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INNOVATION, R&D SPILLOVERS AND PRODUCTIVITY: THE ROLE OF KNOWLEDGE-INTENSIVE SERVICES

Agustí Segarra-Blasco

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INNOVATION, R&D SPILLOVERS AND PRODUCTIVITY: THE ROLE OF KNOWLEDGE-INTENSIVE SERVICES[*]

Agustí Segarra-Blasco[†]

Abstract:

This paper analyses the performance of companies' R&D and innovation and the effects of intra- and inter-industry R&D spillover on firms' productivity in Catalonia. The paper deals simultaneously with the performance of manufacturing and service firms, with the aim of highlighting the growing role of knowledge-intensive services in promoting innovation and productivity gains. We find that intra-industry R&D spillovers have an important effect on the productivity level of manufacturing firms, and the inter-industrial R&D spillovers related to computer and software services also play an important role, especially in high-tech manufacturing industries. The main conclusion is that the traditional classification of manufactured goods and services no longer makes sense in the 'knowledge economy' and in Catalonia the regional policy makers will have to design policies that favour inter-industrial R&D flows, especially from high-tech services.

Keywords: Innovation, R&D spillovers, KIS services, Productivity.

JEL classification: 140, 310, L100

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[†] Contact: Agustí Segarra-Blasco: agusti.segarra@urv.cat , Industry and Territory Research Group & Rovira i Virgili University, Department of Economics – Av. Universitat, 1 (43204 Reus – Spain)

1. Introduction

If innovation is the solution for promoting productivity growth and competitiveness in European regions such as Catalonia, what is the problem? In the so-called Lisbon Agenda, in 2000 the countries of Europe made a commitment to develop the policies needed to allow the European economy to reach high levels of social cohesion and to provide the basis for an economy in which knowledge will be the driving force of economic growth. The route map left no doubt as to its interpretation and the commitments were shared by all. After some years the registered balance offered poor results (Kok, 2005). The EU is far from the expected scenario; the solution is quite clear, so what has happened during these years? The promotion of innovation as an instrument of business change and adaptation in an increasingly open world environment is without a doubt an elegant commitment. However, Innovation Policy in Europe needs to be accompanied by a reform of the labour market, the creation of a single European market and a gradual reduction in the trade barriers and the business initiative that persists in the member countries.

A good level at which to design a suitable innovation policy is that of regional government. Indeed, the innovation process depend both the individual firms' characteristics than the industry specific, but location and regional proximity play a significant role in the promotion of self-organized innovation networks, the improvement of regional knowledge capacity and the generation knowledge spillovers. In recent years the regionalisation of Innovation Policy can count on noteworthy experiences in the EU. The interest shown by regional governments in designing their own innovation policies can be justified by the considerable importance of innovation in the economic transformation and stimulation of regional development (Fritsch and Stephan, 2005).

Catalonia was chosen for various reasons, among which we have to highlight the extreme dynamism of Catalan firms in R&D compared to the rest of the Spanish regions, the existence of an urban system dominated by the Barcelona metropolitan area, but with a network of small and medium-size towns with great economic and social vitality, and finally, the region's industrial tradition based on manufacturing industries of medium and low technological intensity. In this region, the new knowledge-intensive services have to play an important role in facilitating the spread of knowledge and an active role in innovation as a primary instrument of competition (Baumol, 2002).

As we all know, innovation is a complex process characterised by a large element of change and varied sources. Usually R&D expenditures play an important role in the innovation process, but intramural R&D is not the only source of innovation. This paper deals with the link between productivity and innovation and pays special attention to the different patterns of manufacturing and service firms in R&D and innovation performance. In addition, in a sample of 3,247 Catalan firms we analyse the impact of R&D spillovers generated between firms in the same sector –intrasectorial spillovers- and those that result from the cross fertilization between firms in different sectors –intersectorial spillovers. On this point we analysed how the R&D spillovers generated by high-tech services affected the productivity level of manufacturing firms, especially ‘Computer and related activities’ and ‘Research and development services’.

The analysis of the factors that determine why in a particular region some firms decide to invest in R&D or carry out innovations, while others resist doing so, becomes very interesting from the academic point of view and also from the perspective of the policy maker. Moreover, it is essential to dilute the barrier that separates manufactured goods from services. In the current ‘knowledge economy’ this traditional division becomes meaningless for various reasons. Firstly because of the growing interdependence between manufactured goods and services, due to the intense outsourcing undertaken by manufacturing firms, and the growing specialisation of services in knowledge-intensive activities. The second reason is that the link between R&D, innovation and economic growth takes place through market operations, but is also due to the knowledge overflow effect generated between firms that make up the industrial-mix of a specific region. Thirdly, the wide disparity between European regions in R&D and innovative activities highlights the need to study the generation of knowledge spillovers in the heart of a region, with the aim of determining the nature of the barriers to innovation that limit the number of firms that use technology and the innovation process as the driving force behind their competitiveness. This consideration is particularly important for regions such as Catalonia, which in recent years has registered an intense process of opening up to the outside, accompanied by a considerable erosion of its comparative advantages resulting in a continuous deterioration of its trade balances with the rest of the world.

The increased availability of micro-level data in the EU in recent years, especially with the so-called Community Innovation Survey (CIS) since 1990, has led to a growing number of studies on the links between R&D, innovation and productivity at firm level. A survey carried out on business innovation in many European countries has allowed light to be shed on the “black box” that represents the innovation process undertaken by firms. Also, access to a large amount of information about the innovation process performed by firms and the output of innovation activities has resulted in a new analytical perspective.

In recents years an intense empirical debate has taken place about the nature and magnitude of R&D spillovers (see Griliches, 1995 and Geroski, 1995). The overall appraisal found that technological externalities are widespread both inter- and intra-industry, although their magnitude varies considerably across industries. Today there is a vast amount of literature on the impact of technological activities and innovation processes on productivity, including important recent empirical estimations using firm level data.

Firstly, for eighteen years the empirical literature has focused on input-oriented innovation indicators in analysing the impact of innovation on firm's productivity. In this research the production-function approach predominated, including R&D measures as an additional input factor following the proposal made in the seminal Griliches work (1979) on the effects of R&D in the knowledge production function. Since then, the empirical literature has used different measures of innovative effort. Various academics introduced R&D expenditure in the knowledge production function into the earliest research on the effects of R&D on productivity, with the aim of calculating the output elasticity of R&D (Mansfield, 1965; Griliches, 1973). A second group of studies used a simple patent count as a measure of innovative output (see survey in Griliches, 1990). Later, different researchers noted that a simple patent count is not an accurate measure of innovative activity and attempted to incorporate the quality rather than the quantity of innovative output using the number of citations received by a patent (Pakes, 1986; Jaffe and Trajtenberg, 2005; Hall, Jaffe and Trajtenberg, 2000, Gayle, 2001). Despite the significant advances in the empirical methodologies and databases at a firm level, the input-oriented innovation indicator dealt only partially with the complex process entailed in business innovation.

Secondly, during recent years the access to data sources designed specifically for empirical research into the innovation process at firm level has opened up a wide range of possibilities to deal with the subject from a new dimension. Since the early nineties, two main initiatives undertaken by international bodies have initiated projects that will have a favourable bearing on later research. On the one hand, a collective project under the auspices of the OECD on the nature and measurement of innovation activities, carried out by statisticians, resulted in the so-called *Oslo Manual* (1992). Subsequent versions of the *Oslo Manual* (1996, 2005) provide new views of the innovation process in firms. In particular, the most recent version of the *Oslo Manual*, together with product and process innovation, notes the role of organizational and marketing innovation. On the other hand, following the guidelines set out in the *Oslo Manual*, a number of countries have designed a common core questionnaire on firm's innovation activities. Sine 1990, many European countries have launched different versions of the Community Innovation Survey. Up to now there are four editions of the CIS: CIS-1 covering the period

1990-1992, CIS-2 covering the period 1994-1996, CIS-3 covering the period 1998-2000, and CIS-4 covering the period 2002-2004. In European countries the CIS facilitates access to a range of information related to the innovation behaviour of European firms.

Access to this information permits a more reliable study of the factors that determine innovation in manufactured goods and services, as well as the effects of R&D and innovation on productivity. In European countries the information provided by innovation surveys has meant a major quantitative and qualitative improvement. Based on a common questionnaire design, the comparative studies and the application of econometric studies have led to significant advances in empirical research. Moreover, as the questionnaire makes an in-depth study of the internal factors of the firm that carries out an innovation and the effect of the innovation on its market position, since the nineties the focus of empirical research has changed in favour of output-oriented innovation indicators. The economic explanation for this new perspective interpreted innovation as a dynamic process in which innovator firms cooperate and learn with other firms and public institutions.

In this second wave of empirical literature the study of a particular country predominates (see survey in Smith, 2005) or the comparison between different countries (Mohnen, Mairesse, Dagenais, 2006, Peters, 2005) usually in manufacturing industries. However, despite the prominence of services in the European economies, the studies that analyse the effect of innovation on productivity in the services are scarce (Cainelli, Evangelista and Savona, 2006; Tether, 2002; Lööf, 2004). However, service innovation is a subject of growing interest for academics and policy makers (Miles, 2005).

Therefore, in this paper we propose to study innovative behaviour in manufacturing and service firms in a specific geographical area. We have paid particular attention to three topics: how firm size affects its propensity to innovate, the role of internal and external R&D inputs on the propensity to innovate, and how intra- and inter-industry R&D spillovers affect firms' productivity.

The paper is organised as follows: The second section describes the growing strategic role of knowledge-intensive services in the spreading of knowledge and the carrying out of innovations. The rest is structured into three steps. In first step we applied a selection equation to analyse the determining factors that led the firm to carry out internal R&D. In the second step we analysed the effect of different inputs on firm's decision to innovate. In a third step we applied a truncated method for estimating the impact of a firm's individual characteristics and R&D

spillovers on productivity. Finally, the paper concludes with the main results obtained and the implication of these results for competition policy.

2. Innovation and productivity: What is the role of services?

The factors that determine innovation process are not strictly individual. The interactions between the firms and agents that make up the regional innovation system (universities, research and transfer centres, firms carrying out R&D activities, etc.) generate external economies of knowledge that benefit the firms. Most research on the geographic scope of knowledge spillovers suggests that they are local or regional. The Catalan innovation system, for example, can be seen as a hierarchical layering of a series of regional innovation systems, starting with a central nucleus formed by the metropolitan area of Barcelona. It could be argued, therefore, that the Catalan innovation system consists of the Catalan system of science and technology on the one hand (including universities, public research centres and R&D departments), and innovating firms located in Catalonia, on the other. Depending on the field in which the learning occurs, we can differentiate between learning that takes place in firms (‘organizational learning’), learning carried out by employees (‘individual learning’) and learning that takes place as a result of interaction between the agents who make up the regional innovation system (‘systemic learning’).

In general, the main body of studies deals with innovation in manufactured goods and rarely includes services. The aim of this paper is to determine the interaction between manufacturing sectors and services. Usually, services are interpreted as a labour-intensive activity, less productive than the manufactured goods. Baumol (1967) developed a growth model that explains the expansion of service employment in terms of a productivity differential. In Baumol’s model the share of service sector employment is larger in high-income countries and grows with rising income. The so-called ‘cost-disease’ hypothesis relies on the assumption that the share of goods and services in real output is constant over time. In summary, the expansion of employment in services may be the result of three sources: a shift in the structure of final demand from goods to services, changes in the inter-industry division of labour favouring the rise of specialized service activities, and inter-industry productivity differentials (Schettkat and Yocarini, 2003).

However, during recent decades services have undergone a profound transformation, particularly in some aspects: in the growing importance of knowledge-intensive services (KIS), such as logistical activities, telecommunications, financial intermediation, information technology and business activities; the changing structure of employment, with an increasing presence of qualified personnel – engineers, economists, analysts, lawyers – and of the knowledge content; increasing relations with other sectors through outsourcing from manufacturing to services; and, finally, the growing importance of the external trade in knowledge-intensive services by means of offshoring of certain activities to other countries. For this reason we have to interpret the services as a varied range of activities that differ in the qualification of the workers, in the use of knowledge as a key factor in competitiveness, and the development of innovations.

The huge growth in new information and communication technologies places knowledge-intensive services in the position of a key strategic element for the spread of technology and the growth of productivity. However, studies carried out to date have found little evidence of the positive effect of information and communication technologies (ICTs) on productivity. Several research projects found that ICT has not influenced productivity, while some find a negative effect on productivity. The impact of ICTs on productivity is not easy to measure, and probably requires time to lead to productivity enhancement.

In the emerging 'knowledge economy', services not only comprise a large part of the economy in developed countries, but also represent an important engine for promoting innovations and economic growth. As is well known, innovation is not a linear process that begins with basic research, instead it passes through applied research and technological development, and materialises in the internal company framework, generally of manufacturing firms. It is an interactive process, which is much more complex where different agents are involved and where the ability to create new combinations from existing elements is often more important than the creation of new knowledge.

In the 21st century, services appear as major users of technology, not the least ICTs, and they often use these in creative rather than standard ways, and their need for new functionality is a major stimulus to innovation by manufacturing firms (Howells and Tether, 2004). On other hand, in the 'knowledge economy' the relationship between knowledge and economic growth is not a linear process, given that knowledge changes economic activity and economic activity changes knowledge, in a constant round of change (Howells, 2005). In this respect, the service sector, especially KIS, has a dominant role in the spread of knowledge and the adoption of innovations (Hempell, 2005; Becchetti and Adriani, 2005). Many services employ a high volume of low-qualified workers, and in general these activities registered only sporadic increases in productivity, as Baumol, among other academics, indicated in his study (1967). However, during the last few decades an increasing number of activities related to ICTs have appeared – financial services, logistics, business and knowledge management. Making an in-depth study of the industrial firms and service companies in Catalonia will also help to understand the strategic role of knowledge-intensive services in regional innovation policies.

3. The database and some descriptive statistics

The data set used is based on the 2004 official Catalan Innovation Survey, which was part of the Spanish sample of Community Innovation Surveys (CIS4). In order to analyse the innovation behaviour of Catalan firms we have a data source at company level carried out by the INE in the Technological Innovation Survey. This database contains much information about the strategies and performance of business innovation during the 2002 and 2004 period. The Spanish CIS-4 covered private sector firms with at least 10 employees. This survey asked firms which sources they used in their innovation process. The innovation sources include cooperation agreements with other firms and public institutions, internal R&D, barriers to innovation, public funds, and a large amount of quantitative and qualitative data on the firms' innovation behaviour.

Our database includes the CIS questionnaires completed by 3,267 Catalan firms.
It includes 2,573 firms in the manufacturing industries –codes 15 to 36 SIC, except sector 23-, and 694 firms in the knowledge-intensive services (KIS) –codes 64 to 67 and 72 to 74. Bearing in mind our interest in studying the determining factors of R&D and innovation activities and the effect of R&D spillovers in the manufacturing and services industries, we have excluded from our database the energy sectors, recycling, trade, catering, education, health and cultural activities.

The industrial classification based on technology and knowledge intensity in manufacturing and services follows the OECD criteria (see Annex 1). In a first step, the OECD defined technology intensity in manufacturing sectors on the basis of the ratio of R&D expenditure to added value. Later, this method was expanded to take account of the technology embodied in intermediate and capital goods. This new measure could also be applied to service industries, which tend to be technology users rather than technology producers. New classification provides four groups according to their technology intensity –high, medium-high, medium-low and low- in manufacturing sectors and a range group of knowledge-intensity services (OECD, 2006). However, in services we only considered five sectors: high-tech services (sectors 64, 72 and 73), financial intermediary activities (sectors 65, 66 and 67) and other business activities (sector 74). Finally, in order to facilitate the presentation we grouped these sectors into three categories: high-tech manufacturing, low-tech-manufacturing, and services.

As we can see in Table 1, 39.6 per cent of the firms on our database undertake permanent R&D activities. A company is considered as carrying out permanent R&D activities when it responds in the affirmative to the following question in the survey: "*Does your company undertake continuous R&D?*" Likewise, 35.3 per cent of the firms are innovative. A company is considered innovative if it undertook product or process innovation and, at the same time, internal R&D during the period 2002-2004. We can see that the rate at which firms carry out permanent R&D activities or systematically innovate varies according to the technological level of the industry. In the high-tech manufacturing firms, 62.2 per cent had permanent R&D programmes, whereas the same was true for only 28.6 per cent of low-tech manufacturing firms.

Table 1
Sample Catalan innovation survey, CIS-4

	R&D permanent firm		**Innovative firm**		**Total**
	Number	**%**	**Number**	**%**	**Number**
Total sample	1,295	(39.6)	1,156	(35.8)	3,267
Manufacturing industries	1,022	(39.7)	933	(36.3)	2,573
High technology sectors	608	(53.8)	559	(49.7)	1,130
High tech	183	(62.2)	162	(55.1)	294
Medium-high tech	425	(50.8)	397	(47.4)	836
Low technology sectors	414	(28.7)	374	(25.9)	1,443
Medium-low tech	147	(28.8)	137	(26.8)	510
Low tech	267	(28.6)	237	(25.4)	933
Knowledge-intensive services	273	(39.3)	223	(32.1)	694

Note: percentage innovative firms or non-innovative firms in bratches
Source: Catalan Innovation Survey

An initial view of the descriptive data offers a heterogeneous panorama of the frequency with which Catalan firms undertake R&D and innovation. This situation is emphasised if we go down to the sectorial level, as we can see in Table A-2 in the appendix. During 2004 the intramural R&D activities in our sample companies were valued at 1,593 million euros and innovative activities at 2,897 million euros. However, investment in R&D and the bulk of innovation expenditure are concentrated in a small number of industries. The Research and Development services firms made 23.2 per cent of the investment, pharmaceutical industry firms were responsible for 21.8 per cent, chemical industry firms 7.1 per cent, IT firms 6.9 per cent, and the vehicle manufacturing industry 5.7 per cent. Thus, five industries were responsible for 64.7 per cent of R&D investment and 68.27 per cent of innovation-related expenditure in Catalonia.

A total of 8,407 research workers were employed by Catalan firms in R&D programmes. If we take into account that the total number of employees was 527,511, we can see that only 1.59 per cent of staff were involved in R&D. This is without doubt a very low percentage, even more so if we take into account the fact that the majority of research staff were concentrated in two sectors: research and development services and the pharmaceutical industry.

In Catalonia, medium-tech manufacturing industries such as the automobile or chemical are very active in the fields of R&D and innovation. These results tally with those obtained by Leydesdorff *et al* (2006) for Dutch companies, where medium-tech manufacturing sectors make a large contribution to the knowledge base of the economy. On the other hand, the lack of vitality of Catalan low-tech industry firms is worrying. There can be no doubt that Catalonia's technological challenge lies in creating incentives to encourage firms that operate in these sectors to take a much more active role in making innovation a driving force in their competitiveness.

Moreover, innovation and R&D patterns differ between the manufacturing and service sectors (see appendix Table A-2). In high-technology manufacturers, internal R&D plays an important role and firms invest more in innovation. On the other hand, R&D intensity and innovation inputs in low-technology sectors show very low levels. In service industries R&D is at a level similar to that of the industrial manufactured goods group, whereas investment in innovation exceeds the average for manufactured goods. This initial look at the data indicates that the patterns of behaviour in relation to intramural R&D and innovation differ notably between manufactured goods and services. In the former, internal R&D investment represents the main source of innovation activity, while in services the remaining sources of innovation reach noteworthy levels despite low expenditure on R&D.

4. R&D, innovation and productivity: an econometric model

We developed the theoretical model in three steps. Firstly, we paid special attention in how the internal characteristics of the firm and external factors affected intramural R&D expenditures. Secondly, we developed a decision equation to establish the effect of innovation input sources on the firm's decision to innovate. Thirdly, we used the well-known framework to determine intra- and inter-industry R&D spillovers on productivity. The theoretical framework for the model is an individual version of the Cobb-Douglas production function that relates physical output to physical input for a given state of knowledge at a company level. In our model, the representative firm has a technology with a constant scale economy of productive factors and its level of productivity depends on the efficiency level of its technology and the effect of knowledge spillovers (Campbell, 1997). The production function of the individual firm is given by

$$Q_i = A_i e^{\lambda t} K_i^{\alpha} L_i^{\beta} R_i^{\gamma} \mu_i \qquad (1)$$

where Q is a measure of output, K is a measure of physical capital, L is a number of employees and R is a knowledge capital for the firm "*i*"; A is a productivity index, λ represents disembodied technical change; α, β and γ are the elasticities of output with respect to physical capital, labour and knowledge capital; and, finally, μ is a random error term.

The analytical framework described by Crépon, Duguet and Mairesse (1998) offers the possibility of establishing a sequence that ranges from the factors determining firms' R&D activities, to the innovation performing firms and the effect on productivity. According to the analytical framework proposed by Crépon *et al* (1998) and applied to a wide range of empirical research (Kremp, Mairesse and Mohnen, 2004; Lööf, 2004), the structural model consists of three equations. In the first step, firms decide whether or not to carry out intramural R&D projects (selection equation); the second step deals with the factors determining the firm's decision to innovate (selection equation); finally, in the third step, using Cobb-Douglas' production function, the effects of innovation output and R&D spillovers on firm productivity are determined.

In adition, we are interested in calculating the differences in firms behaviour between manufacturing and service industries. For this reason we focus our analysis on the factors determining investment in R&D and innovation, in order to subsequently analyse its effect on productivity. Following Crépon *et al* (1998) and Kremp *et al* (2004), and taking into account that our database provides information from dichotomous variables regarding R&D and innovation decisions, we present an econometric model with three equations, one for research, one for innovation and one to calibrate the effects of R&D and innovation on productivity. The selection equation describes whether a firm is reporting R&D activities or not, which we can show through the following expression,

$$RD_{1i} = 1 \;\text{ if }\; RD^{*}_{1i} = \beta_1 X_{1i} + \mu_{1i} > 0, \;\text{ and }\; RD_{1i} = 0 \;\text{ otherwise} \qquad (2)$$

where RD_{1i} is the observed binary endogenous variable being zero for no R&D and one for R&D reporting firms, RD^{*}_{1i} is a latent decision variable which measures the propensity towards R&D, X_{1i} is a vector of explanatory variables the R&D decision, β_1 is the corresponding coefficient vector and μ_{1i} a random error term. In this specification the firms' decisions to engage in R&D are determined by a series of firm and industry characteristics such as company size, market share, export profile, investment in physical capital, and external R&D acquisitions. The second equation of the model explains the determining factors in innovation decisions made by firms. The innovation decision selection equation will adopt the following expression,

$$IN_{2i} = 1 \quad \text{if} \quad IN^{*}_{2i} = \beta_2 X_{2i} + \mu_{2i} > 0, \text{ and } \; IN_{2i} = 0 \; \text{ otherwise} \qquad (3)$$

where IN_{2i} is the observed binary variable - 1 for innovative firms and zero for non-innovative firms, IN^{*}_{2i} is a latent decision variable which measures the propensity to innovate, X_{2i} is a vector of explanatory variables like firm size, external sources for innovation, R&D expenditure, among others, β_2 is the corresponding coefficient vector and μ_{1i} a random error term.

The final equation of our model explains the determining factors of productivity level by means of an augmented Cobb-Douglas production function with conventional inputs – employment and investment in physical capital, a vector with different knowledge proxies, such as innovation expenditure, innovation output-, a vector with firm's characteristics – size, market share- and two variables that take in the intra- and inter-sectorial knowledge spillovers. Under the supposition of constant scale outputs of productive factors from the equation (1) applying logarithms, the relationship can be expressed as a linear one in terms of labour productivity,

$$(q-l)_{3i} = a_{3i} + \alpha\ (k-l)_{3i} + \gamma\ \mathrm{r}_{3i} + \lambda_j + \mu_{3i} \qquad (4)$$

where lower case letters y, l, k and a denote output, labour, physical capital and Hicks' neutral technical change in logs; α and γ are the elasticities of output with respect to physical capital and R&D expenditure, λ is an industry dummy and μ is an error term. According to the method proposed by Caballero and Lyons (1990) we can factorise the technical change into various components: a parameter that takes in the knowledge spillovers that take place due to the spread of knowledge generated through R&D carried out by firms in the same sector -r_j ; another that includes the intersectorial knowledge spillovers that take place due to the cross fertilisation of the knowledge generated in the remaining sectors - $r_{k\neq j}$; a vector of the individual characteristics of a firm - X_i ; and, finally, a residual effect that includes the technical progress in the strictest sense. By introducing these parameters into the equation we have:

$$(q-l)_{3i} = \theta_i + \beta_{31i}\, r_{aja} + \beta_{32i}\, a_{rk\neq j} + \beta_{33i}\, X_{3i} + \alpha\ (k-l)_{3i} + \gamma\ r_{3i} + \mu_{3i} \qquad (5)$$

The generalised logit model is applied when selecting the equation both of R&D activities (2) and of innovation (3). And a correction bias method proposed by Heckman (1979) is applied in the estimations of the effects of R&D spillovers on labour productivity, paying special attention to differentiating between intrasectorial and intersectorial spillovers. In all our estimates we include industry dummies corresponding to SIC 2-digit industries (see annexe).

5. The Empirical Results

5.1 Determining factors of R&D behaviour.

We first estimate the characteristics of the firms that influence the probability that the firm will carry out a permanent R&D programme. We are particularly interested in observing how the size of the firm and a series of individual characteristics affect the probability of undertaking R&D. More specifically, the information available allows us to determine whether exporting firms are more likely undertake R&D programmes, as well as showing the effect on market share and investment in machinery and equipment. As per Crépon et al (1998), we specify the empiric model that will act as a basis for the econometric estimate in the following expression,

$$\begin{aligned} RD^{*}_{1i} = \beta_{10} + \beta_{11} Size_i + \beta_{12} Sizeq_i + \beta_{13} Newproduct_i + \beta_{14} Group_i \\ + \beta_{15}\ MarketShare_i + \beta_{16}\ Export_i + \lambda_j + \varepsilon_i \end{aligned} \qquad (6)$$

where the R&D decision of the firm “i” is a function of the firm size and firm size squared both measured in log of the firm’s employees; the share of new goods or services over total sales of the firm; a dummy that adopts the value 1 when the firms acquire external R&D; a dummy that indicates whether the company belongs to a group; the firm’s market share in logs.; a dummy that indicates whether the company exports; the investment in machinery and equipment per employee; a vector with industry dummy variables and a error term.

The results obtained using a logit binomial model shows sectorial differences that need to be analysed. In the first place, the firms in high-tech manufacturing sectors and KIS services present a non-linear relation between R&D intensity and firm size. These results tell us that the small and large manufacturing companies with a high intensity in technology and services are those that have a greater propensity to undertake intramural R&D, while medium-size companies have a lower propensity to carry out intramural R&D. In accordance with Scherer (1992) our results show that large firms have a greater incentive to carry out intramural R&D,

but it also indicates that small firms that are not part of a business group, when they are in the high-tech industries and KIS services, also have a large incentive to carry out R&D. However, in the low-tech manufacturing industries the firm size does not play a determining role in the amount of intramural R&D carried out.

TABLE 2
Selection equation R&D activities

	High-tech Industries	**Low-tech Industries**	**KIS Services**
Size (log.)	-0.1466 (0.081)***	0.0442 (0.067)	-0.4642 (0.071)*
Size square (log.)	0.0177 (0.008)**	-0.0024 (0.007)	0.0382 (0.006)*
New product	0.0058 (0.007)*	0.0040 (0.0004)*	0.0055 (0.008)*
Group (dummy)	-0.1176 (0.042)*	0.0224 (0.031)	0.0201 (0.055)
Market Share (log.)	0.1008 (0.025)*	0.0675 (0.016)*	0.0840 (0.023)*
Export firm (dummy)	0.1617 (0.043)*	0.1013 (0.027)*	0.2169 (0.053)*
Constant	2.5796 (1.510)***	-0.1096 (1.248)***	5.6188 (1.285)*
Sectorial dummies	yes	yes	yes
Number observations	1,130	1,443	694
Chi q	237.83	296.29	293.80
R^2	15.25	17.13	31.58
Note: parameters marginal effects on R&D decision variable			

The percentage of new products and services is a variable proxy of the obsolescence rate of the product or service and its life cycle. In markets where the differentiation of products becomes the driving force in market competition, the share of new products or services in the company's total production will be higher. As is to be expected, our results indicate that firms with a high presence of new products are more likely to carry out internal R&D.

Contrary to our expectations, we found that belonging to a group of companies did not provide any significant advantage. In fact, in high-tech industries, belonging to a group of companies has a negative impact on the probability of carrying out intramural R&D. These results suggest that firms that belong to foreign industrial groups do not carry out R&D in Catalonia, and that the bulk of R&D is carried out by local firms.

Finally, the firm's market share and exports has a positive effect on the propensity of the firm to undertake intramural R&D. These results are particularly important in manufactured goods of high technological intensity, given that the elasticities of the market share and the orientation towards the foreign markets reach a high level. In keeping with the Schumpeter hypothesis

(1942) our results reject a direct and linear link between firm size and R&D intensity, but we find in relation to the second Schumpeterian hypothesis that the market power of the firms stimulates R&D activities. These results agree with other studies (Blundell et al, 1999) and indicate that the dominant firms in their regional markets have a relatively higher incentive to innovate.

These results agree with those obtained for Spanish industrial firms during the 1994-2004 period where market product competition promotes firm's productivity growth when the firms enjoy positive but moderate margins (Segarra and Teruel, 2006). Firms with reduced business margins do not have the necessary cash flow to invest in additional high-risk R&D and innovation. These results also agree with those obtained in the large amount of theoretical and empirical literature that as been published in recent years, based on the new neo-Schumpeterian models that show greater incentives to innovate when there is a certain level of competitive rivalry in the market, while allowing the firms to obtain positive profit margins (see survey in Aghion and Griffit, 2005).

5.2 Determining factors in innovation behaviour.

To estimate the decision equation for innovation activities we incorporated into our empirical model a series of variables related to the companies' sources of innovation, together with the characteristics related to size, market share and exporting activities. The generalised Tobit model applied is written as follows

$$\begin{aligned} IN^{*}_{2i} = {} & \beta_{20} + \beta_{21} Size_i + \beta_{22} Sizeq_i + \beta_{23} R\&D_i + \beta_{24} External_i + \beta_{25}\ Coop_i \\ & + \beta_{26} Public_i + \beta_{27} MarketShare_i + \beta_{28}\ Export_i + \lambda_j + \varepsilon_i \end{aligned} \qquad (7)$$

where the innovation decision of the firm "*i*" is a function of the firm size and firm size squared both measured in log of the firm's employees; the firm's R&D investment per employee in log; a vector of external sources of inputs innovation in dummy variables; a dummy that adopts the value 1 when the firms make cooperation agreements for R&D projects with external partners; a dummy that indicated whether the firm receives public funding for R&D and innovation in the EU, Spain or Catalonia; the firm's market share in log; a dummy that indicates whether the firm exports; a vector with industry dummy variables and a error term.

The results show that the size of the firm has a lesser effect on decisions taken on whether to undertake innovations, although in services the relation between the size of the firm and the probability of innovating continues to describe a U-shape curve. This means that the service companies with a greater propensity to innovate are the small and large ones, while the intermediate-size firms are less likely to innovate. On the other hand, we have to emphasise the different effect of the firm size in relation to the R&D intensity, since in relation to innovation intensity, the firm's size presents a linear relationship with innovation propensity.

TABLE 3
Selection equation innovation activities

	High-tech Industries	**Low-tech Industries**	**KIS Services**
Size (log.)	0.1843 (0.088)**	0.1126 (0.063)***	-0.0818 (0.052)**
Size square (log.)	-0.0090 (0.009)	-0.0079 (0.006)	0.0127 (0.005)*
R&D per employees (log.)	0.2183 (0.022)*	0.0700 (0.013)*	0.0659 (0.018)*
R&D external (dummy)	0.1824 (0.046)*	0.0873 (0.034)*	0.1680 (0.057)*
Machinery (dummy)	-0.0095 (0.046)	0.0171 (0.026)	0.0234 (0.047)
Training (dummy)	0.2191 (0.043)*	0.1123 (0.032)*	0.2464 (0.051)*
Market (dummy)	0.2507 (0.042)*	0.2614 (0.037)*	0.1137 (0.054)**
Cooperation (dummy)	0.0127 (0.052)	0.1578 (0.045)*	0.2285 (0.062)*
Public funds (dummy)	-0.0058 (0.049)	0.0504 (0.045)	0.0559 (0.054)
Market share (log.)	-0.0088 (0.029)	0.0254 (0.016)	-0.01021 (0.019)
Export firm (dummy)	0.2455 (0.049)*	0.0725 (0.026)*	0.0968 (0.049)**
Constant	-4.4791 (1.699)*	-3.5228 (1.442)*	-2.9971 (1.382)**
Sectorial dummies	yes	yes	yes
Number of observations	1,128	1,443	694
Chi square	526.96	496.50	332.33
R^2	33.64	30.07	38.13

Note: parameters marginal effects on Innovation decision variable

Our results indicate that in manufacturing firms there are important economies of scale in innovation activities due to the sunk cost linked to R&D or the capacity of the company to finance and achieve a return on their innovations (Cohen and Klepper, 1996). However, despite the fact that large firms have a greater capacity to undertake permanent innovations, the relationship between persistence and firm size is not simple. Cefis and Orsenigo (2001) observe with panel data on patent applications to the European Patent Office in the period 1978-1993 that some large firms were persistently analysed as non-innovators, whereas small firms were persistent innovators.

The CIS-4 questionnaire compiles interesting information about activities undertaken by a company to carry out innovations during the 2002-2004 period. The results show that R&D carried out by a firm has a strong effect in high technology intensive industries, while in the two remaining groups the effects of intramural R&D on innovation is lower. These results indicate that for high technology intensive manufactured goods the efforts put into intramural R&D and the amount of innovation are closely linked, while in low technology intensive manufactured goods and services the sources of innovation are much more diverse.

With the aim of examining the effects on the propensity to innovate of sources other than internal investment in R&D (‘*R&D’*), that also constitute channels for the acquisition of knowledge and the development of innovations, we have incorporated into the econometric estimates a vector composed of four variable dummies that include complementary sources to intramural R&D, the object of which is to initiate innovations.

In the first place, we can see that externally acquired R&D purchased by a company and undertaken by other companies (including other companies within their group) or by public or private research organisations (‘*R&D external’*) have a positive bearing on innovation development, particularly in high-tech manufacturing and KIS services. We should emphasise the high level of elasticity in the external acquisition of R&D by high-tech manufacturing firms. In those industries, firms that acquire R&D externally have an 18.2 per cent greater possibility of permanent innovation. Secondly, the acquisition of machinery, equipment and software (‘*Machinery’*) gives ambiguous results with low levels of significance. Thirdly, firms that carry out internal or external training of their personnel (‘*Training’*), specifically for the development or introduction of innovations, have a greater probability of permanent innovation, particularly in services. Finally, market penetration and the introduction of new or significantly improved goods and services (‘*Market’*) also facilitate the undertaking of permanent innovative activities, particularly in manufactured goods.

The results suggest that the ways to innovate differ according to the characteristics of the industry. In manufactured goods with a high technological content, intramural R&D expenditure takes on considerable importance, while in low-tech manufactured goods undertaking activities to apply innovations to the market becomes a key element for carrying out permanent innovations. Finally, in the service sectors the acquisition of external R&D and employee training takes on greater importance. These results suggest that the incorporation of external R&D combined with the firm’s internal competence and knowledge provides an increasing incentive to carry out innovations, particularly in the high-tech manufacturing and service firms. In this respect, the introduction of an innovation is always the result of the blending and recombination of elements of technological knowledge both as an asset and embodied in capital goods, external knowledge, organisational procedures and routines introduced elsewhere (Antonelli, 2006).

Cooperation agreements for R&D projects ('*Coop'*) increase the probability that the firm will periodically undertake process or product innovations, while the award of public funding for R&D and innovation projects ('*Public'*) has no effect on the probability of innovation in the three groups studied. Finally, the values obtained in relation to the firm's market share ('*Market Share'*) give much more ambiguous results compared to those previously mentioned in the R&D equation selection, although exporting ('*Export'*) has a positive effect on the probability of innovation, especially in high-tech manufacturing firms.

Table 4
Expenditure in innovation in 2004

	All firms	**High-tech Industries**	**Low-tech Industries**	**KIS Services**
Intramural R&D	477,7	705,2	131,8	826,5
External R&D	191,7	452,5	16,5	131,4
Machinery and software	135,9	262,1	66,4	75,1
External knowledge	10,9	13,1	1,8	26,1
Training	6,5	6,3	1,7	16,7
All forms of design	19,7	31,4	11,6	17,8
Marketing expenditures	40,4	19,3	30,5	95,5
Total expenditures	882,9	1,489,9	260,4	1,189,1
Number of firms	3,267	1,130	1,443	694
Number of permanent R&D firms	1,295	608	414	273
Number of innovator firms	1,156	559	374	223

Note: average firm amounts in thousands euros
Source: Catalan Innovation Survey

Table 4 shows firms' expenditure on innovation projects. The first figure to emphasise is expenditure on intramural R&D, particularly in the high technology manufacturing industries and services. The high volume of this entry in services is due to expenditure on Research and Development Services (the fifty firms in the sample indicate an average expenditure of 7,355 thousand euros). Among the other entries, the acquisition of external R&D and the purchase of machinery, equipment and software stand out, particularly due to the average expenditure of high-tech manufacturing firms. The remaining sources of innovation register more moderate amounts. We have to highlight the lack of enthusiasm to invest in the low-tech manufacturing firms in Catalonia. Bearing in mind that the Catalan industrial-mix is well known for its traditional specialisation in medium and low technological industries, this situation is extremely worrying.

Table 4 shows that the relation between intramural R&D, innovative inputs and innovative outputs does not necessarily remain constant. There are important differences between firms and industries. As we have seen, intramural R&D expenditure plays an important role in high-tech industries and knowledge-intensive services, but the acquisition of R&D from external laboratories and the purchase of machinery, equipment and software stand out as important sources for the incorporation of knowledge.

5.3. Innovation, productivity and R&D spillovers

Since Arrow (1962) suggested in his seminal paper that privately owned firms are likely to underinvest in R&D and innovation because they are unable to fully appropriate the returns from these activities, technological spillovers linked with R&D have been the focus of a large number of empirical and theoretical studies. Along these lines, Griliches (1979) suggests two types of economic spillovers: rent spillovers and knowledge spillovers. Rent spillovers occur when the producer of an innovation cannot charge a price that fully reflects the benefits of the innovation to the innovation user. Knowledge spillovers appear because the production of knowledge has public-good characteristics limiting the ability of the firm to prevent another firm from exploiting it. We concentrated our work on the second concept provided by Griliches and distinguished between intra- and inter-industry R&D spillovers. In this respect we adapted the way Glaeser *et al.* (1992) dealt with the external intra- and inter-industrial effects of the object we were studying.

Nevertheless, between firms transmission of technological or pecuniary externalities is a complex and varied phenomenon that should be looked at within a specific geographical framework. In this respect, we should not forget that when firms are clustered in a territory, in a region such as Catalonia, and share a certain technological space, two types of effects linked with R&D spillovers appear. On the one hand, the dissemination of technology allows a firm to appropriate and potentially benefit from the R&D of other firms. On the other hand, however, the impact of competition between firms operating in the same technological field provides the possibility of imitating the results of R&D and innovation (Hanel and St-Pierre, 2002).

The relationship between R&D, innovation and productivity has been widely examined during last two decades. Many studies find a significant link between innovation and productivity (Griliches and Mairesse, 1998), but other studies fail to find a string link between innovation and productivity. In general, empirical works based on cross-section data are more likely to find a significant link between innovation and productivity (Crépon et al, 1998).

Therefore, having analysed the way in which individual characteristics and the conditions of the market in which the company operates are relevant elements for carrying out R&D and innovation, this section studies the innovative effort measured by the amount each company spends on innovations and how the knowledge spillovers derived from the R&D activities carried out by other firms affect productivity. Calculating the relationship between R&D flow and innovation on productivity growth is not easy (Hall and Mairesse, 1995). Given the limitations of our database in the empirical estimation, we cannot apply delays to the knowledge flows assuming that this relationship takes place immediately. The restriction has a moderate effect on the results, given that, as Scherer (1982) pointed out, R&D intensity in manufacturing firms is relatively stable over time and therefore the timing of the variable seems to have little effect in practice. Using the expression (5) we can directly derive the empirical model that will serve as a basis on which to study the effect of R&D spillovers on firm productivity. The objectives of this section are basically twofold: to demonstrate the importance of the firm's characteristics and to quantify the effects of R&D spillovers on productivity in Catalan firms.

In the vector of variables that takes in the individual characteristics we continue to maintain some of the variables used in the previous estimations, as well as incorporating new ones: the size of the firm measured by the number of workers ('*Size*'); the size squared ('*Size Square'*); expenditure on innovation per worker ('*Innovation*'); the percentage of production corresponding to new products and services ('*Newproduct'*)[1]; the company's market share ('*Market Share'*); and the investment in physical capital per worker ('*Investment*'). As we have seen, firms have internal knowledge-generating sources, particularly R&D, but they also acquire outside knowledge incorporated in technology, equipment or software, or they access R&D undertaken by external agents, therefore in our estimations we have leant towards using innovation costs as a variable input of a firm's knowledge, which includes both intramural R&D investment and other sources of input innovation.

The incorporation of a large series of variables that take in some of the characteristics a company has as an objective demonstrates that the characteristics of a firm have an effect on productivity that often exceeds the effects derived from sectorial or regional factors.

In order to take in the R&D spillovers we defined two types of externalities. On the one hand, the knowledge flow produced between companies in the same sector ('*R&D intra-industry'*) is the R&D expenditure in 2004 of firms in the same sector, excluding the firm's own R&D. On other hand, the inter-industry knowledge flow ('*R&D inter-industry*') is the R&D expenditure in

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[1] Innovation output is defined by the *Oslo Manual* as share of sales due to product innovation.

2004 of the firms from other industries, calculated using the technical coefficient of the table showing the input-output of the Catalan economy during 2001. This variable reflects the flow of inter-industry R&D spillovers and is calculated following the method applied by Scherer (1982). As such, the expression used in the econometric estimate expressed in logarithmic terms will be

$$(q-l)_i = \theta_{30} + \beta_{31} r_j + \beta_{32} r_{k \neq j} + \beta_{33}\, Size_i + \beta_{34}\, Sizeq_i + \beta_{35}\, (Inn\text{-}l)_i + \beta_6\, InnOutput_i + \beta_7\, MarketShare_i + \beta_8\, (Inv\text{–}l)_i + \gamma\, r_{3i} + \mu_{3i} \quad (8)$$

Unlike Crépon et al (1998) in this estimation we considered all firms. The appropriate econometric method to resolve this problem is the two-step method suggested by Heckman (1976, 1979) to control the bias caused by the higher productivity of innovating firms. This proposes the introduction of an additional explanatory variable in the least squares regression – the reverse of Mill's Ratio– obtained from a probit model on company innovative decisions. The probit equation we use is

$$IN_i = \beta_o + \beta_l\, Size_i + \beta_2\, (Inn\text{-}l)_i + \beta_3\, Patent_i + \beta_4\, Export + \mu_i$$

where IN_{is} is a binary variable being 1 for innovative firms and zero for non-innovative firms and explanatory variables are a firm's size, investment in innovation per employee, and two dummies related to the ability of the company to register patents and its export activities. Our estimations find that Mill's ratio is significant, which would suggest that there is a significant sample selection bias (Greene, 2003). Moreover, the values of ρ and σ are significant and therefore the use of a Heckman equation corrects the bias inherent in the greater productivity of innovating firms.

TABLE 5
Labour productivity

	High-tech Industries		**Low-tech Industries**		**KIS Services**
Size (log.)	0.6616	0.6691	0.6206	0.5694	0.4868
	(0.087)*	(0.087)*	(0.126)*	(0.124)*	(0.103)*
Size square (log.)	-0.0597	-0.0611	-0.0695	-0.0622	-0.0632
	(0.009)*	(0.009)*	(0.014)*	(0.014)*	(0.011)*
Innovation per employees (log.)	0.0620	0.0560	0.0551	0.0583	0.0443
	(0.027)**	(0.026)**	(0.029)***	(0.029)**	(0.041)
New product	0.0205	0.0203	0.0166	0.0168	0.0369
	(0.006)*	(0.006)*	(0.006)*	(0.006)*	(0.013)*
Quota	5.7793	5.5498	15.7032	15.2270	6.2872
	(0.780)*	(0.736*	(1.622)*	(1.611)*	(1.169)*
Investment per employees (log.)	0.1047	0.1058	0.0439	0.0443	0.0772
	(0.016)*	(0.016)*	(0.017)*	(0.017)*	(0.028)*
Intra (log.)	0.8939	0.9377	2.8578	2.6139	-0.2624
	(0.224)*	(0.219)*	(0.432)*	(0.416)*	(0.874)
Inter (log.)	-3.4325		6.8519		1.5108
	(3.866)		(3.452)**		(2.824)
Computer services Spillovers		1.8183		0.7436	
		(0.848)**		(0.129)*	
Research and Development Services Spillovers		-0.9166		-4.0232	
		(0.449)**		(0.706)*	
Constant	6.8863	3.3771	-24.9422	-0.8332	-0.5580
	(10.293)	(1.167)*	(10.945)**	(0.763)	(13.855)
Sectorial dummies	Yes	Yes	Yes	Yes	Yes
Number of observations	1,125	1,125	1,440	1,440	688
Censored observations	328	328	679	679	339
Chi square	395.56	394.25	288.11	282.17	417.06
Rho	-0.4014	-0.4169	-0.3981	-0.4341	-0.7151
	(0.172)**	(0.171)**	(0.183)**	(0.170)*	(0.258)*
Sigma	-0.5120	-0.5092	-0.4092	-0.4954	-0.1167
	(0.034)*	(0.034)*	(0.042)*	(0.034)*	(0.084)
Mill's ratio	-0.3868	-0.3981	-0.3369	-0.3305	-0.3896
	(0.124)*	(0.123)*	(0.137)*	(0.137)*	(0.273

The results obtained in the three groups indicate that size has a positive effect on productivity, which means that companies, particularly in the manufacturing sector, appear to benefit from internal economies of scale. However, when a certain threshold is surpassed the largest firms are subject to diseconomies that have a negative effect on their productivity. Therefore, in keeping with other empirical studies, the relation between productivity and a firm's size takes on a moderate inverted U shape. On the other hand, investment in innovation and physical capital per worker has a positive effect on productivity[2]. As far as market characteristics are concerned, those companies that have a larger market share and a larger percentage of new products or services also reach higher levels of productivity.

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[2] Like our results for a sample of Spanish manufacturing firms, Huergo and Jaumandreu (2004) find that the innovation process at some point leads to extra productivity growth, which persists over time but decreases with the years.

When we incorporate a dummy related to a firm's exporting activities we find a close relationship between export activities and a firm's productivity, particularly in the low-tech manufacturing sectors. As in other studies (Baily and Solow, 2001), we find empirical evidence that international competition has a disciplinary effect on the company, making it reach higher productivity levels, especially in the mature industrial sectors in Catalonia that have suffered considerable external pressure in recent years.

The task of determining empirically the effects of R&D spillovers on productivity at company level is by no means easy. The multiple sources of knowledge generation, transmission and capture within the reach of firms cast doubt on the use of a single variable to measure knowledge spillovers. In this respect relating R&D activity to productivity level is not necessarily simple and clever, because the notion of innovation is much richer and it is a process that is subject to the uncertainty of market response and the changing nature of competitive rivalry. Therefore the empirical evidence is often ambiguous. Indeed, the papers surveyed by Griliches (1992) found a positive association between several R&D spillover proxies and productivity growth rates, but another scholar found no empirical evidence of the R&D spillovers and their effect on productivity (Gerosky, 1995). Some sceptical voices demonstrated the complexity of suitably capturing the knowledge spillovers[3].

Despite the care we took, the results are relevant. As far as the effects of R&D spillovers are concerned, the notable differences recorded between the manufacturing and service firms stand out. In the manufacturing industries we found empirical evidence of intra-industry spillover, although we found no positive effects for the inter-industry spillovers generated by R&D undertaken by firms operating in other industries. In the low-tech manufacturing industries the results indicated a positive effect of intra- and inter-industry R&D spillovers on productivity[4]. While in the service companies no evidence was found of the effect of R&D spillovers on the productivity of services. In services, however, the internal characteristics of the companies and the conditions of the markets in which they operate have a highly significant effect on the firm's productivity level.

In general, in manufactured goods there is a predominance of the R&D spillovers that take place between firms in the same industry, which agrees with the findings of another study into externalities in Spanish manufacturing firms (Segarra and Arcarons, 1999). As with our results, Wakelin (2001) found strong evidence of the effects of the level of R&D carried out by other

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[3] There is no necessary relation between the rate of technological transformation of the economy on the one hand and the rate of productivity growth on the other hand (Carlaw and Lipsey, 2003).

[4] For a sample of 278 firms Hanel and St-Pierre (2002) found R&D spillovers had a direct and positive effect on profitability, especially in industries with effective patent protection.

firms in the same sector –intrasectorial spillovers, but found no significant evidence of the effects of spillovers of R&D intensity from related sectors when he introduced a proxy to capture rent spillovers based on producer-user relationships.

Finally, we included in the equation (8) the R&D spillovers generated by two key activities for the development of innovations and the spread of knowledge: *Computer and related activities* and *Research and D&D services.* During 2004 *Computer and related activities* invested 110.4 million euros in intramural R&D and *R&D services* 490.2 million euros. The 237 firms included in both sectors carried out 30.22 per cent of the total R&D investment in Catalonia. As can be seen in Table 5, we found evidence that R&D spillovers related to computer services have a positive effect on the productivity level of firms in the manufacturing industries, especially in high-tech industries. On the other hand, the effect of research and development services on the productivity level is negative. These results suggest an interesting differential role played by two strategic high-tech services on the manufacturing firms. According to our results activities related to computer services and software applications generated positive knowledge flows on the whole Catalan industrial-mix.

6. Conclusions

In this paper we have attempted to link the effect of a firm's decisions on R&D and innovation activities and the R&D spillovers on productivity in a range of firms in the Catalonia region. During recent decades, Catalan firms have experienced major changes in the competitive rules of the game. Since the Spanish economy became part of the EU, the opening-up of markets and the penetration of imports have increased notably. In general, Catalan firms, particularly those that form part of the traditional industrial-mix based on medium- and low-technology manufacturing sectors, have shown considerable capacity for adaptation. However, today there are still serious structural imbalances that condition the behaviour and the change of companies. In recent years, universities and public research centres have been playing an increasing role in the innovation system of Catalonia, but the effects on the low-tech traditional industries are limited. In this respect this paper sheds some light.

Firstly, the decision of the firm to undertake a permanent R&D programme is determined by the internal characteristics of the firm, and above all by market factors, such as a presence in foreign markets, the novelty of services and goods, and the firm's market share. However, only a small number of firms operating in a limited number of industries are responsible for most of the R&D carried out in Catalonia. Secondly, the decision of the firm to undertake process or product innovations is affected by the diversity of sources of innovation input. In this respect, internal R&D plays an important role, but the acquisition of external R&D services, training employees to undertake innovations, and carrying out activities to develop the firm's innovations in its respective markets are also key elements in regular innovation. On the other hand, cooperation agreements with other partners and access to public grants have little effect on the decision to innovate, except in the case of KIS service firms.

Secondly, R&D spillovers play an important role in the productivity of the firms in the same industry, particularly in manufacturing sectors, although the importance of inter-industrial R&D spillovers is low in high-tech manufacturing and services. When we analyse the effect on the productivity of firms from two high-tech service industries very important for the promotion of R&D and innovation we find interesting results. The inter-industry R&D flow related to '*Computer and software services*' is positive and highly significant in both manufacturing groups, especially in high-tech industries. On the other hand, the effect of inter-industry R&D flow related to '*R&D services*' is negative.

In the 'knowledge economy' the ICT services play a key role in the promotion of innovation and the economic growth of firms and whole regional economies. When a region has an important and dynamic ICT industry, the efficiency of firms increases greatly. However, the presence of knowledge-intensive services must be accompanied by a suitable business environment for the systematic and persistent incorporation of innovations. In effect, a firm's performance in R&D and innovation is not sporadic, in the sense of temporal power in the firm's market, but rather it is a structural phenomenon that is closely related to the history of the company. Breaking with the past is not easy.

If innovation is the solution, what is the problem? This is the question we asked before. We think the most important problem in Catalonia will not be found in the lack of the actors essential to bring about a change in the methods of production and ways of competing in the market, but in the limited incentives given to firms that operate in the traditional manufacturing sectors to make them consider innovation as the key to their competitive position in the marketplace.

APPENDIX: Variable Definition

Continuous R&D engagement: Dummy variable, which takes the value 1 if the company reports continuous R&D engagement in intramural R&D activities during the period 2002-2004.

R&D intensity: R&D expenditure in 2004, per employee (in log.).

Innovation engagement: Dummy variable, which takes the value 1 if the company reports product or process innovation and continuous R&D engagement in intramural R&D activities during the period 2002-2004.

Innovation intensity: Innovation expenditure in 2004, per employee (in log.).

Process innovation: Dummy variable, which takes the value 1 if the company reports having introduced new or significantly improved production, processes during 2002-2004.

Product innovation: Dummy variable, which takes the value 1 if the company reports having introduced new or significantly, improved products during 2002-2004 (new to the market or only new to the firm).

Productivity: Sales per employee in 2004 (in log.).

Market Share: Firm's sales divided by the value of its industry's sales in the sample by SIC industry division (in log.)

Investment intensity: Gross investments in tangible goods in 2002, per employee (in log.).

Export intensity: Exports as a share of total turnover in 2002 (in log).

Innovation output: Share of turnover in 2004 due to new or significantly improved products introduced during 2002-2004.

Group: Dummy variable, which takes the value 1 if the company belongs to a group of companies.

Cooperation: Dummy variable, which takes the value 1 if the company had some cooperative arrangements in innovation activities during 2002-2004.

Research employees: personnel (researchers and grant holders) involved full time in intramural R&D carried out by the company.

Public funding: Dummy variable, which takes the value 1 if the company received EU, regional or local, funding for innovation projects during 2002-2004.

Intrasectorial R&D spillovers: R&D expenditure in 2004 of the firms in the same sector as the firm, excluding the firm's own R&D.

Intersectorial R&D spillovers: R&D expenditure in 2004 of the firms from other industries weighted by the technical coefficient of the input-output table of the Catalan economy during 2001. This variable reflects the flow of inter-industry R&D spillovers and is calculated according to the method applied by Scherer (1982).

TABLE A-1
R&D and innovation activities, year 2004

	Innovative firms		
	High-tech industries	**Low-tech Industries**	**Services**
Innovative firms			
Employment (average) [1]	231.6	181.9	354.3
Sales (average) [2]	64.4	34.9	71.4
Export by sales (%)	33.9	21.6	2.6
R&D expenditures by employee [3]	7.0	3.3	15.8
Innovation expenditures by employee [3]	10.4	8.2	19.3
Innovation output by sales (%)	26.9	22.8	39.2
Non-innovative firms			
Employment (average) [1]	90.1	90.4	273.6
Sales (average) [2]	19.0	19.3	18.6
Export by sales (%)	27.1	16.8	2.9
R&D expenditures by employee [3]	2.1	0.8	5.8
Innovation expenditures by employee [3]	3.1	2.1	7.5
Innovation output by sales (%)	9.4	7.1	6.0

Note: 1 size in employees; 2 sales in million euros; 3 R&D and innovation expenditure by employees in thousand euros.
Source: Catalan Innovation Survey

Table 2A: R&D, innovation and production by industries, year 2004

Industries	Firms	Sales	Export	Investment	R&D investment	Innovation Investment	Employees	Research employees
High-tech manufacturing	**294**	**15.633**	**3.404**	**400**	**473**	**710**	**44.698**	**2.252**
Aircraft and spacecraft	2	6,2	1,9	0,4	0,3	0,8	84	2
Pharmaceuticals	106	9.568,3	1.783,6	281,1	345,5	533,8	27.021	1.201
Office, accounting and computing machinery	7	1.364,9	17,9	30,7	45,4	59,9	2.581	314
Radio, TV and communications equipment	71	3.665,6	1.361,3	34,6	51,9	75,5	8.989	484
Medical, precision and optical instruments	108	1.028,1	239,0	53,1	29,8	40,0	6.023	251
Medium- high-tech manufacturing	**836**	**42.267**	**15.843**	**1.567**	**324**	**974**	**136.271**	**1.883**
Electrical machinery and apparatus, n.e.c.	122	6.283,3	1.687,7	196,9	58,8	99,9	25.546	470
Motor vehicles, trailers and semi-trailers	106	17.900,0	8.413,4	800,5	90,9	616,7	50.087	385
Chemical products	285	13.500,0	3.977,8	470,3	113,2	175,1	37.774	675
Railroad equipment and transport equipment	31	1.515,9	601,1	25,0	15,5	22,2	5.098	37
Machinery and equipment, n.e.c.	292	3.068,2	1.163,3	74,4	45,5	59,6	17.766	316
Medium- low-tech manufacturing	**357**	**11.161**	**2.521**	**617**	**58**	**108**	**49.523**	**307**
Rubber and plastic products	17	3.231,1	1.005,7	146,5	14,4	33,2	17.009	76
Other non-metallic mineral products	88	3.172,0	412,4	132,6	16,1	20,1	11.581	68
Metallurgy	58	2.210,4	444,9	134,4	9,2	15,5	5.600	32
Metal products	194	2.547,7	658,0	203,3	18,6	38,7	15.333	132
Low-tech manufacturing	**933**	**28.665**	**5.479**	**1.156**	**131**	**268**	**115.248**	**538**
Furniture and other manufactures	137	1.547,0	353,1	36,7	13,4	17,5	9.506	42
Wood and cork	28	182,5	54,2	3,7	0,1	0,9	1.449	8
Paper industries	86	3.599,3	970,5	262,1	6,2	17,8	13.563	36
Printing industries	120	1.983,3	340,4	105,4	6,1	17,7	11.419	37
Food products, beverages and tobacco	242	17.073,9	2.047,8	630,9	54,1	105,6	50.448	238
Textile industry	233	2.331,6	868,2	79,5	27,5	81,1	17.964	117
Clothing and furrier’s	59	1.633,4	672,0	27,8	20,0	23,0	8.272	41
Leather articles and footwear	28	313,8	173,1	9,6	4,1	4,6	2.627	20
Knowledge-intensive services (KIS)	**765**	**19.154**	**1.740**	**1.184**	**606**	**838**	**181.771**	**3.427**
Post and Telecommunications	40	4.894,6	38,4	453,2	20,5	38,4	8.191	26
Financial intermediation	127	6.841,8	883,4	490,7	44,6	66,0	19.090	88
Computer and related activities	187	3.384,1	520,4	50,6	110,4	161,6	31.066	982
Research and development	50	489,7	85,3	31,0	367,8	484,3	5.430	1.931
Other business activities	361	3.543,3	213,0	158,3	62,9	87,7	117.994	399
Total	**3.185**	**116.880**	**28.988**	**4.923**	**1.593**	**2.897**	**527.511**	**8.407**

Source: Catalan Innovation Survey

Table A.3
Classification of manufacturing and service industries

High-tech manufacturing sectors	ISIC rev. 3
Aircraft and spacecraft	353
Pharmaceuticals	242
Office, accounting and computing machinery	30
Radio, TV and communications equipment	32
Medical, precision and optical instruments	33
Medium- high-tech manufacturing sectors	
Electrical machinery and apparatus, n.e.c.	31
Motor vehicles, trailers and semi-trailers	34
Chemical products	24 excl. 2423
Railroad equipment and transport equipment, n.e.c.	35 excl. 353
Machinery and equipment, n.e.c.	29
Medium- low-tech manufacturing sectors	
Rubber and plastics products	25
Other non-metallic mineral products	26
Metallurgy	27
Metal products	28
Low-tech manufacturing sectors	
Furniture and other manufactures	36
Wood and cork	20
Paper industries	21
Printing industries	22
Food products, beverages and tobacco	15-16
Textile industry	17
Clothing and furriers	18
Leather articles and footwear	19
Knowledge-intensive services (KIS)	
Post and telecommunications	64
Financial intermediation	65 + 66 + 67
Computer and related activities	72
Research and development	73
Other business activities	74

Note: Coke, refined petroleum products and nuclear fuel (sector 23) is excluded; sectors, 64, 72 and 73 are considered high-tech services.
Source: OECD

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