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Innovation sources and productivity in Catalonian firms: a quantile regression analysis

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ABSTRACT

This paper explores the effects of two main sources of innovation — intramural and external R&D— on the productivity level in a sample of 3,267 Catalonian firms. The data set used is based on the official innovation survey of Catalonia which was a part of the Spanish sample of CIS4, covering the years 2002-2004. We compare empirical results by applying usual OLS and quantile regression techniques both in manufacturing and services industries. In quantile regression, results suggest different patterns at both innovation sources as we move across conditional quantiles. The elasticity of intramural R&D activities on productivity decreased when we move up the high productivity levels both in manufacturing and services sectors, while the effects of external R&D rise in high-technology industries but are more ambiguous in low-technology and knowledge-intensive services.

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

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I. Introduction

The effect of innovative activity on growth and productivity at firm level has received much attention in recent years. The increased availability of micro-level data from innovation surveys in the EU has led to a growing number of studies on the links between R&D, innovation and productivity. The analytical framework described by Crépon, Duguet and Mairesse (1998) makes it possible to establish a sequence that ranges from the factors that determine firms' R&D activities to innovation and the effect that it has on firm's productivity. Despite the considerable heterogeneity of firm innovation, the literature still mainly uses the regression methodology based on standard OLS. Because the distribution of innovation expenditures is highly skewed, the usual assumption of normally distributed error terms is not warranted. Few empirical analyses, however, use conditional regression techniques.

The aim of the present paper is twofold. First, we observe the effects of the two main innovation sources—internal and external R&D investment—on productivity in 3,267 Catalan firms in manufacturing and services industries. Despite the increasing weight of services in innovation activities and the overall economy, very few studies link innovation sources and productivity at firm level in both manufacturing and services industries (Miles, 2005). Second, we use quantile regression to observe the effects of intramural 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 the paper is organized as follows. Section II presents the data set and describes the variables used in the analysis. Section III provides the empirical results, and section IV the concluding remarks.

II. Data and summary statistics

The data used in this study was provided by a sample of Catalan firms that responded to the fourth version of the Community Innovation Survey (CIS-4) during the period 2002-2004. Our database contains the CIS questionnaires completed by 3,267 Catalan firms, of which 1,130 are in high-tech manufacturing industries, 1,443 in low-tech manufacturing industries and 694 in knowledge-intensive services (KIS). The industrial classification based on technology and knowledge intensity in manufacturing and services follows the OECD criteria.

The CIS survey provided exhaustive information about innovation expenditures. The questionnaire asked the 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: Intramural R&D; Acquisition of R&D; Acquisition of machinery, equipment and software; Acquisition of external knowledge; Training; All forms of Design; Marketing expenditures.

Intramural R&D projects are carried out by 1,503 firms and are 54.1% of the total innovation expenditure of the firms in the database. A total of 679 firms bought external R&D services with an expenditure of 21.7% of the total. Overall, the two main innovation sources related to R&D account for three out of every four euros that Catalan firms expend in their innovation projects. The remaining sources of innovation register more moderate amounts.

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				
Intramural 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 parenthesis
Source: Catalan Innovation Survey

Like other economies, in Catalonia R&D and innovation also differ across industries and firms. Our database shows that one per cent of the firms that made the largest investments in innovation concentrated 48.6% of the total and five per cent of the firms made 70.1% of the total investment. The skewed distribution of innovation expenditures at 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 actors have the necessary financial capacity to engage in innovation projects that 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.

III. Quantile regression results

In our case, the quantile regression procedure allows us to estimate a whole set of numbers which give a more complete picture of the underlying relationship between innovation sources and productivity. Quantile methods may be preferable to the usual regression methods for several reasons. First, the standard least-squares assumption of normally distributed errors does not hold for our date 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 Basset (1978) as an alternative to OLS when errors are not normally distributed. The central idea in quantile regression is to minimize the absolute residuals sum 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, a multiplicity of applications have been published in a variety of fields: firm-size distribution (Machado and Mata, 2000), barriers to entry (Mata and Machado, 1996; Gorg, Strobl and Roane, 2000; Arauzo and Segarra, 2005), innovation and firm growth (Coad and Rao, 2006a, 2006b; Marsilli 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, Duguet and Mairesse (1998) and their succesive reexaminations (Mairesse and Mohen 2004) here we explore the relationships between two main sources of innovation — intramural and external R&D— and productivity in a sample of 3,267 firms. Their basic 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. We applied OLS and quantile method in the third equation. We are specially interested in observing the evolution of R&D elasticity across the entire conditional distribution of productivity. We estimated the following linear regression model,

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

where for each individual firm 'i', y is productivity measured by sales per employee; *R&Dinternal* is the in-house 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 company belongs to a group; *Investment* is the physical capital investment per employee and μ is the standard error. The first two independent variables are the innovation sources related intramural 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, and all estimations are also controlled by 2-digit industry dummies.[1]

In the empirical analysis we consider only the direct R&D-productivity relationship, not the indirect effect related to the innovation output – product and process innovation, patents, new products, etc. Table 2 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, $\Delta Q_\theta (y_i / x_i) / \Delta x$.

In OLS estimations, in-house R&D has a positive effect on productivity in manufacturing and services sectors, but external R&D services have an ambiguous role with parameters that are not significant. In addition, market structure, firm belonging to a group and investment in physical capital has a positive effect on productivity. Finally, in OLS regression firm size is directly related to productivity in manufacturing industries and plays the opposite role in services industries.

Table 2
Effects of innovation sources on productivity

	OLS	**Quantile regression**				
		10%	**25%**	**50%**	**75%**	**90%**
High-tech industries (1,130 obs.)						
Intramural 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)*
Sectorial dummies	yes	yes	yes	yes	yes	yes
[Pseudo-]R^2	0.3279	0.2195	0.2108	0.1986	0.2050	0.2279

[1] The information provided by the CIS questionnaire on the expenditure of firms on various innovation sources is characterized by many observations with 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 changing the substance of the data, which is almost the same as zero.

Low-tech industries (1,443 obs.)						
Intramural 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)**
Sectorial 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.)						
Intramural 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)*
Sectorial 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 percentatge points. For the *Group* dummy variable the marginal effect is the discrete change from 0 to 1. Sectorial dummies in 2-digit industries. * significant at 1% and ** significant at 5%.

Quantile regression results show that intramural R&D expenditure has an important role in high-tech firms with lower levels of productivity, while the elasticity of internal R&D decreases as we move up the high productivity levels. The patterns of external R&D are more erratic and show the opposite pattern. The elasticity of external R&D increases across the quantiles. If we compare median (50%) quantile results with OLS results, we find that median quantile external R&D expenditures are positive and significant, which highlights that the acquisition of external R&D plays an important role in firms in the intermediate levels of the productivity distribution. The trade-off between in-house R&D and external R&D as we move up to the medium and upper quantiles shows that firms first spend more on internal R&D to increase their absorptive capacity and then invest in external R&D activities (Veugelers, 1997).

In low-tech industries all parameters are positive and statistically significant, except in the external R&D variable. The effect of internal R&D

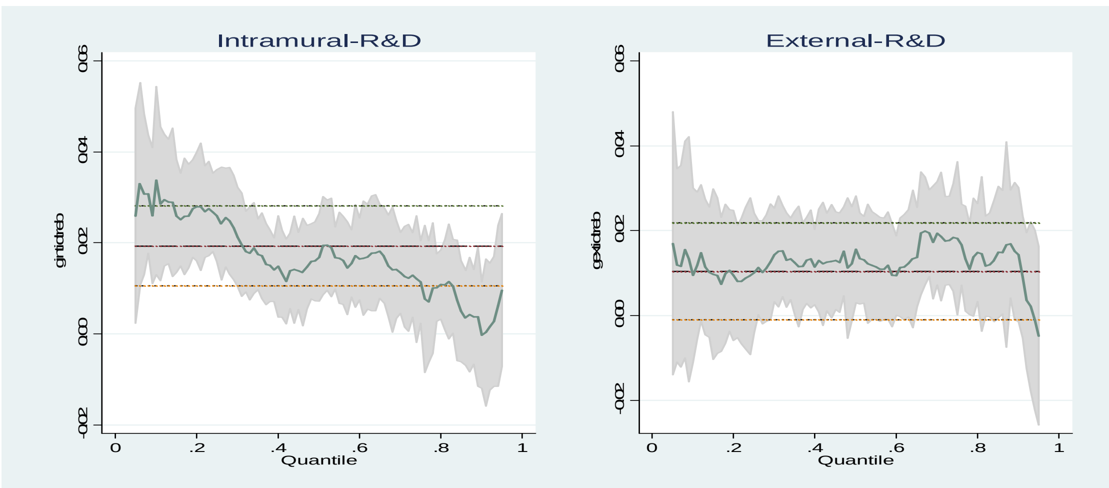
on productivity is very important and reaches the marginal effect on productivity (2.9%). The role of firm size and investment in physical capital are very important in the lower quantiles but decreases when we move up to high productivity levels. The positive effect of market share increases when we move to the upper quantiles.

In knowledge-intensive services, OLS results show that the in-house R&D effect is very important but external R&D is not statistically significant. Firm size presents a negative effect. In this respect, empirical results suggest that the smallest service firms are often the most dynamic in R&D and innovation activities and are also often those that attain the highest levels of productivity. Our quantile results in services show that the pattern of internal R&D is similar to that of manufacturing industries. The elasticity 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%).

Finally, to show the evolution of the marginal effect of innovation sources on firm productivity in greater detail, figure 1 presents six graphs that describe the dynamics of intramural and external R&D elasticity when the level of productivity varies.[2]

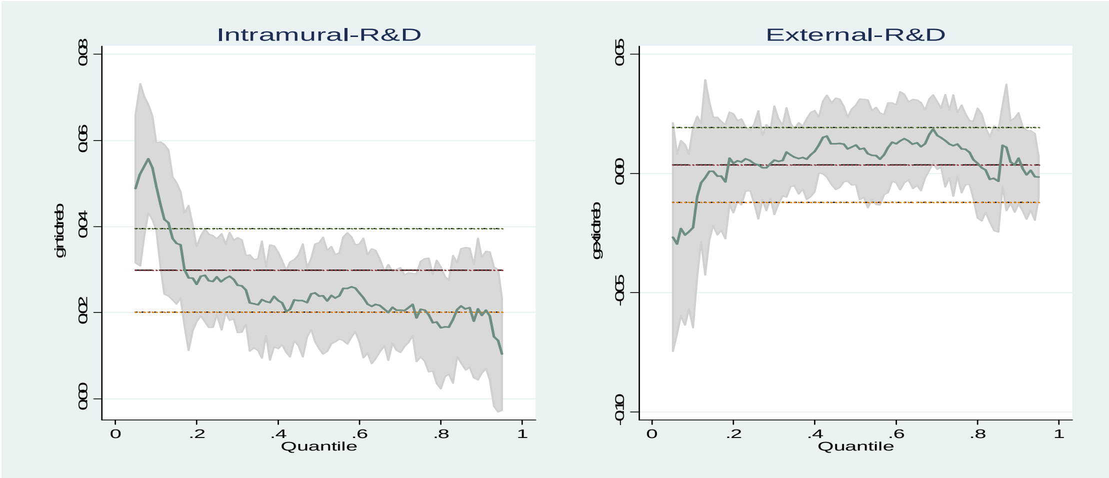
Figure 1: Marginal effects of R&D on productivity over the conditional quantiles

High-tech manufacturing industries

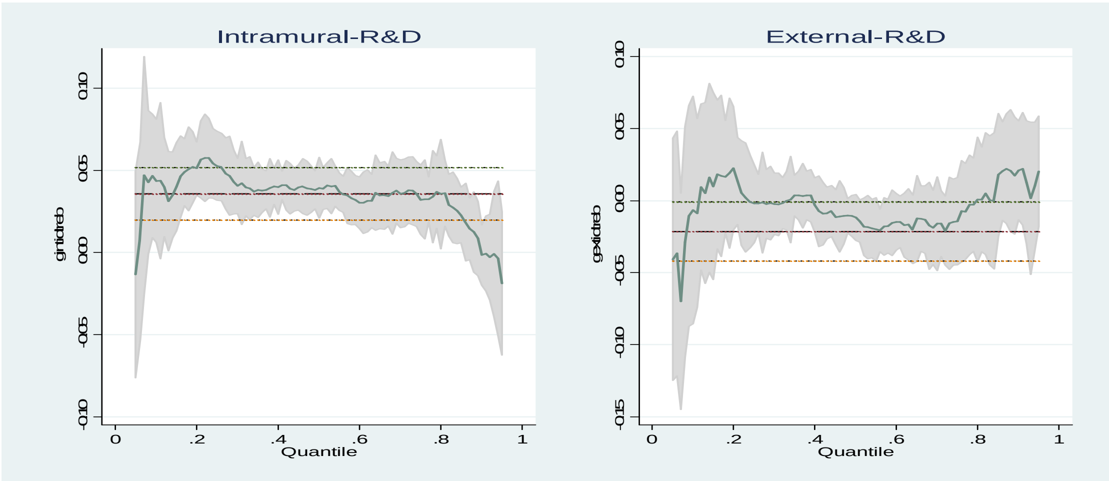


[2] Estimations were made using Stata and graphs were made using the 'grqreg' Stata module (Azevedo, 2006)

Low-tech manufacturing industries



Services industries



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

The marginal effect patterns of intramural R&D expenditures are very clear in high-tech and low-tech manufacturing industries. In both cases, the elasticity of intramural R&D expenditures decreases when firm productivity rises. In addition, in manufacturing industries the marginal effect of external R&D is higher for intermediate levels of productivity. In services industries, the patterns of marginal effect on productivity-related R&D activities are more stable over all the quantiles, although it should be pointed out that there is a substitution effect between intramural R&D and external R&D when the firm productivity levels increase.

IV. Concluding remarks

In recent years the relationship between R&D, innovation and productivity has been widely examined. Many studies have found a significant link between innovation and productivity (Griliches and Mairesse, 1998), but other studies have not. In general, empirical studies based on cross-sectional data are more likely to find a significant link between innovation and productivity.

When quantile regression techniques are used, the results are more significant. Internal R&D has an important effect on productivity. This effect is greatest at the lower conditional quantiles, but decreases as we move up to the high productivity level. These results indicate that in firms with relatively low levels of productivity, intramural R&D activities have a considerable positive effect on firm productivity.

Results on the external R&D and productivity relationship are less clear. The role of external R&D services differs between sectors and firms: in high-technology industries, external R&D services are 30.4 per cent of the total innovation expenditures, in low-technology industries they are only 6.3 per cent, and in services they are11.0 per cent. The effect of external R&D on productivity also presents different patterns. In high technology industries, the elasticity of external R&D rises when we move up to higher productivity levels. But in low technology industries and services sectors, external R&D has little effect on productivity and is statistically not significant, for all conditional quantiles.

In addition, we found differences in size between manufacturing and service firms. Firm size increased the firm's productivity at practically all the quantiles in manufacturing industries. However, in service industries we found that firm size had the opposite effect. The parameter of the firm's market share was always positive and mostly statistically significant and, in general, effect on productivity was much larger at higher quantiles. Finally, quantile regression results found that belonging to a group of companies has a significant effect on productivity, particularly in the upper quantiles.

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