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Innovation and productivity in manufacturing and service firms in Catalonia: a regional approach

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This article analyses the determinants of research and development (R&D) and the role of innovation on labour productivity in Catalan firms. Our empirical analysis found a considerable heterogeneity in firm performances between the manufacturing and service industries and between low- and high-tech industries. The frontiers that separate manufacturing and service industries are increasingly blurred. In Catalonia high-tech knowledge-intensive services (KIS) play a strategic role in promoting innovation in both manufacturing and service industries, and driving growth throughout the regional economy. Empirical results show new firms created during the period 2002–2004 that have a greater R&D intensity than incumbent firms (54.1% in high-tech manufacturing industries and 68.8% in high-tech KIS). Small and young firms in the high-tech KIS sector are very prone to carrying out R&D and they invest more in innovation projects. R&D expenditures, output innovation, investment in physical capital, market share and export have positive effects on labour productivity in both the manufacturing and service sectors. Firm size, on the other hand, has a positive effect on productivity in manufacturing industries but not in services.

Keywords: innovation; R&D; productivity; knowledge-intensive services

JEL Classification: 140; 310; L100

1. Introduction

This article explores the determinants of research and development (R&D), innovation and productivity at the firm level in both manufacturing and service industries in Catalonia. In general, empirical literature focuses on manufacturing firms and only a few contributions shed some light on the services sector (Strambach 2001; Tether 2003; Miles 2005; Hempell 2005; Cainelli, Evangelista, and Savona 2006; Lööf and Heshmati, 2006; Arvanitis 2008). Despite the increasing prominence of services in the European economies and the central role acquired by knowledge-intensive services (KIS) in the emerging knowledge-based economies few articles have dealt with both manufacturing and services industries.

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However, in R&D and innovative activities there is considerable heterogeneity among firms and among industries.

The determinants of R&D and innovation and their effects on productivity at the firm level have been subject to increasing interest in recent years (Griliches 1995; Crépon, Duguet, and Mairesse 1998; Mairesse and Mohnen 2004; Hall and Mairesse 2006; Mohnen, Mairesse, and Dagenais 2006). The greater availability of micro-level data in the EU, especially since the advent of the Community Innovation Survey (CIS), has led to a growing number of studies on the links between R&D, innovation and productivity at the firm level. Access to the micro-aggregated data of the innovation surveys in different European countries has also resulted in a new analytical perspective. Some empirical studies estimate a production function of knowledge by relating R&D to innovation, measured as the number of patents or the share of innovative sales. Others link R&D, innovation output and productivity at the firm level using the framework proposed by Crépon, Duguet and Mairesse (1998) for France (henceforth, the CDM model). We apply a structural model that describes the link between R&D expenditure, innovation output and productivity proposed by these authors and its successive modifications (Griffith et al. 2006; Hall and Mairesse, 2006; Mohnen, Mairesse, and Dagenais 2006). The CMD model proposes a simple framework that links innovative and productive activities, and provides estimation methods that are appropriate to the specification of the model and the nature of data. In this article we estimated a three-stage econometric model linking research, innovation and labour productivity using recent firm-level data.

This article contributes to the literature by investigating the different patterns of manufacturing and service firms in Catalonia. The data set is a broad sample of 3554 Catalan firms that answered the Spanish version of the CIS questionnaire in 2002–2004. CIS-4 has been considerably improved with respect to previous editions: it is representative of firms with more than 10 employees (versus 20+ employees in CIS-3) and of both manufacturing and service firms (CIS-3 was representative of the manufacturing industry only). The aim of this article is to investigate the links between R&D, innovation and productivity in Catalan firms from both the manufacturing and service industries.

The main empirical results are the following. New firms created during the period 2002–2004 present high levels of R&D expenditures in high-tech manufacturing and service industries. High-tech industries and high-tech KIS are more sensitive to market share, public funds and export activities. In low-tech industries and services the market share increases the propensity to engage in R&D but the export activity and the presence of new firms have no direct effect on firm R&D intensity. As far as the determinants of output innovation were concerned, the main results were the following: the probability that a firm will innovate increases with its size, R&D inputs and the contracting of research personnel. Finally, in the link between innovation and productivity empirical results show that labour productivity was directly affected by R&D intensity, output innovation and firm market share.

In this article we adopt an integrated approach in which manufacturing and service firms do not follow entirely different innovation processes but present important differences in the nature of innovation. Service firms are less likely to acquire knowledge and technology through 'hard' sources (R&D, acquisition of external R&D or the incorporation of new equipment) and are more likely to source knowledge and technology through 'soft' sources (relations with suppliers and customers, cooperation with partners or internal organizational changes). Despite these differences in the nature of the innovation process between manufacturers and services, the answer to the question 'Do services innovate differently?' is no, in the sense that service firms have no particular innovation pattern (Tether 2005).

Although the services sector has been the only one in the European economy to have generated jobs in the last two decades, innovation studies are largely associated with manufacturing industries in one particular country (see Smith 2005) or different countries (Mohnen, Mairesse, and Dagenais 2006; Peters 2009; Pianta and Vaona 2007). In recent years, however, increasing attention has been paid to innovation and the innovation process in service firms (Evangelista 2000; Howells and Tether 2004; Miles 2005).[1]

In addition, the fact that KIS have become involved in innovation and research in a particular region is of great importance. Some studies show that innovation rates are greater in those regions where the concentration of KIS is high, since KIS generate an increasing number of innovations and facilitate knowledge transfer and the adaptation of existing knowledge to the specific needs of manufacturing firms (Strambach 2001). For 107 European regions, Camacho and Rodríguez (2005a) show that KIS have a central role in regional innovative performance. In nine European innovation systems (those of Denmark, Finland, France, Germany, Greece, Italy, the Netherlands, Spain and the United Kingdom), Camacho and Rodríguez (2005b) found that, first, many service activities innovate and secondly, that some services, in particular KIS, play a key role in diffusing knowledge.

The aim of the present article is threefold. First, we observe the factors that determine whether firms carry out R&D and the effects of R&D and innovation on productivity. Second, we focus on the different performance of firms in the manufacturing and service industries. Third, we explore the importance of KIS in Catalonia and the role of services in regional innovation systems.

In recent years Catalonia has undergone an intense process of economic opening and had its comparative advantages in traditional industries eroded, which has given rise to significant changes in its industrial mix. In 2006, the services sector accounted for 63.7% of total employment, whereas the manufacturing sector was responsible for only 22.7% of total employment. In Catalonia, between 1996 and 2006, employment in the manufacturing sector increased at an annual rate of 3.0%, whereas employment in total services increased at an annual rate of 5.8% and KIS increased by 8.1%. The Catalan economy had 540,175 employees in KIS industries in 1996 and 979,788 employees in 2006. Catalonia is an interesting case for study for various reasons. First, because Catalan firms are much more committed to R&D activities than the rest of the Spanish regions. Secondly, because the urban system is dominated by the Barcelona metropolitan area, but there is also a network of medium-sized cities with considerable economic and social vitality. Thirdly, the region's industrial tradition is based on medium- and low-technology manufacturing industries and is undergoing increasing specialization in services, particularly in high-tech KIS. Finally, in Catalonia KIS play an important role in spreading knowledge and in firm innovative projects.

The remainder of the article is organized as follows: in Section 2, we describe the growing strategic role of KIS in spreading knowledge and carrying out innovations. In Section 3, we present the database used on a sample of Catalan firms and the main descriptive indicators of innovation activities. Section 4 presents the structural model that describes the link between R&D expenditure, innovation output and productivity based on the framework proposed by Crépon, Duguet and Mairesse (1998). Section 5 describes the econometric results in three steps. In the first step we applied selection and intensity models to analyse the determinants of the firm's decision to carry out internal R&D. In the second step we analysed the effect of several inputs on innovation. In the third step we analysed the link between R&D, innovation and firm productivity. Finally, Section 6 summarizes the main results obtained in the empirical work.

2. Innovation and productivity: the role of services

All advanced economies of the world are increasingly dominated by service activities, in terms of value added and employment. In recent decades, net employment growth has been absorbed entirely by the service industries (Schettkat and Yocarini 2003). In 2004 in the EU-15 countries, the services sector accounted for 68.9% of total employment, whereas the manufacturing sector only accounted for 18.1%. In other terms, almost 113 million people were employed in services, whereas only 30 million were employed in the manufacturing sector. Between 1999 and 2004 employment in the manufacturing sector in the EU-15 decreased at an annual rate of 1.2%. Whereas employment in total services increased at an annual rate of 1.9%, KIS increased by 2.6% and high-tech KIS by 2.9%.

The economic literature has made two classic analyses of the expansion of the service sector in industrialized economies. From the demand-side perspective, Clark (1940) argues that when income grows in industrialized countries, consumer demand for services is far greater than for manufactured goods and this increases the participation of services in the labour force and real output. From the supply-side perspective, Baumol (1967) developed a model in which the share of services and goods in real output is constant over time and across countries. In this model the low productivity of the services sector is the driving force that explains the increasing share of services sector employment in industrialized countries. For Clark, the shift to service employment is the result of changing final demand and for Baumol it is the result of differential productivity growth between manufacturing and service industries.

Baumol's pessimistic vision of the negative impact of increasing specialization in the services sector on the growth of aggregate productivity has been subject to review from two perspectives. First, as Oulton (2001) argues, Baumol's model of unbalanced growth is only correct if the relatively stagnant service industries produce final products. When services produce intermediate products (e.g. ICT activities, financial and business services), the aggregate growth rate of productivity does not necessarily fall. Second, service sectors that are part of the KIS in computer services, R&D services and financial and business consultancy have an increasing role in innovation and register high growth rates in terms of productivity (Barras 1986). Subsequent research has highlighted that the shift to the services sector in industrialized countries has given rise to increasing productivity differentials in service industries (Fuchs 1968; Schettkat and Yocarini 2003). Nevertheless, as Griliches (1992) has pointed out, there is a stronger downward bias in service-output measurement and in some service industries this measurement bias leads to an underestimation of productivity growth, particularly in KIS activities.

The intense transformation of services, particularly into KIS, makes it necessary to question two of the traditional myths of the services sector: namely, low productivity and moderate innovative activity. Some services – particularly those catering for end consumer demand and non-market services – still use a considerable number of low-qualified workers, and in general these activities register only sporadic increases in productivity. Other industry services, however, register high productivity growth rates, are highly innovative and require considerable numbers of skilled workers. What is more, service industries, particularly in the KIS sector, are more internationalized and they face increasing market competition (Barras 1986; Wolff 1999; Oulton 2001).

In the last two decades the innovative activities of service firms have changed considerably. Service firms are becoming more R&D intensive; innovation output in service firms is increasing and service firms increasingly centre on non-technological, disembodied forms of innovation. In this respect, innovative behaviour in manufacturing industries is not a good mirror for services. There are important differences in the nature of innovation processes between manufacturing and service industries, and the traditional indicators used to evaluate R&D and innovation outputs cannot be used for services. There are various reasons for this: the traditional concept of R&D has been shaped by technological innovations in the manufacturing sector; organizational and marketing innovation play an important role in services; the division between R&D investment and non-R&D innovation expenditures is not at all clear in services and, finally, patent applications are of limited use as output indicators for service firms.

Service industries have undergone a profound transformation in several aspects: the importance of KIS has been growing; the presence of qualified personnel – engineers, economists, analysts, lawyers – and knowledge content has increased; relations with other sectors have been encouraged through outsourcing from manufacturing to services and, finally, the international trade in KIS has grown by offshoring some activities to other countries. The increasing tradability of KIS and the ease with which KIS can be transmitted over long distances facilitate the internationalization of KIS firms and give KIS a major role in regional innovation systems.

In addition, KIS play a crucial role in the creation and commercialization of new products, processes and services (Metcalfe and Miles 2000; Miles 2005). High-tech KIS in particular play a central role in regional innovation systems, especially in those dominated by SMEs. Innovative activities link SMEs and high-tech KIS through the process of generating, transferring and spreading knowledge (Muller and Zenker 2001). Face-to-face interaction is very important in the relationships that KIS firms have with their customers and these relationships tend to be long term (Cohen and Levinthal 1989). Service firms acquire explicit and tactical knowledge about their customer firm which enables them to adopt innovative problem solutions to organization specific requirements and to integrate them into the corresponding firm structure and culture (Strambach 2001).

The interactions between firms and institutions that make up the regional innovation system (universities, research and transfer centres, innovative firms, etc.) generate external economies of knowledge that benefit firms. Most research on the geographic scope of knowledge spillovers suggests that they are local or regional (Jaffe, Trajtenberg, and Henderson 1993; Audretsch and Feldman 1996; Ciccone and Hall 1996). 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. In this context, KIS firms play an increasing role in the generation and transfer of new knowledge.[2]

The effects of KIS on the regional innovation system are direct and indirect. On the one hand, the innovative activities of KIS firms have direct effects such as new knowledge generation, and process, product, organizational and market innovations.[3] In this respect, this study presents empirical evidence about the difference in innovative behaviour between manufacturing and service firms. In manufacturing firms technological innovation is more important, but in service firms innovative activity is more varied, and innovation related to organizational change has greater weight. On the other hand, KIS have indirect effects on and give positive feedback to manufacturing firms. The role of KIS in the regional innovation system is closely related to the nature of their products: expert knowledge, consultancy in different areas, R&D ability and problem-solving ability.

3. The survey

Since the early 1990s, international bodies have initiated two main projects that facilitate the study of the determinants of innovation in both manufacturing and service industries.

On the one hand, a collective project under the auspices of the OECD on the nature and measurement of innovative 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. The most recent version, in particular, points out 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 firms' innovative activities. Since 1990, many European countries have launched different versions of the CIS,[4] which provide access to a range of information about the innovative behaviour of European firms in both manufacturing and services sectors.

The data set used was based on a sample of Catalan firms and was part of the Spanish sample of CIS. This database contains extensive information about the strategies and performance of business innovation during the period 2002–2004. 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, public funds and a large amount of quantitative and qualitative data on the firms' innovative behaviour.

Given that the aim of this article is to study the determinants of innovative activities in both manufacturing and service firms, it is advisable to properly delimit the activities that are included in the services. The KIS sector has often been defined as consisting of many forms of technical and management consultancies and a wide variety of specialists – for example, in financial management, marketing and advertising, staff recruitment and development, trade promotion or distribution logistics (Wood 2002). Eurostat divides the KIS sector into a variety of groups. Knowledge-intensive business services working in telecommunications, computer services and R&D activities – codes 64, 72 and 73 – play an increasing role in the production and diffusion of knowledge in innovation processes (Muller and Zenker 2001). Other KIS related to financial activities, transport and distribution logistics, education, health and social services – codes 61, 62, 65–67, 70, 71, 74, 80, 85 and 92 – play an increasingly more important role in the business environment and affect the ability of companies to innovate.

Our database includes the CIS questionnaires completed by 3554 Catalan firms. In order to analyse the differences between innovation patterns in the manufacturing and service sectors the firm sample is grouped into four categories (Table 1): high-technology manufacturing industries (1130 firms); low-technology manufacturing industries (1443 firms); high-technology KIS (277 firms) and other KIS (704 firms).

3.1. Some descriptive statistics

Before describing the econometric model we shall present some indicators of R&D and innovative activities. We pay special attention to the differences between the four categories. Our data source is the Catalan sample of CIS-4, and the variables used in the empirical work are defined in the appendix. Table 2 shows that in the period 2002–2004 manufacturing firms were more prone to carrying out innovative activities than service firms. In the high-tech industries, 60.0% of firms are innovative; in the low-tech industries, 34.5% of firms are innovative; in the high-tech KIS the percentage of innovative firms rises to 53.4% and, finally, in the other KIS only 20.8% of firms are innovative.[5]

In addition, the number of firms that undertake permanent R&D activities differs between groups. Permanent R&D is applied by 66.2% of the firms in high-tech industries but only by 39.6% firms in low-tech industries. However, permanent R&D is carried out by 67.1% of

Table 1. Classification of manufacturing and service industries.

	ISIC rev. 3
High-tech manufacturing industries	
Aircraft and spacecraft	353
Pharmaceuticals	242
Office, accounting and computing machinery	30
Radio, TV and communications equipment	32
Medical, precision and optical instruments	33
Electrical machinery and apparatus, n.e.c.	31
Motor vehicles, trailers and semi-trailers	34
Chemical products	24 exclusive 2423
Railroad equipment and transport equipment, n.e.c.	35 exclusive 353
Machinery and equipment, n.e.c.	29
Low-tech manufacturing industries	
Coke, refined petroleum products and nuclear fuel	23
Rubber and plastic products	25
Other non-metallic mineral products	26
Metallurgy	27
Metal products	28
Food products, beverages and tobacco	15–16
Textile industry	17
Clothing and furriers	18
Leather articles and footwear	19
Wood and cork	20
Paper industries	21
Printing industries	22
Furniture and other manufactures	36
High-tech knowledge-intensive services	
Post and telecommunications	64
Computer and related activities	72
Research and development	73
Other knowledge-intensive services	
Financial intermediation	65 + 66 + 67
Real estate	70 − 71 − 72 − 73
Health and social work	85
Recreational, cultural and sporting activities	92

Source: OECD and Eurostat.

high-tech KIS firms and only 26.8% of other KIS firms. Also, manufacturing firms usually carry out sporadic R&D activities more frequently than service firms.

In general, there are differences in R&D and innovation between service and manufacturing firms. However, there are also considerable differences in the innovation indicators according to the technological intensity level. High-tech KIS firms have an intense R&D and innovation rate, they are more frequently provided funds by public programmes in support of R&D and innovation, they are more prone to entering into cooperation agreements with partners and they usually register the patents resulting from their research. On the other hand, other KIS have a more moderate KIS activity that rarely apply for public funds and register patents only occasionally.[6]

Innovation inputs in our four categories, however, are very different. In high-tech industries, the ratio of research personnel to total employees is 7.6%; innovation investment per employee is 6764 euros and internal R&D expenditure is 4559 euros. In low-tech industries the ratio of research personnel decreases to 2.1%; innovation investment per employee decreases to 3738 euros and internal R&D expenditure is only 1470 euros. In high-tech KIS

Table 2. Descriptive Statistics sample Catalan CIS-4.

	High-tech industries	Low-tech industries	High-tech KIS	Other KIS
R&D and innovation activities in 2004 (share of firms %)				
Innovation projects	71.50	49.75	71.11	37.78
Permanent R&D	66.28	39.63	67.14	26.84
Sporadic R&D	12.47	10.94	7.22	7.24
Pubic support in R&D	26.99	19.26	43.32	16.61
Cooperative agreements in R&D	25.66	12.19	28.88	13.21
Patents	23.00	11.85	21.66	4.54
Innovative firms by type of innovation in 2002–2004 (share of firms %)				
Innovative firms	60.00	34.58	53.42	20.88
Product innovation	58.84	36.93	54.87	25.42
Process innovation	51.32	44.76	41.15	32.38
Organizational innovation	48.14	38.39	58.84	42.32
Market innovation	26.28	19.81	24.18	13.06
Product or process innovation	70.97	52.94	62.81	38.35
Product and process innovation	39.20	28.75	33.21	19.46
Process product (1)	66.61	77.86	60.52	76.53
Product process (1)	76.37	64.24	80.70	60.08
Product permanent R&D (1)	78.23	69.75	72.04	57.14
Process permanent R&D (1)	65.55	73.60	51.61	65.07
Output product innovation				
New for the firm (% sales)	11.73	7.98	11.11	6.40
New for the market (% sales)	6.33	3.22	14.07	3.19
Average size (workers)	160.14	114.18	161.32	320.15
Average size (sales, millions euros)	51.23	27.59	31.65	39.28
Export over sales (%)	26.06	16.49	9.05	3.03
Number of firms	1130	1443	277	704
R&D and innovation expenditures by firm				
Research personal (% total workers)	7.62	2.19	24.53	4.39
Innovation expenditure per worker (euros)	6764	3748	19,118	4719
Intramural R&D	4559 (67.40)	1470 (39.22)	15,590 (81.55)	3463 (73.38)
External R&D	1346 (19.89)	173 (4.62)	2571 (13.45)	406 (8.60)
Machinery and software	462 (6.83)	1.159 (30.92)	233 (1.22)	586 (12.42)
Other sources	396 (5.85)	943 (25.16)	721 (3.77)	262 (5.55)

Source: Catalan Innovation Survey.
Note: (1) conditional frequencies.

the ratio of research personnel increases to 24.5% of total employees; innovation expenditure per employee increases to 19,118 euros and internal R&D investment is 15,590 euros. In other KIS the ratio of research workers is 4.4%; innovation expenditure is 4719 euros and R&D internal expenditure is 3463 euros.

Descriptive analysis shows that the main differences are between high- and low-tech industries, both manufacturing and service high-technology industries have more firms that systematically innovate, carry out R&D projects and are provided with public funds for R&D. On the other hand, low-technology industries and other KIS have fewer innovating firms that are involved in permanent R&D activities. The number of innovating firms is particularly low in the other KIS group. Manufacturing firms tend to carry out more product and process innovation that is often a novelty for the firm but not for the market.

Service firms, however, carry out less product or process innovation but it is more often innovation for the market. Service firms also carry out more organizational and market innovation than manufacturing firms. Descriptive data show interesting differences between the manufacturing and service sector and between the high- and low-tech sectors in the fields of R&D, sources of innovation and innovation output.

3.2. *Performance and size*

Innovation expenditure and the ratio of innovative firms depends not only on the technological level of an industry and whether an industry belongs to the manufacturing or service sector, but also on firm size (Acs and Audretsch 1988; Acs, Audretsch, and Feldman 1994; Audretsch and Vivarelli 1996). Table 3 shows some interesting information on the relation between firm size and R&D and innovation performance for three quantiles: 0.10, 0.50 (hence the median) and 0.90. In the high-technology manufacturing sector the presence of permanent R&D and innovative firms increases with firm size but innovation expenditure has a U-shaped relation (in small firms the innovation investment is high, in medium firms it is lower and in larger firms it is higher). In the low-technology industries, the number of permanent R&D and innovative firms increases with firm size, but R&D and innovation investment per worker decreases. In the high-technology KIS sector the number of permanent R&D and innovative firms has a U-shaped relation with firm size, and R&D and innovation investment is very high in small firms and decreases with firm size. Finally, in the other KIS group, the number of permanent R&D and innovative firms decreases with firm size and innovation expenditure has a U-shaped relation with firm size. In high-technology manufacturing and service industries there is a U-shaped relationship between firm size and innovative activity according to previous empirical studies (Audretsch and Acs 1991).[7]

In Catalonia, medium-tech manufacturing such as the automobile or chemical industries are very active in the fields of R&D and innovation. These results tally with those obtained by Leydesdorff, Dolfsma, and Panne (2006) in Holland, where medium-tech industries make a large contribution to aggregate innovation. The lack of vitality of Catalan low-tech industrial firms, however, 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

Table 3. R&D and innovative firms by size in 2004 (10%, 50% and 90% quantiles).

Manufacturing industries	High-tech industries			Low-tech industries		
	10%	50%	90%	10%	50%	90%
Permanent R&D firms (%)	55.07	61.81	84.07	27.67	38.92	61.11
Innovative firms (%)	45.65	50.00	79.64	22.01	32.88	52.77
R&D intensity	9839	3799	5483	3049	1792	1017
Innovation intensity	14,205	5032	9134	6678	3885	1690
	High-tech KIS			Other KIS		
Service industries	10%	50%	90%	10%	50%	90%
Permanent R&D firms (%)	98.02	60.71	85.18	45.34	27.14	30.00
Innovative firms (%)	62.06	42.85	74.07	33.72	20.05	28.03
R&D intensity	39.514	11,018	9953	15,905	1846	4067
Innovation intensity	53.933	12,586	13,634	18,198	3286	6438

Source: Catalan Innovation Survey.
Note: R&D and innovation expenditure is expressed in euros per employee.

a much more active role in making innovation a driving force in their competitiveness, especially larger firms that operate in international markets.

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

This section presents a structural model linking R&D, innovation and productivity. It is based on the analytical frame described by Crépon, Duguet and Mairesse (1998), and its successive reexaminations (Kremp, Mairesse, and Mohnen 2004; Mairesse and Mohnen 2004; Griffith et al. 2006; Mohnen, Mairesse, and Dagenais 2006). The CDM model explains productivity in terms of innovation output and innovation output in terms of R&D investment. The basic structure of the model describes how firms decide whether to make an effort to innovate, how much effort to make and how much knowledge is produced as a result of this investment; and output is produced using physical and labour factors and knowledge input.

The CDM model establishes a sequence that ranges from the factors that determine firms' R&D activities, to the effect that innovating firms have on productivity. In the first step, firms decide whether or not to carry out intramural R&D. In the second step, we analyse the determinants of R&D investment. In the third step, we deal with the factors that determine the firm's innovation output. Finally, in the fourth step, we use Cobb–Douglas' production function to determine the effects of innovation output and R&D on firm productivity. We also try to calculate the differences in the behaviour of manufacturing and service firms.

We use our data in four different equations to calculate: (i) firm's decisions to carry out continuous R&D, (ii) the intensity of R&D investment, (iii) the determinants of innovation output and (iv) the output production function where knowledge is an input.

We also describe an econometric model for observing the determinants of R&D decision, innovation output and productivity. The first equation describes whether a firm is engaged in R&D activities or not. We assume there is a latent dependent variable rd_i^* for firm 'i' that expresses some decision criteria, such as the expected present value of the firm's profit related to R&D investment (Crépon, Duguet, and Mairesse 1998). R&D is modelled as a generalized tobit model that expresses R&D decision as follows,

$$\mathrm{rd}_i^* = \beta X_i + \mu_i \tag{1}$$

where X_i is a vector of determinants of R&D decision, β is a vector of parameters to be estimated and μ_i is a random error term. In this binary model, the latent variable, the propensity to engage in R&D activities rd_i^* is not observed. Therefore, the dependent variable is an unobservable latent variable (Greene 2003). The CIS questionnaire only provides information about whether the firm carries out continuous R&D activities or not. Using rd_i to denote the binary variable indicating that firm 'i' engages in continuous R&D activities, we obtain,

$$\mathrm{rd}_i = \begin{cases} = 1 & \text{if } \mathrm{rd}_i^* > 0 \\ = 0 & \text{if } \mathrm{rd}_i^* \leq 0 \end{cases} \tag{2}$$

where rd_i is the observed binary variable which is zero for non-R&D firms and one for R&D firms. As explanatory variable X_i we include firm size and firm size square measured as the log of the firm's employees; a dummy that indicates whether the firm belongs to a group; a dummy that indicates whether the firm receives public financial support in R&D projects; an export dummy; the firm's market share in logs and a dummy with a value of one if the firm was created between 2002 and 2004 and zero otherwise. We also introduce a vector with industry dummy variables that captures the heterogeneity between industries.

The second equation in our generalized tobit model measures a firm's R&D intensity as the amount of R&D expenditure per employee. A firm's R&D effort is described by the latent variable r_i^*,

$$r_i^* = \alpha Z_i + \varepsilon_i \tag{3}$$

where Z_i is a vector of determinants of R&D effort, α is a vector of parameters to be estimated and ε_i is a random error term. As explanatory variables of R&D intensity, we use firm size, firm size square, a group membership dummy, public funds for R&D projects, firm market share, an export dummy and four dummy variables that capture sources of information that are proxies of knowledge spillovers: internal information sources within internal departments or other firms of the group; market information sources from clients and suppliers; institutional information sources from public research centres and universities; and tacit information sources from conferences, trade fairs and face-to-face contacts. In all estimations we also introduce a vector with industry dummy variables. We can see the amount of resources that an individual firm devotes to R&D projects and firm research effort is defined as follows,

$$r_i = \begin{cases} r_i^* = \alpha\alpha_i + \varepsilon_i & \text{if } \mathrm{rd}_i = 1 \\ 0 & \text{if } \mathrm{rd}_i = 0 \end{cases} \tag{4}$$

From expressions (1) and (3) we can estimate the determinants of the propensity to invest and the intensity of investment in R&D in our four sectorial groups: high-tech manufacturing industries, low-tech manufacturing industries, high-tech KIS and other KIS. Our decision equation takes into account all firms and the intensity equation concentrates on innovative firms that carry out continuous R&D activities.

A firm's R&D activity generates knowledge and gives rise to various innovation outputs. We measure knowledge output with six indicators. Four dichotomic variables are related to product, process and organizational innovation and patent applications, and two continuous variables are related to the share in the sales of new products or services new to the firm or to the market. In general the output innovation equation depends on R&D and has the following general form,

$$g_i = \gamma r_i + \delta W_i + \upsilon_i \tag{5}$$

where r_i is the firm's R&D intensity measured as the amount of R&D expenditure per employee, W_i is a vector with the remaining determinants of knowledge production and υ_i is a random error term. Since output innovation presents two types of variables – a percentage of innovative output on sales and a dichotomic output related to product, process and organizational innovation and patent applications – the appropriate model is a generalized tobit model, with four selection equations and two intensity equations (Mairesse and Mohnen 2005). In these estimations we are interested in determining the effect of R&D on innovation. We control for size and firm market share expressed as logs; a dummy that indicates whether the firm belongs to a group; a dummy that takes the value 1 when the firms make cooperation agreements for R&D projects with other partners; a dummy that indicates whether the firm receives public funding for R&D and innovation in the EU, Spain or Catalonia; a dummy that indicates whether the firm exports; a vector with industry dummy variables and an 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 in-house R&D expenditures and innovation output) and a vector with the firm's characteristics. Under the assumption of constant returns to scale and by applying logarithms, the output production takes the following form,

$$y_i = \pi_1 l_i + \pi_2 k_i + \pi_3 g_i + \pi_4 X_i + \nu_i \qquad (6)$$

where y_i is the firm productivity level measured as sales per employee, l_i is the labour factor, k_i is the physical capital measured by physical investment, g_i is a vector of output innovation and, finally, X_i is a vector of firm characteristics and ν_i is a random error term. As explanatory variables we include output measures, in particular the innovative share of sales per employee, and two measures of input innovation related to the number of scientific personnel per total employees and R&D expenditures per total employees. We also control for size and market share in logs, patents, group, cooperation in R&D, and export and sectorial characteristics expressed as dummy variables.

5. Results

In this section we summarize the results of our econometric analysis. All results are expressed in terms of the marginal effect of the explanatory variables in the R&D and innovation equations. In all estimations we have obtained specific results for four subsamples of firms in accordance with the technological intensity in the manufacturing sector and the knowledge intensity in the service sector.

First we estimate what characteristics affect the probability that a firm will carry out permanent R&D activities. In line with the recent literature, we are interested in observing how a firm's individual characteristics affect the probability of undertaking permanent R&D.

5.1. Determining factors of R&D behaviour

Table 4 compares the marginal effects of the explanatory variables in the permanent R&D equation. The results obtained using a logit binomial model show that the propensity to engage in permanent R&D increases with a firm's market share (particularly in manufacturing industries), the availability of public funds and whether the firm exports. When firms are involved in foreign markets the propensity to engage in continuous intramural R&D increases by 20.2 percentage points in high-tech manufacturing industries, by 15.6 percentage points in low-tech manufacturing industries, by 13.1 percentage points in high-tech KIS and by 10.0 percentage points in other KIS. In contrast, the relation between the propensity to engage in permanent R&D and size describes a U-shape curve. These results tell us that small and large firms have a greater propensity to undertake permanent R&D, whereas medium-size companies have a lower propensity to carry out permanent R&D. In particular, there are numerous small firms that carry out continuous R&D in high-tech KIS: in the first decile 89.1% of the smallest firms in the sample carried out continuous R&D, whereas the mean number of firms with continuous R&D was 39.3% in the high-tech KIS subsample.

Contrary to our expectations, we found that belonging to a group of firms has different effects on the probability of carrying out continuous R&D. In high-tech industries, belonging to a group has a positive impact on the R&D intensity, but in other KIS firms it has a positive effect on the carrying out of continuous R&D. These results may reflect that the variable propensity to R&D has a lower informative capacity than the variable R&D intensity in high-technology industries. In addition, new firms created during the period 2002–2004 are more prone to carrying out continuous R&D activities in high-tech manufacturing industries.

Finally, the firm's market share and exports have a positive effect on the propensity of firms to undertake internal R&D. These results are particularly important in manufactured

Table 4. Determinants of permanent R&D.

	High-tech industries		Low-tech industries		High-tech KIS		Other KIS	
	Propensity to R&D	Intensity of R&D	Propensity to R&D	Intensity of R&D	Propensity to R&D	Intensity of R&D	Propensity to R&D	Intensity of R&D
Size	−12.591	−106.115	−17.842	−137.223	−36.179	−38.484	−28.820	−105.283
	(0.076)***	(0.148)*	(0.084)**	(0.228)*	(0.107)*	(0.190)**	(0.062)*	(0.236)*
Size square	1.545	4.299	1.879	7.473	4.063	−3.165	2.162	2.494
	(0.008)***	(0.014)*	(0.009)**	(0.024)*	(0.012)*	(0.021)	(0.005)*	(0.026)
Group	−10.898	20.492	3.545	19.002	−6.067	15.416	13.419	10.526
	(0.039)*	(0.094)**	(0.038)	(0.119)	(0.066)	(0.204)	(0.047)*	(0.212)
Public funds	30.230	64.677	42.530	60.857	28.364	77.888	59.322	99.843
	(0.025)*	(0.080)*	(0.033)*	(0.103)*	(0.062)*	(0.177)*	(0.049)*	(0.187)*
New firm	24.053	54.150	−1.575	33.185	7.772	68.848	−1.676	−65.181
	(0.040)*	(0.280)**	(0.120)	(0.440)	(0.077)	(0.279)*	(0.108)	(0.456)
Export	20.285	−29.668	15.688	−3.977	13.106	23.206	10.099	−6.087
	(0.041)*	(0.109)*	(0.032)*	(0.122)	(0.051)*	(0.165)	(0.056)***	(0.201)
Market share	6.516	39.871	8.654	25.843	2.634	33.734	6.629	22.125
	(0.022)*	(0.059)*	(0.020)*	(0.070)*	(0.030)	(0.087)*	(0.019)*	(0.102)**
Internal information sources		12.967		14.377		43.038		−9.749
		(0.078)***		(0.096)		(0.167)*		(0.193)
Market information sources		1.785		4.326		6.050		61.142
		1.785		4.326		6.050		61.142
Institutional information sources		−0.003		64.311		55.495		−6.260
		(0.118)		(0.182)*		(0.201)*		(0.259)
Tacit information sources		9.304		16.789		−0.323		28.992
		(0.095)		(0.128)		(0.200)		(0.243)
Sectorial dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Number observations	1130	749	1443	572	277	186	704	189
Chi *q*	243.39	259.51	354.52	180.13	131.39	129.44	250.54	181.71
R^2	16.85	11.03	18.29	9.32	37.46	19.42	30.59	27.33

Source: Catalan Innovation Survey.
Note: All marginal effects on R&D decision variable are in percentage points. Size, size square and market share are expressed in logs; group, public funds, new firm and export are dummy variables; and all regressions include a dummy variable for industry effects (8 in high-tech industries, 13 in low-tech industries, 3 in high-tech KIS and 9 in other KIS).
*Significant at 1%; **significant at 5%; ***significant at 10%; standard errors in parentheses.

goods of high technological intensity, given that the elasticities of the market share and the orientation towards the foreign markets are high. Our results show that firm size does not have a linear effect on R&D, but, in relation to the second Schumpeterian hypothesis, we find that the market power of firms stimulates R&D activities. These results agree with other studies (Blundell, Griffith, and Van Reenen 1999) and indicate that the dominant firms in their regional markets have a higher incentive to innovate.

These results agree with those obtained for Spanish industrial firms during the period 1994–2004 that showed that market product competition promotes productivity growth when 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 extensive theoretical and empirical literature that has been published in recent years, based on the neo-Schumpeterian models that show greater incentives to innovate when there is a certain level of competitive rivalry in the market, while allowing firms to obtain positive profit margins (see survey in Aghion and Griffith 2005).

When we analyse the marginal effects of explanatory variables on R&D intensity in the four subsamples of innovating firms, we observe considerable differences between the determinants of continuous R&D and the intensity of R&D expenditures. R&D intensity in all subsamples is positively affected by the firm's market share and the availability of public funds. In addition, new firms that were created during the period 2002–2004 present high levels of R&D expenditures in high-tech industries, in both the manufacturing and service sectors. New firms increase R&D intensity by 54.1 percentage points in high-tech manufacturing industries and by 68.8 percentage points in high-tech KIS. Internal sources of information from other firms in the group play an important role in high-tech manufacturing industries and high-tech KIS, and information from public organizations and universities positively affects R&D intensity in low-tech manufacturing industries and high-tech KIS. Tacit information channels are not significant.

There are interesting differences between the propensity to engage in continuous R&D and R&D intensity in different industries. High-tech manufacturing and service industries are more sensitive to public funds and export activities, and firms that are new or that have internal sources of information tend to have greater R&D intensity. The market share of low-tech manufacturing and service industries increases the propensity to engage in R&D, but its effect on R&D intensity is lower.

5.2. Determining factors of innovative behaviour

In this section we analyse a set of indicators of innovative output. The CIS questionnaire provides qualitative and quantitative indicators of innovative output. Two of the indicators are quantitative and measure the product innovation new to the firm (but not necessarily to the sector) and the product innovation new to the market. Products new to the firm are the share in sales of products or services new to the firm but not to the market, and products new to the market are the share in sales of products and services new to the market. These indicators relate the novelty of the sales to the product innovation of a firm during the period 2002–2004. Products new to the firm are already on the market and firms imitate other competitors. Products new to the market are examples of true innovation: that is to say, innovative firms discover new products or services. In markets where product differentiation is the driving force in market competition, the share of new products or services will be higher. Both indicators provide quantitative information about product innovation and this can be interpreted as a measure of innovativeness (i.e. shares in sales taken by new products).

In addition, we use four dichotomous indicators of innovation output: a firm's product, process and organizational innovation and patent applications. The CIS-4 questionnaire provides interesting information about activities undertaken by a firm to carry out innovations during the period 2002–2004. Table 5 presents the results of econometric analysis in terms of the marginal effect on the various innovation indicators. We are especially interested in comparing the marginal effects of R&D intensity (R&D expenditures per employee) and research employees (numbers of researchers per total employees) on eight measures of innovation output.

In general these results show that the probability that a firm will innovate increases with its size, with a higher R&D input and with contracts being given to research personnel. Product and process innovation correlates positively with firm size, except in other KIS activities, but firm size has little marginal effect on the propensity to materialize innovation outputs. The probability that a firm will engage in product or process innovation increases with R&D intensity and firm size in both manufacturing and service high-tech industries, but not in low-tech industries. Large firms have a greater capacity to undertake permanent innovations, but the relationship between innovation and firm size is not simple. In our sample, large firms are more prone to engaging in continuous innovation but the number of innovative small firms is high, particularly among those created during the period 2002–2004.[8] Our results differ from those obtained by Lööf and Heshmati (2006) with data from Swedish manufacturing and service firms in the mid-1990s. They found that the probability of innovating increased with firm size in both manufacturing and service industries. However, after controlling for industry and obstacles to innovation investment, they found that innovation intensity was not constant and decreased with size.

When we compared the marginal impact of R&D, research workers and size in the four groups of industries we found important differences. In particular, the propensity to register patents is low in other KIS sectors, and R&D intensity, research workers and size do not significantly affect the probability that a firm will do so. Traditionally, service sector firms have developed new products and processes in the absence of legal protection mechanisms (Encaoua, Guellec, and Martínez 2006). However, innovative firms in high-tech KIS have started to patent extensively in Catalonia in recent decades. In 2004, 21.66% high-tech KIS firms have some patents.

In general terms, the marginal effects of the explanatory variables on the different indicators of innovation output are quite different in different sectorial groups. The differences between high- and low-tech industries, in both the manufacturing and service sectors, are particularly important. Therefore, high-tech industries are not a good mirror for low-tech manufacturing industries or other KIS in relation to determinants of output innovation.

Our results indicate that in high-tech manufacturing industries internal R&D per employee, research employees and size increase the probability of innovation. The positive effect of firm size shows the presence of important economies of scale in innovation activities due to the sunk cost linked to R&D or the capacity of the firm to finance and achieve a return on their innovations (Cohen and Klepper 1996). In product and process innovations, the elasticity of internal R&D activities, researchers/employees and size is high. In high-tech industries if the R&D intensity increases by 100% the probability of introducing product innovation increases by 9.0%, the probability of introducing a new process increases by 4.2% and the probability of applying for a patent increases by 5.7%. These results are in line with the similar marginal effects obtained for other European countries (Mairesse and Mohnen 2005). The probability of making new products is sensitive to R&D intensity. If R&D intensity increases by 100%, the probability of obtaining products new to the firm increases by 8.3% and the probability of developing products new to the

Table 5. Determinants of innovation activities.

	Product new to the firm		Product new to the market					
	Yes/no	Share in sales	Yes/no	Share in sales	Product innovation Yes/no	Process innovation Yes/no	Patents Yes/no	Organizational innovation
High-tech industries								
R&D intensity	8.300	−2.443	5.702	1.200	9.066	4.274	5.723	2.771
	(0.024)*	(0.021)	(0.019)*	(0.024)	(0.026)*	(0.023)***	(0.015)*	(0.023)
Research employees	0.275	0.368	0.463	0.427	0.729	−0.078	0.129	0.220
	(0.002)	(0.001)**	(0.001)*	(0.002)*	(0.002)*	(0.002)	(0.001)	(0.002)
Size	11.925	3.457	1.195	−2.190	8.516	5.464	4.354	7.639
	(0.033)*	(0.031)	(0.028)	(0.040)	(0.033)*	(0.032)***	(0.024)***	(0.032)*
R^2	12.08	11.22	10.87	15.13	20.14	8.10	19.83	10.05
Number of firms	1130	536	1130	328	1130	1130	1130	1130
Low-tech industries								
R&D intensity	−1.807	6.166	1.198	0.761	−2.519	−5.626	1.787	−2.338
	(0.017)	(0.025)*	(0.012)	(0.028)	(0.022)	(0.025)**	(0.009)***	(0.021)
Research employees (% total workers)	0.951	−0.692	0.427	0.704	1.873	1.619	0.334	0.583
	(0.002)*	(0.004)	(0.001)*	(0.004)	(0.003)*	(0.004)*	(0.001)*	(0.003)***
Size	1.042	2.469	0.899	−1.808	1.202	1.602	2.174	−1.783
	(0.022)	(0.040)	(0.016)	(0.039)	(0.026)	(0.028)	(0.012)***	(0.025)
R^2	9.73	8.15	11.75	25.18	15.25	16.30	14.79	8.43
Number of firms	1443	401	1443	242	1443	1443	1387	1443

High-tech KIS								
R&D intensity	5.456	3.407	10.755	7.846	8.681	5.346	0.124	8.365
	(0.040)	(0.039)	(0.041)*	(0.050)	(0.048)***	(0.044)	(0.029)	(0.045)***
Research employees (% total workers)	−0.209	0.299	−0.161	−0.037	−0.274	−0.134	0.243	−0.366
	(0.001)	(0.001)***	(0.001)	(0.002)	(0.002)	(0.002)	(0.001)***	(0.002)***
Size	2.085	0.085	7.803	−0.273	6.132	7.692	0.725	3.857
	(0.043)	(0.047)	(0.046)***	(0.059)	(0.050)	(0.047)***	(0.032)	(0.046)
R^2	6.33	30.97	18.27	16.47	17.92	11.52	17.87	8.91
Number of firms	277	97	277	99	277	277	277	277
Other KIS								
R&D intensity	−1.368	−3.833	−0.623	−12.15	−4.299	−5.997	0.623	−7.874
	(0.017)	(0.056)	(0.008)	(0.051)**	(0.021)**	(0.027)**	(0.007)	(0.032)
Research employees (% total workers)	0.019	0.148	0.145	0.521	0.246	0.267	0.026	0.360
	(0.001)	(0.003)	(0.000)*	(0.002)	(0.001)	(0.002)	(0.000)	(0.002)
Size	−3.555	−7.342	0.355	4.508	−5.034	−1.877	−0.259	1.520
	(0.015)**	(0.053)	(0.009)	(0.087)	(0.019)*	(0.022)	(0.006)	(0.022)
R^2	16.10	15.38	26.37	38.68	24.56	18.98	17.92	12.38
Number of firms	704	133	665	68	704	704	648	704

Source: Catalan Innovation Survey.
Note: Research employees (% total workers).
Product new to the firm and product new to the market are expressed as the share of sales. Product innovation, process innovation, patent applications and organizational innovation are dichotomic variables. All marginal effects are in percentage points. All regressions include instrumental variables. Size and market share are expressed in logs; group, public funds, cooperation R&D and export are dummy variables; dummy variable for industry effects (8 in high-tech industries, 13 in low-tech industries, 3 in high-tech KIS and 9 in other KIS).
*Significant at 1%; **significant at 5%; ***significant at 10%; standard errors in parentheses.

market increases by 5.7%. However, R&D intensity does not have a significant effect on the share in sales of new products.

In low-tech industries, the effect of R&D intensity, research personnel and firm size on innovation is more ambiguous. The marginal effect of R&D intensity on the share of new products on the market and patent applications is small and positive, but the presence of researchers on a firm's staff has a positive marginal effect on all dichotomous measures of output innovation. When the number of researchers per total employees in the firm increases by 100%, the propensity to carry out product innovation increases by 1.8% and the propensity to carry out process innovation increases by 1.6%.

In high-tech KIS the effect of R&D intensity on innovation in general is strong. The marginal effect of R&D intensity is high on the share of new products, product innovation and organizational innovation. In contrast, in other KIS the effect of R&D intensity, the ratio of researchers to total employees and firm size are not relevant, and often present negative parameters.

5.3. Productivity and innovation effects at the firm level

The relationship between R&D, innovation and productivity has been widely examined in the last two decades. Many studies have found a significant link between innovation and productivity (Griliches and Mairesse 1998), but other studies have failed to do so. In general, empirical studies based on cross-section data are more likely to find a significant link between innovation and productivity (Crépon, Duguet, and Mairesse 1998).

Therefore, having analysed how the individual characteristics and conditions of the market in which firms operate affect R&D and innovation, this section explores how different indicators of innovation affect a firm's productivity. R&D and innovation activities increase productivity in different ways. First, they generate new knowledge and bring new products to the firm and the market. In this respect, physical technologies play a leading role in the process of economic growth, but social institutions are required to reduce transaction costs, promote financial support, protect property rights and define the rules of the game (Nelson and Nelson 2002). Secondly, intramural R&D plays the dual role of producing new knowledge and promoting a firm's 'absorptive capacity' from external sources of information (Cohen and Levinthal 1990). This means that R&D can affect productivity by facilitating the absorption of new technologies (Parisi, Schiantarelli, and Sembenelli 2006). Finally, R&D directly affects a firm's knowledge capital and spillovers on productivity (Jaffe 1986; Griliches 1992), increases profitability (Geroski, Machin, and Van Reenen 1993; Hanel and St-Pierre 2002; Cefis and Ciccarelli 2005) and has a positive effect on the probability of survival (Cefis and Marsili 2006). Innovating strategies increases a firm's turnover growth (Morone and Testa 2008) and are crucial for the fastest growing firms (Coad and Rao 2008).

Our estimation approach has some potential problems. Given the limitations of our database in the empirical estimation, we cannot include lagged innovation measures in our equation assuming that innovation affects productivity in the same period. However, the timing of the relationship between innovation and productivity is not clear (Hall and Mairesse 1995). When lagged innovation indicators have been included, they tend to reduce the explanatory power of other variables due to the widely observed persistence of innovation activities (Hall, Griliches, and Hausman 1986). Therefore, this restriction has a moderate effect on the results because as Scherer (1982) pointed out, R&D intensity in manufacturing firms is relatively stable over time so the timing of the variable seems to have little effect in practice. In addition, the persistence of R&D and innovation activities versus time is strong across firms (Cefis and Orsenigo 2001; Roper and Hewitt-Dundas 2008) and the distribution of the returns of innovating firms is also extremely stable (Marsili and Salter 2005).

Using expression (6) we can directly derive the empirical model that will serve as a basis on which to study the effect of innovation indicators on firm productivity. As determinants of a firm's productivity level we introduce five variables related to output and input innovation: the percentage of new products and services in each worker's sales; the number of scientific personnel per total employees; R&D intensity measured as internal R&D investment per worker; a dummy that indicates whether the firm has registered any patents and a dummy that indicates if the firm has any cooperation agreements with other partners.[9] All regressions include a set of control variables related to the individual characteristics of the firms: the firm size, measured as the number of workers; a dummy that indicates if the firm belongs to a group; the investment in physical capital per worker; the firm's market share; a dummy that indicates if the firm exports and a set of sectorial dummies.

Unlike Crépon, Duguet and Mairesse (1998), we considered all firms in our estimation. But before analysing econometric results, the problems of measuring the elasticity of labour productivity with respect to innovation indicators in both manufacturing and services need to be taken into account. Our database provided only a weak measure of production: total sales per total workers of the firm. These considerations are particularly important in the service sector. Indeed, the problems of measuring the elasticity of productivity with respect to innovation indicators in the service sector are a difficult task. For some authors quality improvements in service production are sometimes almost impossible to measure (Aghion and Howitt 1998), and for others it is harder to achieve productivity improvements in services than in manufacturing industries (Lööf 2004). In this respect, the introduction of an innovation is always the result of blending and recombining elements of technological knowledge both as assets and embodied in capital goods, external knowledge, organizational procedures and routines introduced elsewhere (Antonelli 2006).

The results obtained in the four sectorial groups considered indicate that size has a positive effect on productivity in manufacturing industries but not in services. Investment in physical capital, market share, export activities and membership of a group appears to be significantly associated with labour productivity. Investment in physical capital (more accurately, investment per employee) has a positive effect on productivity.[10] As far as market characteristics are concerned, those firms that have a larger market share and a larger percentage of new products or services also reach higher levels of productivity. 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 sectors of both manufacturing and service industries. In line with 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.

As we expected, all columns in Table 6 show that R&D intensity increases labour productivity.[11] It increased productivity by 7.9 percentage points in high-tech manufacturing industries, by 6.0 percentage points in low-tech manufacturing industries, by 11.7 percentage points in high-tech KIS and by only 2.5 percentage points in other KIS. These results are in line with those of other studies (Crépon, Duguet, and Mairesse 1998; Kafouros 2005), and highlight how R&D intensity increases labour productivity, particularly in high-tech service and manufacturing industries.[12] When we measured output innovation as a share of sales we found that this factor positively affects labour productivity. The elasticity of the share of new products and services of total sales is about 7 percentage points, except in other KIS, which have a more moderate elasticity of about 5.7%.

Table 6. Labour productivity.

	High-tech industries	Low-tech industries	High-tech KIS	Other KIS
New product per worker	7.597 (0.012)*	7.171 (0.014)*	7.111 (0.039)***	5.781 (0.029)**
Research employees	−0.304 (0.002)	0.531 (0.014)	−0.517 (0.003)	−0.032 (0.003)
R&D intensity	7.969 (0.028)*	6.063 (0.029)**	11.702 (0.068)***	2.589 (0.043)
Size	5.274 (0.021)*	2.999 (0.022)	−1.910 (0.048)	−22.132 (0.025)*
Patent	−4.802 (0.050)	−6.750 (0.061)	−10.524 (0.142)	6.384 (0.165)
Group	29.958 (0.048)*	25.569 (0.049)*	39.89 (0.127)*	45.228 (0.076)*
Cooperation	−5.718 (0.049)	3.841 (0.060)	−9.277 (0.132)	−2.129 (0.110)
Investment per worker	8.652 (0.014)*	8.299 (0.013)*	7.412 (0.036)**	15.058 (0.019)*
Market share	3.268 (0.005)*	6.248 (0.008)*	4.136 (0.011)*	7.291 (0.009)*
Export	36.288 (0.050)*	50.989 (0.042)*	−10.145 (0.117)	45.768 (0.094)*
Sectorial dummies	Yes	Yes	Yes	Yes
Number observations	1130	1443	277	704
R^2	38.21	36.29	20.29	52.76

Source: Catalan Innovation Survey.
Note: All marginal effects on R&D decision variable are in percentage points. New products per worker, size and market share are expressed in logs; group, public funds, new firm and export are dummy variables; and all regressions include dummy variables for industry effects (8 in high-tech industries, 13 in low-tech industries, 3 in high-tech KIS and 9 in other KIS).
*Significant at 1%; **significant at 5%; ***significant at 10%; standard errors in parentheses.

In contrast, the three remaining innovation indicators – the share of scientific personnel per total employees of the firm, patent applications and cooperation agreements on R&D projects with other partners – have no significant effect on productivity in the four sectorial subgroups studied.

6. Conclusions

In this article we have attempted to link the determinants of firms' R&D decisions and innovation activities and the effect of innovation on productivity in a range of firms in the Catalonia region. 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 are part of the traditional industrial mix based on medium- and low-technology industries, have shown a considerable capacity for adaptation. However, today there are still serious structural imbalances that condition the behaviour and the change of firms. 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. An increasing number of firms in KIS plays a dynamic role in the promotion of innovation and productivity gains. Previous econometric work on the determinants of R&D activities provides interesting empirical results and shows notable differences between manufacturing and service industries, and high- and low-tech industries.

The empirical findings can be summarized as follows. First, a firm's propensity to engage in permanent R&D increases with its market share, specially in manufacturing industries, and when firms sell in foreign markets. When a firm exports, its propensity to engage in continuous intramural R&D increases by 20.2 percentage points in high-tech manufacturing industries, by 15.6 percentage points in low-tech manufacturing industries, by 13.1 percentage points in high-tech KIS and by 10.0 percentage points in other KIS. Secondly, the link between R&D decision and firm size describes a U-shape relation. Small and large firms have a greater propensity to undertake continuous R&D than medium-size firms. This relation is more pronounced in high-tech KIS where numerous small firms undertake continuous R&D. In terms of R&D firm decisions and R&D intensity our results do not show a linear link between firm size and R&D. However, in accordance with the Schumpeterian hypothesis, we find that market power encourages firms to undertake R&D and innovation activities.

R&D intensity in all sectorial categories is also directly affected by the availability of public funds and firm market share, but the export orientation of the firm only positively affects R&D investment in service industries. In addition, new firms created during the period 2002–2004 present high levels of R&D expenditures in high-tech manufacturing and service industries. Firms less than 3 years old increase R&D intensity to 54.1 percentage points in high-tech manufacturing industries and to 68.8 percentage points in high-tech KIS. High-tech manufacturing industries and high-tech KIS are more sensitive to market share, public funds and export activities. In low-tech industries and services the market share increases the propensity to engage in R&D, but the export activity of a firm and the presence of new firms have no direct effect on firm R&D intensity.

When we applied a probit model to analyse the determinants of output innovation the main results were the following: the probability that a firm will innovate increases with its size, with higher R&D inputs and with the contracting of research personnel. The probability of product or process innovation increases with R&D intensity and firm size in high-tech manufacturing and service industries, but its effect is much more moderate in low-tech industries. Large firms are more prone to engage in continuous innovation but the number of innovative firms is high among small and young firms.

When we analysed the link between innovation and productivity, we found that labour productivity was directly affected by R&D intensity, output innovation proxied by the share of new products or services in sales, belonging to a group, investment in physical capital and firm market share on labour productivity. R&D intensity presents positive marginal elasticity on labour productivity in all estimations: 7.9% in high-tech manufacturing industries, 6.0% in low-tech manufacturing industries, 11.7% in high-tech KIS and only 2.5% in other KIS. However, firm size has a positive effect on productivity in manufacturing industries but not in services. In addition, when firms export their productivity level increases, particularly in low-tech manufacturing and service industries.

Catalonia is a good place for analysing the differences and similarities between manufacturing and service industries. There is a high presence of innovative service firms, especially in high-tech KIS. Young and small firms in the KIS sector are very prone to carrying out R&D, they invest heavily in innovation and they are often involved in a wide variety of innovations (product, process, organizational and market). It is clear that if appropriate policies for promoting innovation are to be designed, the determinants of R&D activities and output innovation need to be understood. What is more, when studying the link between firm productivity level and innovation sources we have found some important differences in the behaviour of manufacturing and service firms.

Today the borders separating manufacturing and service industries are increasingly fuzzy. The traditional industrial classification that distinguishes between goods and services is no longer applicable in the current knowledge economy, in which KIS are important driving forces that promote innovation, drive economic growth and enhance international competitiveness.

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Notes

1. Despite this, it is not easy to analyse the nature of the innovation process in services given the characteristics of the information data. The fact that the *Oslo manual* and CIS questionnaire present a clear dichotomous distinction between (technological) product and process innovation limits the possibilities of properly studying the differences in the pattern of innovation in manufacturing and service firms.
2. Empirical studies show that innovation rates are greater in those regions with high concentrations of KIS (Camacho and Rodríguez 2005b).
3. Strambach (2001) argued that KIS, in particular high-tech KIS, have a direct effect on the development of KIS's own innovations and an indirect effect in four different ways: knowledge transfer in the form of specialized technological knowledge or know-how management, integration of the different stocks of knowledge and competences, adaptation of existing knowledge to the specific needs of clients and production of new knowledge. KIS produce and spread knowledge, which is crucial for innovation processes.
4. 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.
5. According to CIS empirical literature a firm is considered to be innovative when it carries out innovation products or innovation processes and permanent R&D activities. A firm is considered to undertake permanent R&D when it responds in the affirmative to the following question in the survey: *Does your company undertake continuous R&D?*.
6. In general, the propensity to patent may differ widely by sectors (Brouwer and Kleinknecht 1999).
7. For a sample of 2954 Catalan firms in manufacturing and service industries Segarra, Garcia and Teruel (2008) found that innovative firms have higher barriers to innovation than non-innovative firms, especially in the cost and knowledge fields. In addition, small firms have higher barriers to innovation than their counterparts, especially in two items related to cost; lack of internal funds and high cost of innovation. At the industrial group level, high-tech manufacturing shows a higher global index of barriers to innovation, especially in the items related to cost factors, than low-tech manufacturing and KIS.
8. 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.
9. For Spanish firms Segarra and Arauzo (2008) found that R&D cooperation performance between firms and partners differs a lot between manufacturing and service industries and between low- and high-tech industries.
10. As we did, in a sample of Spanish manufacturing firms, Huergo and Jaumandreu (2004) found that the innovation process at some point leads to extra productivity growth, which persists but decreases over time.
11. Extensive empirical literature has found that a firm's decisions on R&D and physical investment are affected by financing constraints. For a panel of German firms, Harhoff (2000) found evidence that larger firms have no financing constraints on physical investment but that small firms do. He found no empirical evidence of financing constraints on R&D investments. On the other hand, some research provides empirical evidence that R&D expenditures and physical investment are highly sensitive to cash flow and that R&D activities are affected by financial constraints (Hall 1992).
12. The sensitivity of labour productivity to R&D investment is moderate in developing economies that are still a long way from the technological frontier. For example, in a range of Chilean firms, Benavente (2006) found that R&D does not contribute to productivity.

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Appendix

Definition of variables

Permanent R&D firm: Dummy variable, which takes the value 1 if the firm 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).

Innovative firm: Dummy variable, which takes the value 1 if the firm 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 firm reports having introduced new or significantly improved production processes during 2002–2004.

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

Organizational innovation: Dummy variable, which takes the value 1 if the firm reports having introduced new or significantly amended forms of organization, business structures or practices, aimed at step changes in internal efficiency during 2002–2004.

New firm: Dummy variable that takes the value 1 if the firm was created during the three-year period 2002–2004.

Products new to the firm: Dummy variable, which takes the value 1 if the firm introduced products or services new to the firm but not new to the market during 2002–2004.

Share of products new to the firm: Share in sales of new products or services new to the firm but not new to the market during 2002–2004.

Products new to the market: Dummy variable, which takes the value 1 if the firm introduced products or services new to the market during 2002–2004.

Share of products new to the market: Share in sales of new products or services new to the market during 2002–2004.

New products per worker: Share in sales of new products or services per worker during 2002–2004.

Patents: Dummy variable, which takes the value 1 if the firm made patent applications to protect innovations during the three-year period 2002–2004.

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

Size: Number of employees of the firm (in log).

Size square: Square number of employees of the firm (in log).

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

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

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

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

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

Export: Dummy variable, which takes the value 1 if the firm exports some of its sales in 2004.

Research employees: Personnel (researchers and grant holders) involved full time in internal R&D carried out by the firm.

Internal information sources: Dummy variable, which takes the value 1 if the firm has innovation sources for innovation activities from the enterprise or enterprise group during the period 2002–2004.

Market information sources: Dummy variable, which takes the value 1 if the firm has information sources for innovation activities from suppliers, customers or competitors during the period 2002–2004.

Institutional information sources: Dummy variable, which takes the value 1 if the firm has information sources from universities or public research centres during the period 2002–2004.

Tacit information sources: Dummy variable, which takes the value 1 if the firm has information sources from conferences, trade fairs, exhibitions, technical publications, professional and industry associations or face-to-face contacts during the period 2002–2004.