around 3%). This reflects the importance to a firm of earlier internal R&D activities so as to develop its absorptive capacity and to capture the returns of external R&D. In addition, internal R&D has a positive effect on output innovation measured as a firm's share of new products, both when it produces a moderate innovation –new to the firm- and when it produces substantial innovative output –new to the market. Furthermore, innovation intensity falls when firms do not carry out any internal R&D. However, the effect of R&D activities on labour productivity is less clear. In the manufacturing industries when a firm does not carry out R&D activities, it tends to register lower labour productivity levels, but among service industries this relation between R&D activities and productivity is more ambiguous[7].

However, the relationship between internal and external R&D is complex, because it is affected by both individual and sectoral dimensions. Before analyzing the extent of the impact of R&D sources on productivity, we focus on whether there is a significant difference in return between adopting a *Buy Only*, *Make Only* or a *Buy and Make* strategy. In order to determine this, we analyze the complementarities between internal and external R&D using the theory of supermodularity, a useful instrument (Milgrom and Roberts, 1990). We assume a firm can perform two activities, i.e., internal R&D, A_1, and external R&D, A_2. In relation with each activity a firm can adopt two binary decisions, i.e., $A_i=1$ when a firm performs the activity and $A_i=0$ otherwise. The function $\Pi(A_1, A_2)$ is supermodular and A_1 and A_2 are complementary only if,

$$\Pi(1,1) - \Pi(0,1) \geq \Pi(1,0) - \Pi(0,0)$$

In other words, the complementarity test measures the incremental effect on productivity when a firm adds an activity to another that is already being performed compared to the situation where a firm adopts an activity in isolation. Thus, supermodularity leads to a formalisation of synergies and system effects. Following Mohnen and Roller (2005) and Cassiman and Veugelers (2006), the complementary test was estimated. First, we

[7] The complementarities between practices can also be confirmed by applying a static test of adoption of technology choices. We test the null hypothesis that the unconditional correlations between each pair of choices are zero. In the annex, Table A.2 reports a significant and positive correlation between adoption of internal and external R&D.

regressed firm productivity on combinations of innovation activities (dummy variables that indicate whether the firm performed internal R&D: firms that have no R&D activities (*No Make and Buy*); firms that have only their own R&D activities (*Make Only*); firms that have only external R&D sources (*Buy Only*); and firms that combine their own R&D activities with external R&D sources (*Make and Buy*) depending on whether firms belong to high-tech manufacturing industries, low-tech manufacturing industries or knowledge intensive services. Then we applied a one-sided test of complementarity in order to test the incremental effect of adding an innovation activity.

Table 2
Internal and external R&D firm strategies

High-tech Manufacturing Industries	R&D Strategy	Product new to the firm	Product new to the market	Productivity level
Make and Buy	25.5%	14.5%	11.7%	251.9
Make Only	37.6%	15.6%	7.8%	198.3
Buy Only	3.2%	7.4%	3.5%	249.6
No Make and Buy	33.6%	5.7%	0.9%	165.4
Total firms: 1130	100.0%	11.7%	6.3%	202.6
Complementary test: *Make and Buy-MakeOnly>BuyOnly-NoMake&Buy*			F (1,1126)=0.69 p-value=0.202	
Low-tech Manufacturing Industries				
Make and Buy	11.4%	14.5%	5.2%	218.4
Make Only	23.4%	11.6%	7.3%	221.5
Buy Only	3.6%	8.6%	7.1%	235.8
No Make and Buy	61.4%	5.3%	1.0%	151.3
Total firms: 1443	100.0%	7.9%	3.2%	178.5
Complementary test: *Make and Buy-MakeOnly>BuyOnly-NoMake&Buy*			F (1,1439)=3.99 p-value =0.023	
Knowledge-Intensive Services				
Make and Buy	16.8%	14.4%	20.4%	126.0
Make Only	24.3%	13.9%	16.0%	222.0
Buy Only	2.7%	16.3%	0.26%	108.3
No Make and Buy	56.0%	3.5%	1.9%	171.0
Total firms: 694	100.0%	8.2%	8.4%	174.1
Complementary test: *Make and Buy-MakeOnly>BuyOnly-NoMake&Buy*			F (1,690)=0.02 p-value =0.450	

Note: Productivity level in thousands of euros.
Source: Catalan Innovation Survey

Table 2 shows the test of complementarity classified by sectors. Our results regarding the effects of the source of innovation on productivity show that there is a significant positive impact of carrying out internal and external R&D on productivity for low-tech manufacturers, while this positive relationship is not significant in high-tech manufacturing and service industries. This lack of significance may be due to the fact that low-tech industries rely on external resources, in particular for their process innovation in order to catch-up with the "leaders". This finding can also be related to firm size since larger firms may show a greater tendency to invest in internal R&D. As a consequence, the results of the complementarity tests can be explained by the higher reliance on sources within the firm.

4. Econometric methodology

In our case, the quantile regression procedure allows us to give a more complete picture of the underlying relationship between sources of innovation and productivity. Quantile methods may be preferable to the more usual regression methods for several reasons. First, the standard least-squares assumption of normally distributed errors does not hold for our data because innovation expenditure and innovation intensity present a skewed distribution. Second, while conventional regressions focus on the average firm, quantile regression can describe the complete conditional distribution of the dependent variable. And third, quantile regression is more efficient at treating outliers and heavy-tailed distributions.

The initial quantile regression method was suggested by Koenker and Bassett (1978) as an alternative to OLS when errors are not normally distributed. The central idea in quantile regression is to minimize the sum of absolute residuals by giving different weights to the quantiles being investigated. It is a powerful tool that, given a set of explanatory variables, characterizes the entire distribution of a dependent variable in greater detail than OLS methods (see a survey in Koenker and Hallock, 2001). The quantile regression method specifies the conditional quantile as a linear function of covariates. In our case we can write the θ^{th} quantile as,

$$y_i = x_i^{'}\beta_\theta + \varepsilon_{\theta i},$$

where y_i is the productivity level measured by sales per employee, x_i is a vector of independent variables, β_θ is an unknown vector of regression parameters associated with the θ^{th} quantile and $\varepsilon_{\theta i}$ is an unknown error term. The θ^{th} conditional quantile of y given x is,

$$Q_\theta(y_i \mid x_i) = x_i^{'}\beta_\theta$$

and denotes the quantile of y_i conditional on the regressor vector x_i. The only necessary assumption concerning $\varepsilon_{\theta i}$ is $Q_\theta(\varepsilon_{\theta i}/x_i) = 0$. The θ^{th} regression quantile, $0 < \theta < 1$, is the solution to the minimization of the sum of absolute deviation residuals,

$$\min_\beta \frac{1}{n}\left(\sum_{i:y_i \geq x_i^{'}\beta} \left| y_i - x_i^{'}\beta \right| \theta + \sum_{i:y < x_i^{'}\beta} \left| y_i - x_i^{'}\beta \right| (1-\theta) \right)$$

which is solved by linear programming methods. When θ is continuously increased from 0 to 1, we obtain the entire conditional distribution of y conditional on x (Buchinsky, 1998).

Since Koenker and Bassett's (1978) work, many applications have been described in a variety of fields: firm-size distribution (Machado and Mata, 2000), barriers to entry (Mata and Machado, 1996; Gorg, Strobl and Ruane, 2000; Arauzo and Segarra, 2005), innovation and firm growth (Coad and Rao, 2006, 2008; Marsili and Salter, 2005), R&D and patents (Nahm, 2001; Grasjo, 2005), wage differences (Mueller, 1998; Papapetrou, 2006) and productivity heterogeneity (Krüger, 2006).

Following the analytical frame described by Crépon et al. (1998) and their successive re-examinations (Mairesse and Mohnen 2004), here we explore the relationships between two main sources of innovation —internal and external R&D— and productivity in a sample of 3,267 firms. Their basic model (CDM model) consists of a system of three equations: a tobit model explaining R&D decisions, an equation linking innovation output to R&D and an equation linking labor productivity to innovation and R&D.

Here, we apply a reduced-form estimation of the CDM model in order to determine the direct impact of sources of innovation on productivity.[8] The R&D process impacts on innovation; however, the learning process can also have an indirect impact on productivity, without leading to an innovation output. Since we focus on the relationship between sources of innovation at different productivity levels, we apply the OLS and quantile methods to the reduced-form estimation of the CDM model. We are especially interested in observing the evolution in R&D elasticity across the entire conditional distribution of productivity. We estimated the following linear regression model,

$$y_i = \alpha + \beta_1 \, R\&Dinternal_i + \beta_2 \, R\&Dexternal_i + \beta_3 \, Size_i + \beta_4 \, MarketShare_i + \beta_5 \, Group_i + \beta_6 \, Investment_i + \beta_7 \, SectoralDummies_i + \mu_i$$

where for each individual firm 'i', y is productivity measured by sales per employee. This measure of productivity leads to catch up the appropriability capacity of firm production and, specifically, the capacity of R&D investment to capture the market value. Thus, we aim to capture the appropriability of the value chain of R&D activities. Recently, Roper et al.

[8] For Catalonia, Segarra (2009) applies a complete CDM model following a sequence that ranges from the factors that determine firms' R&D activities, to the effect that innovating firms have on productivity.

(2008) estimated the impact of innovation on the market value measured on labour productivity, sales growth and employment growth. However, here we adopt a direct approach to measure the direct effect of R&D activity on productivity.

R&Dinternal is the internal R&D expenditure per employee; *R&Dexternal* is the amount of external R&D services per employee; *Size* is the firm size measured in employees; *MarketShare* is the firm's market share measured by firm sales divided by its industry's sales, *Group* is a dummy that indicates whether the firm belongs to a group; *Investment* is the physical capital investment per employee; SectoralDummies are 2-digit industry dummies that control for fixed industry effects such as the effect that some sectors have a greater tendency to present higher productivity or different technological regimes; and μ is the standard error. The first two independent variables are the innovation sources related to internal and external R&D expenditures at firm-level and the rest are a group of control variables. Size, productivity, investment and R&D expenditures are expressed in logs.[9]

In the empirical analysis we consider only the direct R&D-productivity relationship, not the indirect effect related to innovation output –product and process innovation, patents, new products, etc-. Table 3 presents the OLS results and five conditional regression quantile results for θ = 0.10, 0.25, 0.50 (hence the median), 0.75 and 0.90. The quantile regression parameters are computed using bootstrapped standard errors (200 replications). In the bootstrap resampling procedure, the quantile regression parameters remain unchanged since only estimates of standard error and significance levels are affected. Quantile regression coefficients can be interpreted as the marginal change in y at the θth conditional quantile due to marginal change in a particular regressor, $\Delta Q_\theta (y_i / x_i) / \Delta x$.

5. Quantile regression results

Generally speaking, in OLS estimations, external and internal R&D have a positive effect on productivity in both manufacturing and service sectors. However, the role of external R&D services is ambiguous because the parameter is not significant. In addition, market structure, firms that belong to a group and investment in physical capital have a positive effect on productivity. Finally, in the OLS regression firm size is positively related

[9] The information provided by the CIS questionnaire regarding the expenditure of firms on various innovation sources is characterized by many observations that take a zero value for the three independent variables. In this case, when we take logarithms, log (0) is not defined, so we record these values as 10^{-7} so that the logarithm can be taken without having to make substantial changes to the data, which is almost the same as zero.

to productivity in manufacturing industries but plays the opposite role in service industries.

Table 3
Effects of innovation sources on productivity

	OLS	Quantile regression				
		10%	25%	50%	75%	90%
High-tech industries (1,130 obs.)						
Internal R&D	1.936 (0.005)*	3.374 (0.010)*	2.598 (0.007)*	1.686 (0.006)*	1.139 (0.006)	-0.028 (0.008)
External R&D	1.040 (0.006)	0.951 (0.014)	1.004 (0.008)	1.561 (0.007)**	1.820 (0.007)**	1.430 (0.010)
Firm size	8.452 (0.021)*	15.213 (0.040)*	9.717 (0.032)*	5.713 (0.034)	-3.057 (0.048)	-15.629 (0.046)*
Market share	3.208 (0.591)*	0.927 (1.646)	2.867 (2.387)	5.128 (3.933)	11.697 (4.928)**	18.863 (7.280)**
Group	30.345 (0.051)*	16.329 (0.086)	25.961 (0.062)*	28.994 (0.049)*	27.959 (0.061)*	38.654 (0.076)*
Investment	9.947 (0.014)*	7.923 (0.028)*	9.411 (0.017)*	8.547 (0.016)*	8.527 (0.018)*	9.432 (0.023)*
Sectoral dummies	yes	yes	yes	Yes	yes	yes
[Pseudo-]R^2	0.3279	0.2195	0.2108	0.1986	0.2050	0.2279
Low-tech industries (1,443 obs.)						
Internal R&D	2.983 (0.005)*	4.931 (0.010)*	2.829 (0.005)*	2.386 (0.006)*	2.083 (0.006)*	1.935 (0.008)**
External R&D	0.364 (0.009)	-2.275 (0.021)	0.417 (0.010)	1.196 (0.009)	1.225 (0.009)	0.640 (0.012)
Firm size	6.620 (0.021)*	11.558 (0.038)*	12.578 (0.026)*	5.259 (0.029)	-6.141 (0.042)	-34.658 (0.085)*
Market share	6.161 (0.927)*	1.693 (1.698)	3.282 (2.408)	8.644 (3.430)**	18.550 (5.289)*	51.951 (12.086)*
Group	26.254 (0.052)*	26.821 (0.110)**	24.144 (0.059)*	25.998 (0.049)*	20.818 (0.053)*	13.769 (0.071)
Investment	11.291 (0.013)*	12.860 (0.030)*	10.905 (0.017)*	10.369 (0.014)*	9.244 (0.016)*	6.355 (0.025)**
Sectoral dummies	yes	yes	Yes	yes	yes	yes
[Pseudo-]R^2	0.2837	0.1942	0.1815	0.1779	0.2040	0.2463
Knowledge-intensive services (694 obs.)						
Internal R&D	3.569 (0.009)*	4.352 (0.025)	5.272 (0.014)*	3.935 (0.009)*	3.205 (0.014)**	-0.158 (0.016)
External R&D	- 2.148 (0.012)	-0.654 (0.045)	-0.216 (0.018)	-1.166 (0.010)	-1.432 (0.020)	2.101 (0.024)
Firm size	-18.264 (0.024)*	-3.854 (0.046)	-12.872 (0.034)*	-19.531 (0.033)*	-24.621 (0.039)*	-40.707 (0.062)*
Market Share	4.851 (0.884)*	3.487 (3.049)	4.786 (1.943)**	4.582 (2.049)**	8.639 (4.314)**	23.793 (12.649)
Group	58.502 (0.075)*	28.277 (0.128)**	44.858 (0.095)*	64.882 (0.067)*	56.597 (0.096)*	64.933 (0.171)*
Investment	15.412 (0.020)*	15.195 (0.043)*	14.031 (0.023)*	14.571 (0.022)*	16.956 (0.029)*	14.222 (0.029)*
Sectoral dummies	yes	yes	yes	yes	yes	yes
[Pseudo-]R^2	0.4425	0.1841	0.2554	0.2654	0.2991	0.3497

*In quantile regression, bootstrapped standard errors in parentheses (200 replications). All marginal effects (dy/dx) are in percentage points. For the Group dummy variable the marginal effect is the discrete change from 0 to 1. Sectoral dummies in 2-digit industries. * significant at 1% and ** significant at 5%.*

However, the analysis that depends on the productivity distribution shows a different pattern. In particular, quantile regression results show that internal R&D plays an important role in high-tech firms with lower levels of productivity, but that this effect decreases as we move up to higher productivity levels. The patterns of external R&D by contrast are more erratic and show the opposite pattern, with the elasticity of external R&D increasing across the quantiles. If we compare the results obtained with OLS regression and the median (50%) quantile, we find that median quantile external R&D is positive and significant, which highlights that the external R&D plays an important role in firms in the intermediate levels of the productivity distribution. Thus, there appears to be a trade-off between the elasticity of internal and external R&D, because as we move up to the upper quantiles the effects of internal R&D are reduced while the effects of external R&D increase. This might be attributed in the main to the fact that firms first spend more on internal R&D to increase their absorptive capacity and only then they invest in external R&D activities (Veugelers, 1997).

According to the results from low-tech industries, all parameters are positive and statistically significant, except in the case of the external R&D variable. The effect of internal R&D on productivity is very marked, recording the highest marginal effect on productivity in the lowest quantile (4.9%). The importance of firm size and investment in physical capital are also very marked in the lower quantiles but fall as we move up to higher productivity levels. Conversely, the positive effect of market share increases when we move up to the upper quantiles of the distribution.

So far in our study, we are aware that there is a trade-off between internal and external R&D activity in manufacturing industries. However, differences also occur depending on the intensity of technology use within these industries. On the one hand, high-tech industries obtain a higher marginal return of external R&D than is obtained by low-tech industries; on the other hand, low-tech industries present a higher sensitivity to internal R&D activity than do high-tech industries. These results highlight the importance of external R&D in high-tech industries and internal R&D in low-tech industries.

As well as manufacturing industries, it is also interesting to analyse service industries, the profile of which has been changed by KIS sectors. However, KIS sectors are not a simple mirror of manufacturing industries and they have their own specificities. In the knowledge-intensive services, our OLS results show that the internal R&D effect is very important, while external R&D has a negative, but statistically non-significant, impact. In part, the higher impact of internal R&D may be due to the fact that service firms apply different internal R&D sources than manufacturing firms. According to Sirilli and Evangelista (1998), firms in the service industries rely on a wide variety of innovation sources. They point out that the impact of a wide range of innovation strategies becomes more important because firms usually use them simultaneously.

Firm size also presents a negative effect, suggesting that the smallest firms in the service sector are also often those that attain the highest levels of productivity. These results are in accordance with the fact that service industries have a lower medium efficient size, thus small firms will survive and obtain high productivity levels in spite of their size (Audretsch et al., 2004; Teruel, 2009). Our quantile results in the knowledge-intensive services show that the pattern of internal R&D is similar to that of the manufacturing industries. The marginal return of internal R&D on firm productivity is very high and statistically significant at lower productivity levels (10% and 25% quantiles) and decreases at higher conditional quantiles (75% and 90%). The quantile results confirm the fact that external R&D does not show a significant pattern in the productivity of service firms.

We are also now in a position to compare the rest of the variables that affect the distribution of productivity. The greatest impact is attributable to the fact of belonging to a group of firms. Thus, small firms in a group can receive financial and technical support that may improve their performance. Furthermore, we should stress the importance attached to investment in physical capital. The market share also has a considerable impact on productivity among the largest quantile, while the effects of firm size on productivity decrease as we move up the distribution.

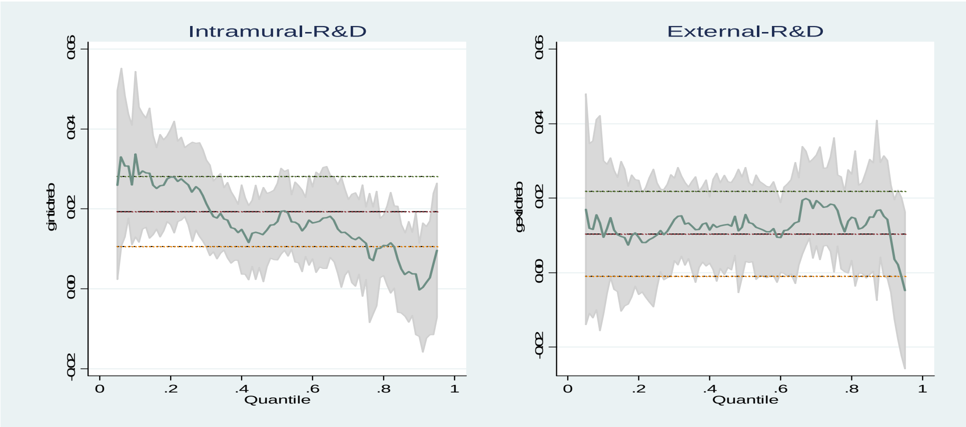
Finally, to show the evolution in the marginal effects of innovation sources on firm productivity in greater detail, Figure 1 presents six graphs that describe the dynamics of internal and external R&D elasticity when the level of productivity varies[10].

Figure 1 shows that the marginal effect patterns of internal R&D are very clear in both high- and low-tech manufacturing industries. In both instances, the marginal returns of internal R&D decreases as firm productivity rises. In addition, in manufacturing industries the marginal effect of external R&D is higher for intermediate levels of productivity.

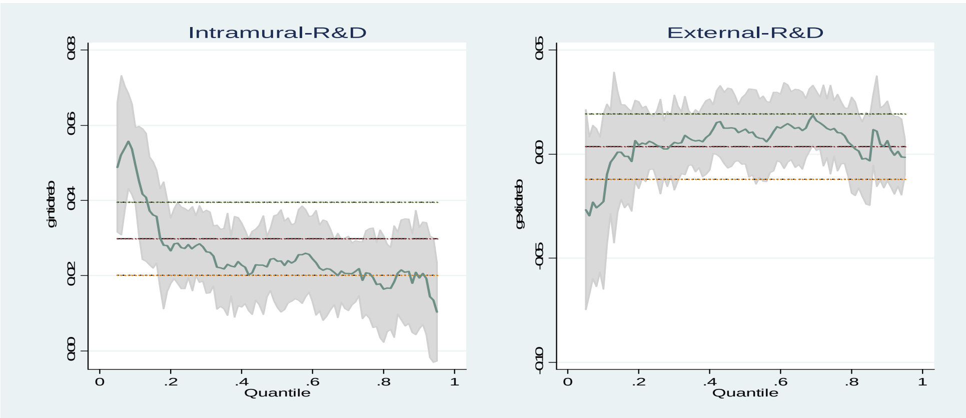
[10] Estimations were made using Stata and graphs were made using the 'GRQREG' Stata module (Azevedo, 2006).

Figure 1: Marginal effects of R&D on productivity over the conditional quantiles

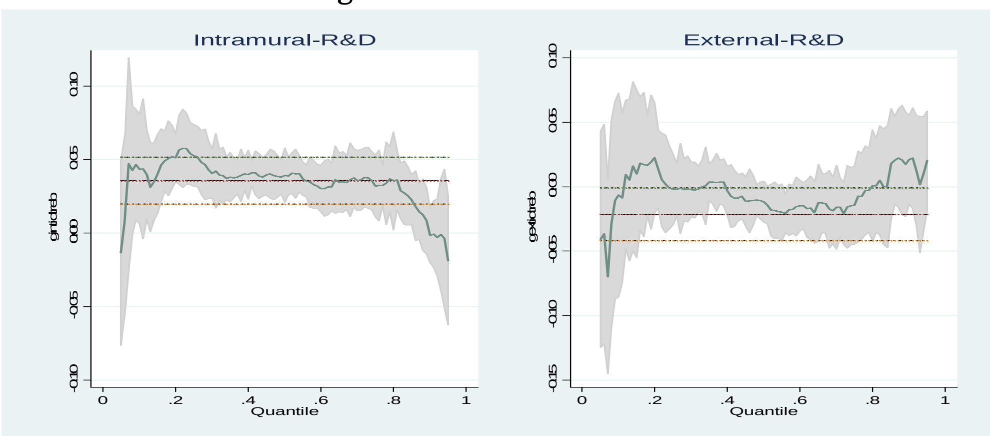
High-tech manufacturing industries



Low-tech manufacturing industries



Knowledge-intensive service industries



The figure presents internal R&D and external R&D coefficients for 90 different quantiles. The respective values are connected by a solid green line along with an estimated 95%-confidence band. The OLS value is a broken horizontal line.

Conversely, in service industries the marginal effects of R&D activities on productivity are more stable over all the quantiles, although a substitution effect does occur between internal R&D and external R&D as firm productivity levels increase. Finally, the shadow area stresses the greater heterogeneity shown by the coefficients between the extreme values of the productivity distribution. The response of the differences in the marginal returns between industries may rely on the sources of internal and external R&D. According with Tether (2004), Salter and Tether (2006) and Freel (2006) there appear differences on the R&D sources of manufacturing and service industries. Those authors point out that about the relative roles of "softer" and "harder" sources of knowledge and technology within services and manufacturing industries. In general terms, services will rely more on "soft" sources of knowledge for innovation (such as cooperation with customers and suppliers), while manufacturing industries will rely more on "hard" sources (such as cooperation with research centers). Thus, it is expectable that these differences are reflected in the marginal returns of R&D sources.

To summarize, a pattern of complementarity can be found between sources of innovation reflecting the level of productivity. At low levels of productivity, internal R&D has a sizeable impact on productivity, while at high levels of productivity external R&D becomes more important for manufacturing industries. These results confirm our hypothesis that firms with low productivity that invest in internal R&D obtain higher returns. As pointed out above, the literature provides two different explanations. First, laggards may follow their competitors'strategies (Veugelers and Cassiman, 1999). Second, laggards may adopt more risky R&D projects to overcome their disadvantage (Anderson and Cabral, 2007). Furthermore, in service industries internal R&D has a moderate positive impact, while external R&D has a negative impact with the exception of some of the lowest and highest quantiles.

6. Concluding remarks

In recent years the relationship between R&D, innovation and productivity has been examined rigorously and while many studies, primarily empirical analyses based on cross-sectional data, have reported a significant link between innovation and productivity (Griliches and Mairesse, 1998), others have failed to find an association. However, there is evidence that internal R&D has an absorptive capacity to capture external knowledge. However, we consider that firms have different capacity depending on their productivity.

The aim of this article is to analyse the relationship between sources of innovation and productivity based on the understanding that a complementary relationship must exist between internal and external R&D. Here we emphasize that high and low productive firms may have different marginal returns of internal and external R&D. We suggest that the absorptive capacity of internal and external R&D differs between high and low productive firms. Furthermore, we also contribute to the empirical literature distinguishing between manufacturing and service industries according with technological intensity.

Quantile regression techniques are able to show the significant impact of the sources of innovation on productivity. Thus, internal R&D has been shown to have an important effect on productivity. This effect is greater at the lower conditional quantiles, but diminishes as we move up to higher productivity levels. These results indicate that in firms with relatively low levels of productivity, internal R&D activities have a considerable positive effect on firm productivity.

Results regarding the relationship between external R&D and productivity are, however, less clear. The role of external R&D services differs between sectors and firms: in high-technology industries, external R&D services account for 30.4% of total innovation expenditure, in low-technology industries they account for just 6.3%, while in services they amount to 11.0%. The effect of external R&D on productivity also varies. In technologically intensive industries, the elasticity of external R&D rises as we move up to higher productivity levels. But in low-tech industries and the service sectors, external R&D has little effect on productivity and is statistically not significant for all conditional quantiles.

In addition, firm size increases firm productivity at nearly all quantiles in manufacturing industries. However, in service industries firm size has the opposite effect. The firm's market share, on the other hand, was always positive and mostly statistically significant and, in general, the effect on productivity was much larger at higher quantiles. Finally, our quantile regression results show that belonging to a group of firms has a significant effect on productivity, particularly in the upper quantiles.

The complementarity test suggests that R&D activities belong to a mutually enhancing system in low-tech manufacturers. Our test results show that productivity increases significantly more when a new R&D activity is added to a previous one than when there is no previous experience in another R&D activity.

Our results have important policy implications on R&D and innovation. It appears that policy makers should promote a firm's investment in internal R&D activity because of its direct and indirect effects: investment increases productivity at low levels and increases the impact of external R&D once a high productivity level has been achieved. Furthermore, managers are in a better position to make more efficient decisions if internal R&D prevails in the case of low productivity levels and external R&D prevails in the case of high productivity levels.

References

Anderson, A. and Cabral, L.M.B. (2007) Go for brake or play it safe? Dynamic competition with choice of variance. *The RAND Journal of Economics*, 38 (3), 593-609.

Arauzo, J. M. and Segarra, A. (2005) The determinants of etry are not idependent of start-up size: Some evidence from Spanish manufacturing. *Review of Industrial Organization*, 27 (2), 147-165.

Arbussà, A. and Coenders, G. (2007) Innovation activities, use of appropriation instruments and absorptive capacity: Evidence from Spanish firms. *Research Policy*, 36 (10), 1545-1558.

Arora, A. and Gambardella, A. (1994) The changing technology of technological change: general and abstract knowledge and the division of innovative labour. *Research Policy*, 23 (5), 523-532.

Arrow, K. J. (1962) Economic welfare and the allocation of resources for invention. In Nelson, R. (ed.) *The Rate and Direction of Inventive Activity*, Princeton: Princeton University Press, 609–625.

Audretsch, D. B., Klomp, L., Santarelli, E. and Thurik, A. R. (2004) Gibrat's Law: Are the services different?. *Review of Industrial Organization*, 24 (3), 301–324.

Azevedo, J.P. (2006) GRQREG: Stata module to graph the coefficients of a quantile regression. Statistical Software Components S437001, Boston College. http://econpapers.repec.org/software/bocbocode/s437001.htm

Baldwin, J. and Gu, W. (2006) Plant turnover and productivity growth in Canadian manufacturing. Industrial and Corporate Change, 15 (3), 417-465.

Bartelsman, E. J. and Doms, M. (2000). Understanding productivity: Lessons from longitudinal microdata. *Journal of Economic Literature*, 38 (3), 569-594.

Beneito, P. (2006) The innovative performance of in-house and contracted R&D in terms of patents and utility models. *Research Policy*, 35 (4), 502-517.

Bönte, W. (2003) R&D and Productivity: Internal vs. External R&D – Evidence from West German Manufacturing Industries. *Economics of Innovation and New Technology*, 12 (4), 343-360.

Bresnahan, T., Brynjolfsson, E. and Hitt, L. (2002) Information technology, workplace organization, and the demand for skilled labor: Firm-level evidence. *Quarterly Journal of Economics*, 117 (1), 339—376.

Buchinsky, M. (1998) Recent advances in quantile regression models: A practical guideline for empirical research. *Journal of Human Resources*, 33 (1), 88-126.

Cabral, L.M.B. (2003) R&D competition when firms choose variance. *Journal of Economics and Management Strategy*, 12 (1), 139–150.

Caroli, E. and Van Reenen, J. (2001) Skill-biased organizational change? Evidence from a panel of British and French establishments. *Quarterly Journal of Economics*, 116 (4), 1449-492.
Caselli, F. (1999) Technological revolutions. *American Economic Review*, 89 (1), 78-102.
Cassiman, B. and Veugelers, R. (2000) External technology sources: Embodied or disembodied technology acquisition. Economics Working Papers 444, Department of Economics and Business, Universitat Pompeu Fabra. Barcelona: UPF.
Cassiman, B. and Veugelers, R. (2006) In search of complementarity in innovation strategy: Internal R&D and external technology acquisition. *Management Science*, 52 (1), 68–82.
Coad, A. and Rao, R. (2006). Innovation and market value: a quantile regression analysis. Economics Bulletin, 5 (13), 1-10.
Coad, A. and Rao, R. (2008) Innovation and firm growth in high-tech sectors: A quantile regression approach. *Research Policy*, 37(4), 633-648.
Cohen, W. M. and Levinthal, D. A. (1989) Innovation and learning: Two faces of R&D. *Economic Journal*, 99 (397), 569-596.
Crépon, B., Duguet, E. and Mairesse, J. (1998) Research, innovation and productivity: An econometric analysis at the firm level. *Economics of Innovation and New Technology*, 7 (2), 115-158.
Dierickx, I. and Cool, K. (1989) Asset stock accumulation and the sustainability of competitive advantage. *Management Science*, 35 (12), 1504-1511.
Freel, M. (2006) Patterns of Technological Innovation in Knowledge-Intensive Business Services. *Industry and Innovation*, 13(3), 335-358.
Görg, H., Strobl, E. and Ruane, F. (2000) Determinants of firm start-up size: An application of quantile regression for Ireland. *Small Business Economics*, 14 (3), 211-222.
Grasjo, U. (2005). Accessibility to R&D and patent production. CESIS, Electronic Working Paper Series, No. 37, The Royal Institute of Technology.
Griffith, R., Redding, S. and van Reenen, J. (2003) R&D and absorptive capacity: Theory and empirical evidence. *Scandinavian Journal of Economics*, 105 (1), 99-108.
Griffith, R., Redding, S. and van Reenen, J. (2004) Mapping the two faces of R&D: Productivity growth in a panel of OECD industries. *Review of Economics and Statistics*, 86(4), 883-895.
Griliches, Z. (1995). R&D and Productivity: Econometric results and measurement issues. In Stoneman, P. (ed.) *Handbook of the Economics of Innovation and Technological Change*, MA: Blackwell Publishers.
Griliches, Z., Mairesse, J., 1998. Production functions: The search for identification. In Ström, S. (ed.) *Econometrics and Economic Theory in the 20th Century: The Ragnar Frisch Centennial Symposium*, Cambridge University Press, Cambridge, 169-203..
Hall, B. and Mairesse, J. (2006) Empirical studies of innovation in the knowledge-driven economy. *Economics of Innovation and New Technology*, 15(4/5), 289-299.
Haltiwanger, J., Lane, J. and Spletzer, J. (2007) Wages, productivity and the dynamic interaction of businesses and workers. *Labour Economics*, 14 (3), 575-602.
Kneller, R. and Stevens, P.A. (2006) Frontier technology and absorptive capacity: evidence from OECD Manufacturing Industries. *Oxford Bulletin of Economics and Statistics*, 68 (1), 1-21.

Koenker, R. and Bassett, G. (1978) Regression quantiles. *Econometrica*, 46 (1), 33-50.
Koenker, R. and Hallock, K.F. (2001) Quantile regression. *Journal of Economic Perspectives*, 15 (4), 143–156.
Krüger, J.K. (2006) Productivity dynamics beyond-the-mean in U.S. manufacturing industries: An application of quantile regression. *Empirical Economics*, 31 (1), 95-111.
Lokshin, B., Belderbos, R. and Carree, M. (2008) The productivity effects of internal and external R&D: Evidence from a dynamic panel data model. *Oxford Bulletin of Economics and Statistics*, 70 (3), 399-413.
Love, J.H. and Roper, S. (2002) Internal versus external R&D: A study of R&D choice with sample selection. *International Journal of the Economics of Business*, 9 (2), 239-255.
Machado, J.A.F. and Mata, J. (2000) Box-Cox quantile regression and the distribution of firm sizes. *Journal of Applied Econometrics*, 15 (4), 253-274
Mairesse, J. and Mohnen, P. (2004) The importance of R&D for innovation: A reassessment using French survey data. *The Journal of Technology Transfer*, 30 (1-2), 183-197.
Mansfield, E. (1986) Patents and innovation: An empirical study. *Management Science*, 32 (2), 173-181.
Marsili, O. and Salter, A. (2005) 'Inequality' of innovation: Skewed distributions and the returns to innovation in Dutch manufacturing. *Economics of Innovation and New Technology*, 14 (1-2), 83-102.
Mata, J. and Machado, J. (1996) Firm start-up size: A conditional quantile approach. *European Economic Review*, 40 (6), 1305-1323.
Miles, I. (2005) Innovation in services. In Fagerberg, J., Mowery, D., Nelson, R., (eds.) *The Oxford Handbook of Innovation*, Oxford: Oxford University Press.
Mohnen, P. and Röller, P. (2005) Complementarities in innovation policy. *European Economic Review*, 49 (6), 1431-1540.
Mohnen, P., Mairesse, J. and Dagenais, M. (2006) Innovativity: A comparison across seven European countries. *Economics of Innovation and New Technology*, 15 (4/5), 391-413.
Mueller, R. (1998) Public-private sector wage differentials in Canada: evidence from quantile regressions. *Economics Letters*, 60 (2), 229–35.
Nahm, J. (2001) Nonparametric quantile regression analysis of R&D-sales relationship for Korean firms. *Empirical Economics*, 26 (1), 259-270.
Papapetrou, E. (2006) The unequal distribution of the public-private sector wage gap in Greece: evidence from quantile regression. *Applied Economics Letters*, 13 (4), 205-210.
Roper, S., Du, J. and Love, J.H. (2008) Modelling the innovation value chain. *Research Policy*, 37 (6/7), 961-977.
Salter, A. and Tether, B.S. (2006). Innovation in Services: Through the Looking Glass of Innovation Studies, Background paper for Advanced Institute of Management (AIM) Research's Grand Challenge on Service Science.
Segarra, A. (2010) Innovation and productivity in manufacturing and service firms in Catalonia: a regional approach. *Economics of Innovation and New Technology*, forthcoming.
Segarra, A. and Arauzo, J.M. (2008) Sources of innovation and industry-university interaction: Evidence from Spanish firms. *Research Policy*, 37 (8), 1283-1295.
Segarra, A., Teruel, M., Arauzo, J.M., Iranzo, S. and Gombau, V. (2008) *Dinámica empresarial, creación de empleo y productividad en las manufacturas*

españolas. Ministry of Industry, Tourism and Trade (Spanish Government), Madrid.
Sirilli, G. and Evangelista, R. (1998) Technological innovation in services and manufacturing: results from Italian surveys. *Research Policy*, 27 (9), 881-899.
Stieglitz, N. and Heine, K. (2007) Innovations and the role of complementarities in a strategic theory of the firm. *Strategic Management Journal*, 28 (1), 1-15.
Teece, D.J. (1986) Profiting from technological innovation. *Research Policy*, 15(6), 285-305.
Tether, B. (2003) The sources and aims of innovation in services: variety between and within sectors. *Economics of Innovation and New Technology*, 12, 481–505.
Tether, B. (2004) Do Services Innovate (Differently)?. CRIC Discussion Paper 66, Manchester: University of Manchester.
Teruel, M. (2009) Gibrat's law and the learning process. *Small Business Economics*, forthcoming.
Veugelers, R. (1997) Internal R&D expenditures and external technology sourcing. *Research Policy*, 26 (3), 303-315.
Veugelers, R. and Cassiman, B. (1999) Make and buy in innovation strategies: evidence from Belgian manufacturing firms. *Research Policy*, 28 (1), 63-80.

Table A.1.- Productivity and Innovation expenditures	New firms	Incumbents firms	Small Size (less 100)	Medium and large size
Productivity (sales by workers)	90,147	155,858	135,089	200,572
Innovation expenditure by employees	35,882	5,590	7,076	4,506
R&D internal by employees	24,316	3,640	4,740	2,694
R&D external by employees	7,660	657	787	922
Size (workers)	32	172	34	492
Note: amounts in euros				

Table A.2.- Correlation between the internal and external R&D activity	internal R&D	external R&D
High-tech manufactures		
internal R&D	1.000	
external R&D	0,336*	1,000
Low-tech manufactures		
internal R&D	1.000	
external R&D	0,361*	1,000
KIS services		
internal R&D	1,000	
external R&D	0,449*	1,000
Note: * Significant at 1%.		

Table A.3.- Innovation expenditures by employees	Mean	First Decil	Mediam	Last Decil
High-tech manufacturing				
Innovation expenditure by employees	6,764	16,423	3,844	10,534
R&D internal by employees	4,559	7,631	3,034	6,878
R&D external by employees	1,346	8,589	197	2,370
New firms rate in 2002-2004)	1.70%	25.80%	0.70%	0.80%
Size (workers)	159.6	41.7	91.8	469.4
Low-tech manufacturing				
Innovation expenditure by employees	3,748	2,044	3,409	6,601
R&D internal by employees	1,470	758	996	3,955
R&D external by employees	173	133	188	269
New firms rate in 2002-2004)	1.75%	4.30%	1.76%	0.80%
Size (workers)	114.5	72.01	78.71	232.12
KIS services				
Innovation expenditure by employees	11,377	4,453	14,542	22,871
R&D internal by employees	9,083	3,468	11,135	21,675
R&D external by employees	1,381	794	2,485	428
New firms rate in 2002-2004)	4.97%	7.88%	2.27%	0.00%
Size (workers)	296.61	507.08	92.38	252.32
Note: amounts in euros				