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The role of learning in innovation: in-house *versus* externally contracted R&D experience

Pilar Beneito, M. Engracia Rochina and Amparo Sanchis[*]

Abstract

This paper analyses the role of learning in firms' innovation success, taking into account the heterogeneous nature of innovation activities, and in particular, distinguishing between learning arising from the internal organization of R&D activities and learning from externally contracting these activities. We use a representative sample of Spanish manufacturing firms for the period 1990-2006, and within an innovation production function approach, we estimate count data models to investigate the influence of firms' in-house and externally contracted R&D experience in the achievement of innovative results. Our results show that learning is important in the achievement of product innovations when the firms organize R&D activities internally, and that experience from externally contracted R&D activities does not influence the number of product innovations.

Keywords: innovation, accumulation of knowledge, in-house R&D experience, externally contracted R&D experience, count data models.
JEL Classification: O30, O34, C23, C10.

Resumen

En este trabajo se analiza el papel del aprendizaje en el éxito innovador de las empresas, tomando en consideración la naturaleza heterogénea de las actividades innovadoras, y en particular, distinguiendo entre el aprendizaje que proviene de la realización interna de actividades de I+D y el aprendizaje que proviene de la contratación externa de estas actividades. Para este trabajo se utiliza una muestra representativa de empresas manufactureras en España durante el período 1990-2006, y dentro del marco de una función de producción de innovaciones, se estiman modelos "count" con el fin de investigar la influencia que tiene en la obtención de resultados innovadores la experiencia que proviene de la I+D realizada dentro de la empresa y de la contratada externamente. Nuestros resultados muestran que el aprendizaje tiene un papel importante en la obtención de innovaciones de producto cuando las empresas organizan sus actividades de I+D internamente, y que la experiencia que proviene de la contratación externa de actividades de I+D no influye sobre el número de innovaciones de producto.

Palabras clave*:* innovación, acumulación de conocimiento, experiencia en I+D interna, experiencia en I+D contratada externamente, modelos para datos "count".

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1. INTRODUCTION

Despite widespread acknowledgement of the importance of continuity in the performance of R&D activities for the achievement of innovation outcomes, the empirical literature has devoted little attention to the role of learning, understood as the accumulation of knowledge, in the process of innovation.

In this paper we follow Beneito *et al.* (2007) and argue that R&D learning, understood as the accumulation of knowledge and measured as past experience in the performance of R&D activities, is an important driver in the achievement of innovation results, and that its effect is not properly measured by R&D capital stock.[1] However, in this paper we extend their analysis by considering that knowledge accumulation and learning derived from the performance of in-house R&D activities, is of a different nature as compared to externally contracted R&D.[2] In particular, our working hypothesis is that in-house R&D experience is more relevant in the achievement of product innovations than the firm' R&D experience related to externally contracted R&D activities. According to Mowery (1983), the performance of R&D activities in-house is usually related to complex research projects requiring knowledge of a highly specialized, idiosyncratic variety, specific to a firm, or knowledge involving a high degree of coordination within the

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[1] The usual approach in the literature to capture the concept of knowledge capital and its cumulativeness nature has been the "knowledge capital" model of Grilliches (1979). This model considers that, similar to physical capital, and using the "perpetual inventory method", knowledge capital is accumulated from period to period at a linear and constant rate proportional to R&D investments, subject to a constant depreciation rate.

[2] The complexity of the process of innovation and the heterogeneous nature of R&D activities has been extensively analysed in the literature. Within the approach of the evolutionary theory of technological innovation, the multiplicity of R&D activities performed by firms has been described by the concepts of technological trajectories (Pavitt, 1984) or technological regimes (Nelson and Winter, 1982, Malerba and Orsenigo, 1990).

firm. On the other hand, extramural performance of R&D activities entails research projects requiring more generic knowledge, applicable to a relatively wide range of industries and firms, and dealing with isolated or separable aspects of a firm's operations. Consequently, one may expect product innovations to be more related to the learning process and accumulation of knowledge associated with the in-house performance of R&D activities, as compared to the extramural performance of these activities.

The aim of this paper is to investigate whether firms' R&D effectiveness, i.e., the rate at which R&D investments yield innovation output, depends both upon firms' accumulated in-house and externally contracted R&D experience, respectively. In particular, we test the hypothesis that in-house R&D experience, measured as the number of years devoted to the performance of in-house R&D activities, is more important for the achievement of firms' product innovations than externally contracted R&D experience.

We use for this purpose a representative sample of the population of Spanish manufacturing firms for the period 1990 to 2006. The dataset is drawn from the *Encuesta sobre Estrategias Empresariales* (ESEE, henceforth), a survey carried out annually since 1990 providing detailed information at the firm level. We estimate, within the framework of an innovation production function and using count data models, the influence of firms' accumulated in-house and externally contracted R&D experience on their R&D innovative effectiveness, measured as the number of product innovations. In order to do this, and following Beneito *et al.* (2007), we treat R&D experience as a moderator variable and, distinguishing between in-house and externally contracted R&D, investigate how it affects the impact of R&D capital on firm innovation output.

The main contribution of this paper to the existing empirical literature is that, to the best of our knowledge, this paper is the first attempt to empirically address the role of in-house and externally contracted R&D experience respectively, in the achievement of product innovations. To anticipate our results we obtain that, after controlling for R&D capital stock and other firms' individual heterogeneity factors, in-house R&D experience matters for the achievement of product innovations, i.e., that the number of years devoted to the performance of in-house R&D activities affects positively to the number of product innovations introduced by firms. We also find that externally contracted R&D experience plays no role in the achievement of product innovations. In addition, we also obtain that the performance of informal innovation-related activities, and the discontinuity in the performance of R&D activities, are significant determinants of the number of product innovations introduced by firms.

The rest of the paper is organised as follows. Section 2 briefly describes our theoretical framework and related literature. Section 3 presents the data. Section 4 discusses the empirical model and section 5 presents the estimation results. Finally, section 6 concludes.

2. THEORETICAL FRAMEWORK AND RELATED LITERATURE

The importance of knowledge accumulation in explaining innovation has been developed by the approach of evolutionary theory (Nelson and Winter, 1982). The argument is based on the idea that experience allows the accumulation of knowledge, which is associated with dynamic increasing returns in the form of learning-by-doing and learning-to-learn effects. This stream of literature considers that innovations are the result of a process of accumulation of firms' specific competencies (Rosenberg, 1976). In particular, by investing in R&D projects, firms develop abilities in the form of knowledge, both scientific and informal know-how, that may be used to develop further innovations at consecutive times. According to this view, firms benefit from *dynamic increasing* *returns* in the form of learning-by-doing, learning-to-learn or scope economies in the production of innovations (Cohen and Levinthal, 1989). [3]

The accumulation of knowledge firms obtain from experience in performing R&D activities is likely to affect positively the achievement of innovation outcomes, as stressed by Nelson (1982, page 462):

> *"Strong knowledge means ability to guide R&D effectively. Stronger knowledge enables a larger expected advance to be achieved from a given R&D outlay: alternatively, strong knowledge reduces the expected cost of any R&D achievement. Strong knowledge enhances efficiency both by enabling R&D to proceed on a generally better set of candidate projects, and by enabling the set worked upon to reflect more accurately particular demands and needs."*

And regarding the sources of knowledge*:*

> *"Knowledge is not only won through specialized knowledge-seeking activities; knowledge is also won as by-product of searching for new technologies. Knowledge of correlates and of effective testing techniques grows through experience. One learns about efficacious R&D strategies through one's successes and failures. What succeeded and fails last time gives clues as to what to try next, etc. The applied R&D system itself generates new knowledge as well as new techniques."* (Nelson, 1982, p. 463).

In order to understand the process of knowledge accumulation, it is useful to characterize R&D activities as iterated cycles of problem-solving, in which organizations select a problem, device a set of potential solutions, and test and choose the optimal option (Newell and Simon, 1972). These cycles of problem-solving build up experience in relevant fields and raise the firms' stock of knowledge (Nelson, 1982, Dosi and Marengo, 1993). As firms accumulate experience and relevant knowledge, the effectiveness of their

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[3] For a review of this literature, see Dosi and Marengo (2007) and references therein.

research and selection processes improves. Experience in previous research projects turns out to be important in at least three categories of knowledge (West and Iansiti, 2003): which problems are more important to solve, improved understanding of the search process and tools, and information about the most likely potential solutions. These sources of knowledge can be considered as different forms of firms' learning.[4]

The theory of "absorptive capacity" by Cohen and Levinthal (1989) may also be used for the foundation of the role of experience in R&D activities. They suggest that R&D "not only generates new information, but also enhances the firm's ability to assimilate and exploit existing information" (Cohen and Levinthal, 1989: 21). [5] By investing in R&D, and therefore by accumulating R&D experience, firms develop their ability to identify, assimilate and exploit externally available knowledge, that is, what they call a firm', "learning" or "absorptive" capacity. This absorptive capacity represents a sort of learning that differs from learning-by-doing: while learning-by-doing refers to the mechanism by which firms become more efficient as they accumulate experience in doing what they are already doing, absorptive capacity allow firms to assimilate outside knowledge in doing new different things. Therefore, the accumulation of knowledge firms obtain from experience in performing R&D activities allow firms to develop their

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[4] The literature of organizational learning also emphasizes the key role of experience in improving organizational performance. According to this literature, the production process creates knowledge about the organization of production that enhances the firm future productivity. The accumulation of this knowledge, or learning, is associated mainly with new technologies or new plants, and gives rise to what is called as organizational capital. This organizational capital, or experience, is usually measured as accumulated output (see, e.g. Bahk and Gort, 1993, and Jovanovic and Nyarko, 1995, and references therein). For instance, Bahk and Gort (1993) introduce experience into the production function as a factor that influences productivity, and construct two measures of the stock of experience: cumulative output since firm birth, and age of the firm.

[5] See Cohen and Levinthal (1990) for a discussion of the cognitive structures underlying learning.

absorptive capacity and thus is likely to affect positively the achievement of innovation outcomes.

Regarding related empirical literature, there is a wide body of empirical literature that has focused on the analysis of the relationship between firms' R&D input (measured as R&D capital stock, R&D expenditures, or as the ratio of R&D expenditures to sales or revenues) and innovative output (measured, e.g., in terms of patents or productivity). The relationship between innovation, R&D and patents has been surveyed by Griliches (1990), who reports a robust R&D-patents relationship at the firm level. Among the most well known works are those of Schmookler (1966, ch. 2), Scherer (1965), Bound et al. (1984), Hausman et al. (1984), Hall et al. (1986), Pakes and Griliches (1984), Scherer (1983) and Acs and Audretsch (1989). See also Henderson and Cockburn (1993), Branstetter (1996) and Crépon et al. (1998). Another strand of the literature has been devoted to the analysis of innovation persistence per se, both in the achievement of innovations (see, e.g., Geroski et al., 1997, Malerba et al., 1997, Cefis, 2003) and in the performance of R&D activities (Máñez et al., 2009, Peters, 2007). These empirical studies, however, have not directly modelled R&D experience as an additional driver of innovation success.

More recently, a number of empirical works have analysed, using CIS surveys, the innovative performance of firms by relating innovation inputs to innovation outputs. Some of these works are Klomp and van Leeuwen (2001) for the Netherlands, Smith and Sandven (2001) for Norway, Lööf and Heshmati (2001) for Sweden, or Mairesse and Mohnen (2005) and Kremp and Mairesse (2004) for France. However, these empirical studies do not explicitly take into account the possibility that the effectiveness of the R&D innovation inputs changes as firms accumulate experience in the performance of their R&D activities. In particular, there is a lack of empirical evidence explicitly analysing the role of firms' experience in R&D activities as a key driver of their innovative success. To the best of our knowledge, only West and Iansiti (2003) and Beneito *et al.* (2007) consider the role of experience in R&D as a key driver of R&D performance. In the context of the evolutionary theory of organizational competencies, West and Iansiti (2003) provide evidence for the US semiconductor industry that experience accumulation and experimentation are two organizational tools that generate flows of new knowledge that through the learning process significantly affect firms' performance. However, their empirical analysis is limited to a reduced number of research projects in one particular industry, and their measure of experience is rather simple and limited: they use a dummy variable indicating if at least one of the project members involved in technology selection decisions has experience in the research organization. On the other hand, Beneito *et al.* (2007), using a representative sample of Spanish manufacturing firms for the period 1990-2002, provide evidence that the performance of R&D activities, that is, R&D experience, matters in the achievement of innovation results. However, in their analysis of how R&D experience matters for the effectiveness of R&D capital, they do not take into account the heterogeneous nature of R&D activities, and in particular, they do not distinguish between in-house and externally contracted R&D experience as different sources of learning, and so as two different ways of performing R&D that may have potentially different roles in the achievement of innovations, and this is the aim of our paper.

3. THE DATA: R&D EXPERIENCE, R&D STRATEGY, AND PRODUCT INNOVATIONS.

The data used in this paper are drawn from the ESEE for the period 1990-2006. This is an annual survey that is representative of Spanish manufacturing firms classified by industrial sectors and size categories.[6] It provides exhaustive information at the firm level

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[6] The sampling procedure of the ESEE is the following. Firms with less than 10 employees were excluded from the survey. Firms with 10 to 200 employees were randomly sampled, holding around 5% of the

on a number of production and market issues, including information on innovation activities.[7] Regarding product innovations, the particular question in the ESEE is as follows: "*Indicate if during year t the firm obtained product innovations (either completely new products or with so important modifications that they are perceived as different from the previous ones). If yes, indicate its number*".

In this section, we present some descriptive statistics that are calculated conditioning to firms that declare to perform R&D at least one year in the sample, and that report information both on the product innovation question and on all the variables involved in estimation. Applying these criteria we end up with a sample of 12,598 observations, corresponding to an unbalanced panel of 1853 firms.

Table 1 lists and describes the variables involved in estimation, according to the following criteria.[8] Regarding the inputs in the innovative process and as formal sources of innovation, the ESEE provides information not only on firms R&D expenditures, but also on whether R&D activities are internally organized within the firm or are externally contracted. The ESEE also reports information on firms' informal innovation-related activities, which may also affect positively to the achievement of innovation results. These informal activities include, following Beneito (2003, 2006): services of scientific and technical information, works oriented to normalization and quality control, efforts to assimilate imported technologies, marketing studies, design, and other activities.[9]

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population in 1990. All firms with more than 200 employees were requested to participate, obtaining a participation rate equal to around 70% in 1990. Important efforts have been made to minimise attrition and to annually incorporate new firms with the same sampling criteria as in the base year, so that the sample of firms remains representative of the Spanish manufacturing sector over time.

[7] See http://www.funep.es/esee/ing/i_esee.asp for further details.

[8] Table 1 also includes a number of variables that are used as control variables in estimation: age and firm size, industry and year dummies.

[9] The information in the ESEE about these informal activities is collected on a 4-years basis.

Table 1. Variables definition

Product innovations	Number of product innovations introduced by the firm during the year.
R: R&D-capital	The knowledge capital derived from the firm's R&D investment follows the historical or perpetual inventory method: $R_{it} = (1-\delta) R_{it-1} + I_{it-1}$ where δ is the rate of depreciation, *R* is the R&D-capital stock and *I* are real R&D expenditures (current R&D has been deflated using industrial prices for the whole manufacturing industry). To calculate the R&D-capital according to the equation above we need an initial value for *I* to start the recursion. We use for that purpose the information about the number of years the firm has been investing in R&D activities. By backwards induction, the sequence of past R&D expenditures can be imputed till the first year of R&D activities, when the initial R&D-capital stock is equal to zero. The R&D-capital is defined for a depreciation rate of 15 percent and a pre-sample growth rate of real R&D investment equal to the mean growth rate for the firms which perform R&D activities and are observed during the sample period, that is g = 4,5%.
E: R&D experience	Number of years the firm has been investing in R&D in the past.
Hired personnel in "t" with R&D experience	Dummy variable taking value 1 if the firm has recruited (during current year) personnel with experience in corporate R&D. Information on this variable is only available from 1998 onwards.
Previous number of spells of R&D inactivity	Previous to *t* number of periods where the firm has not performed R&D (it accounts for the number of intermittencies in which the firms has not performed R&D in the past).
Duration of the last spell of R&D inactivity	Length in years of the last (before *t*) spell of R&D inactivity.
Scientific/technical services	Dummy variable taking value 1 if the firm has undertaken services of scientific and technical information, and 0 otherwise.
Quality control	Dummy variable taking value 1 if the firm has undertaken works of normalisation and quality control, and 0 otherwise.
Imported technology	Dummy variable taking value 1 if the firm has undertaken efforts to assimilate imported technologies, and 0 otherwise.
Marketing	Dummy variable taking value 1 if the firm has undertaken marketing studies orientated to the commercialisation of new products, and 0 otherwise.
Design	Dummy variable taking value 1 if the firm has undertaken design activities, and 0 otherwise.
Other	Dummy variable taking value 1 if the firm has undertaken other informal innovation-related activities, and 0 otherwise.
Age	Age of the firm.
Age squared	Age of the firm to the square.
Size1	Dummy variable that equals 1 if the number of employees of the firm is above 10 and below or equal to 20, and 0 if otherwise.
Size2	Dummy variable that equals 1 if the number of employees of the firm is above 20 and below or equal to 50, and 0 if otherwise.
Size3	Dummy variable that equals 1 if the number of employees of the firm is above 50 and below or equal to 100, and 0 if otherwise.
Size4	Dummy variable that equals 1 if the number of employees of the firm is above 100 and below or equal to 200, and 0 if otherwise.
Size5	Dummy variable that equals 1 if the number of employees of the firm is above 200 and below or equal to 500, and 0 if otherwise.
Size6	Dummy variable that equals 1 if the number of employees of the firm is above 500, and 0 if otherwise.
Industry dummies	Industry dummies accounting for 20 industrial sectors of the NACE-93 classification.
Time dummies	Time dummies accounting for the 17 years in our sample period.
Exclusive externally contracted R&D strategy	Dummy variable that equals 1 for those firms which base their R&D strategy uniquely on externally contracted R&D.

With respect to our measure of innovation output, firms obtain product innovations in 32.52% of the sample observations (therefore, we need to take into account the presence of a high number of zero counts in product innovations for the econometric analysis in section 4).[10] Of these observations, an 81.60% correspond to firms that declare to perform R&D activities and, within this percentage, a 92.49% are observations corresponding to firms that carry out in-house R&D activities (either combined or not with externally contracted R&D activities), and the remaining 7.51% of the observations correspond to firms performing only externally contracted R&D activities. Regarding the 67.48% sample observations where firms do not introduce any product innovation, a 47.59% of these observations correspond to firms that perform R&D activities. Of these, 82.97% of the observations correspond to firms performing in-house R&D activities (again either combined or not with contracted R&D activities), and the remaining 17.03% correspond to firms that perform only externally contracted R&D activities. Regarding informal innovation-related activities, for observations in which firms introduce product innovations, in 86.99% of the cases they perform at least one of the informal innovation-related activities, whereas this percentage is 70.51% for observations in which firms do not introduce product innovations.[11]

[10] Regarding firms, instead of firms' observations, in our sample 67.38% of firms introduce at least one product innovation along the sample period.

[11] More in detail, for observations in which firms introduce product innovations, in 43.54% of the cases there are involved services of scientific and technical information, in 66.93% works oriented to normalization and quality control, in 30.73% efforts to assimilate imported technologies, in 42.79% marketing studies, in 58.53% design, and in 3.39% other activities. For observations in which firms do not introduce product innovations these percentages are as follows: in 26.29% of the cases are involved services of scientific and technical information, in 52.65% works oriented to normalization and quality control, in 20.72% efforts to assimilate imported technologies, in 23.75% marketing studies, in 33.88% design, and in 2.11% other activities.

We now turn into the analysis of the patterns of continuity in the performance of R&D activities. Our central hypothesis is that the accumulation of knowledge and learning firms obtain from experience in performing R&D activities is likely to affect positively to the achievement of innovation results. Thus, one may expect the effect of experience on innovation results to depend upon the degree of continuity in the performance of these activities, that is, upon the degree of continuous accumulation of knowledge over time. To explore this issue, we show in Table 2 the distribution of frequencies for the number of firms in our sample according to the following criteria: total number of accumulated years of R&D experience (irrespective of being continuously accumulated or with periods of R&D inactivity in between), total number of spells of R&D inactivity (intermittencies in the performance of R&D activities), and average duration of R&D inactivity spells. As can be seen in Table 2, 90% of firms in our sample have less than 12 years of total accumulated R&D experience, less than 2 spells of R&D inactivity, and less than 5 years as average duration of the R&D inactivity spells.

In order to describe the link between experience and continuity in R&D activities, and innovation results, measured as the number of product innovations, we perform, with a merely descriptive purpose and following a sequential approach, negative binomial regressions of the number of product innovations on the following variables:[12] total number of accumulated years of firm R&D experience, total number of firm R&D inactivity spells, and average duration of the R&D inactivity spells. Our aim is exploring the potential correlation between the aforementioned variables and the number of product innovations the firm introduces yearly, rather than searching for a causal effect. The results of this analysis are reported in Table 3. As it is shown, the total number of accumulated years of firm R&D experience has a positive and significant correlation with the yearly number of product innovations the firm introduces (Regression 1). However, a

[12] The negative binomial method of estimation will be explained in detail is section 4.

Table 2. Experience and continuity in R&D activities.

Years/Total number of R&D inactivity spells	Percentage of firms according to the total number of accumulated years of R&D experience	Percentage of firms according to the total number of R&D inactivity spells	Percentage of firms according to the average duration of R&D inactivity spells
0		55.29	55.29
1	31.00	33.75	13.40
2	13.78	9.27	8.52
3	10.33	1.50	6.20
4	7.14	0.19	3.63
5	5.82		3.01
6	5.26		2.69
7	5.57		1.50
8	3.13		1.50
9	3.13		0.75
10	2.38		0.69
11	2.00		0.63
12	1.44		0.50
13	2.19		0.50
14	0.69		0.38
15	1.13		0.75
16	1.57		0.06
17	3.44		

Table 3. Descriptive negative binomial regressions for product innovations

Regression 1	Coefficient	P-value
Total number of accumulated years of firm R&D experience	0.086	0.000
Regression 2		
Total number of firm R&D inactivity spells	-0.141	0.468
Regression 3		
Average duration of all the firm R&D inactivity spells	-0.127	0.000
Regression 4		
Total number of accumulated years of firm R&D experience	0.057	0.014
Total number of firm R&D inactivity spells	-0.040	0.808
Average duration of firm R&D inactivity spells	-0.086	0.000

Table 4. R&D experience by R&D strategy, and product innovation results

Intervals of R&D experience (years)	Yearly average number of product innovations for firms with mainly an in-house R&D strategy	Yearly average number of product innovations for firms with mainly an externally contracted R&D strategy
1 – 3 years	4.06	1.95
4 – 6 years	5.17	2.73
7 – 9 years	6.54	5.62
10 – 12 years	9.16	10.43
13 – 17 years	4.01	2.62
Total	4.60	2.35

negative and significant correlation is found with the average duration of firms' R&D inactivity spells (Regression 2), and a negative but not significant correlation with the total number of firms' R&D inactivity spells (Regression 3). In Regression 4 we include the three variables simultaneously and find qualitatively the same results than in the sequential regressions. However, the positive correlation for the total number of accumulated years of R&D experience, although still significant, has been reduced from 0.086 to 0.057. Performing a Hausman test (Hausman, 1978) between the results from Regression 1 and Regression 4 we obtain a chi-squared statistic with a value of 104.36 and a *p*-value of approximately 0. Therefore, we clearly reject the hypothesis of the two coefficients being equal in the two regressions.

The above results suggest that in order to explain the role of accumulated R&D experience on the number of product innovations, in estimation we need to control simultaneously for variables characterising the patterns of discontinuity in R&D activities, otherwise, our results about accumulated R&D experience could be biased. Among the variables we have considered, the one that turns out to be more relevant is the duration of the firm R&D inactivity spells. In section 3, and for estimation purposes, as control variables for each period *t* we will include both the number of previous R&D inactivity spells, and the duration of the previous R&D inactivity spell (in exploratory work this variable has been proved to be a better proxy for depreciation of knowledge than the *average* duration of the previous R&D inactivity spells). To avoid endogeneity problems and, therefore, to take properly into account causal relationships, we include in estimation the previous to *t* values for these variables.

Once we have already noticed that even controlling for discontinuity in the performance of R&D experience, accumulated years of R&D experience still seem to matter, we want to distinguish between two types of R&D experience (associated with in-house or externally contracted R&D activities, respectively). For this purpose, we establish a typology of firms according to the type of R&D activities they mainly perform. We construct two dummy variables taking value one when either the majority of years the firm performs R&D activities it performs in-house R&D activities (and zero otherwise), or when the firm performs externally contracted R&D activities (and zero otherwise), respectively. One firm is defined as having *mainly an in-house R&D strategy* either when the firm only performs such type of R&D activities, or when the majority of years the firm is classified as performing in-house R&D activities (see the definition in more detail in section 4). In the opposite case, the firm is classified as a firm having *mainly an externally contracted R&D strategy*. According to this classification, approximately 73% of firms in our sample are following mainly an in-house R&D strategy, and the remaining 27% are following mainly an externally contracted one. In terms of product innovations results, firms with an in-house R&D strategy obtain a yearly average of approximately 5 product innovations, whereas firms with an externally contracted R&D strategy obtain a yearly average of 2 product innovations.

Finally, using jointly the information about the accumulative nature over time of knowledge through R&D experience and our typology of firms' R&D strategy, we report in Table 4 the averages of the number of product innovations that firms achieve each year when they are in their 1^{st} to 3^{rd} year of R&D experience, in the 4^{th} to 6^{th} year of R&D experience, and so on. Regarding firms performing mainly an in-house R&D strategy, 90% of them accumulate less than 13 years of R&D experience. As for firms performing mainly an externally contracted R&D strategy, 90% of them accumulate less than 9 years of R&D experience. Looking at these 90% of the distributions, we see in Table 4 that the average number of product innovations that firms yearly achieve rise with R&D experience. For the group of firms with an in-house R&D strategy (externally contracted R&D strategy) this average number ranges from 4.06 (1.95) in the first three years of R&D experience to 9.16 (5.62) in the interval of 10 – 12 years of R&D experience (7 – 9 years), where it is reached the 90% of the distribution. Therefore, for the 90% of the distributions, the average number of product innovations is larger for firms with an in-house R&D strategy than for firms with an externally contracted one. The externally contracted R&D strategy seems to be in general a less productive strategy in terms of the number of product innovations firms obtain.

4. EMPIRICAL MODEL AND ECONOMETRIC PROCEDURE

The focus of this paper is to measure the extent to which in-house and externally contracted R&D experience matters in determining the effectiveness of R&D activities, that is, in the achievement of innovation results. Our approach is based on the concept of an *innovation production function* that may be expressed in general as follows

$$N_{it} = f(x_{it}, \beta) \quad (1)$$

where i refers to the firm and t to the time period, N_{it} stands for any chosen indicator of innovation results, and x_{it} represents the vector of innovation inputs in the equation. Usual components of x_{it} are R&D inputs, quite often measured by R&D capital. Following Beneito *et al.* (2007), our innovation production function will differ from the standard one in that the effectiveness of R&D capital is specified as a function of the R&D experience of the firm. In particular, the parameter vector β may be decomposed as

$$\beta = [\beta_1(E_{it}), \beta_2] \quad (2)$$

where β_1 is the parameter measuring the "*innovative effectiveness*" of the R&D input, E_{it} stands for firms' R&D experience, and β_2 stands for other inputs' parameters. Therefore, the effect of R&D in the achievement of innovation outcomes depends on R&D experience, measured as the number of years the firm has been engaged in R&D activities. In particular, for our empirical estimation we assume that expression (1) takes the form

$$N_{it} = A(t) R_{it}^{\beta_1(E_{it})} \exp(z_{it}\beta_2) \quad (3)$$

where R_{it} is knowledge or R&D capital (derived from the flow of real R&D investments),[13] E_{it} is the firm's R&D experience, and z_{it} stands for an index of other inputs and control variables. Expression (3) includes a direct proportionate relationship between the R&D capital and innovation counts moderated by a multiplicative set of variables hypothesized to shift the distribution of expected innovation results.

The econometric approach to estimate equation (3) is conditioned by the kind of data used to measure innovation success, that is, the output of the innovation process (N_{it}). In this paper, innovation output will refer to the number of product innovations introduced by the firm during the period under analysis. This means that our dependent variable is of *count data* type: event counts (non-negative integers) for unit *i* during time period *t*, and in any given year many firms may not introduce innovations, so that we may have a high number of zero counts in our sample.

It is standard in the literature to assume that the Poisson distribution is a reasonable description for such count data. According to the Poisson process, research results are the outcome of an unknown number of Bernoulli trials with a small probability of success. The basic Poisson probability specification is

$$\Pr(N_{it} = n_{it}) = f(n_{it}) = \frac{e^{-\lambda_{it}} \lambda_{it}^{n_{it}}}{n_{it}!} \qquad (4)$$

We may model the single parameter of the Poisson distribution function, λ, as a function of our explanatory variables, *x*, and parameters, β, in the standard fashion

$$\lambda_{it} = \exp(x_{it}\beta) \qquad (5)$$

It is easily shown that

$$E[N_{it} | x_{it}] = Var[N_{it} | x_{it}] = \lambda_{it} = \exp(x_{it}\beta) \qquad (6)$$

[13] For a discussion on the use and construction of the R&D capital, see, for example, Hall and Mairesse (1995). Details about how we construct this measure are given in Table 1.

so that λ_{it} represents the arrival rate of innovations per firm per year, and also the expected number of innovation outcomes per firm per year. Taking logs in (6) we get

$$\log E[N_{it} | x_{it}] = \log \lambda_{it} = x_{it}\beta \quad (7)$$

If the explanatory variables are used in logs, the estimated β are the elasticities of the expected number of innovations with respect to these variables. In our case, we assume that expression (6) takes the form

$$\lambda_{it} = A(t) R_{it}^{\beta_1(E_{it})} \exp(z_{it}\beta_2) \quad (8)$$

One restrictive assumption of the Poisson model is the assumption that the variance of N_{it} equals its mean (see (6)). As Cameron and Trivedi (1998) note, the Poisson regression fails if there is unobserved heterogeneity in the data. Neglecting unobserved heterogeneity leads to overdispersion and excess of zeros. In the presence of such overdispersion, though the estimated parameters may still be consistent, their standard errors will typically be under-estimated, leading to spuriously high levels of significance. The heterogeneity can be modelled as follows:

$$\exp(x_{it}\beta + \mu_i) = [\exp(x_{it}\beta)]\eta_i \quad (9)$$

where η_i is a random term with $E[\eta_i]=1$. The Negative Binomial model (NB) can be derived as a Poisson mixture that assumes a gamma distribution for η_i. In the NB case $E[N_{it}]=\lambda_{it}$ and $Var[N_{it} | x_{it}]=\lambda_{it}+\phi\lambda^{2-K}$, where K is assumed to be 1 or 0 in most empirical applications.[14] Therefore, the NB model nests the Poisson model, and it is possible to test one specification against the other by testing the significance of the parameter ϕ in estimation.

[14] If k=0 then we have $Var[N_{it} | x_{it}]=\lambda_{it}+\phi\lambda^{2}$, which is the default case estimated by the Stata programme that we use for estimation.

Although the NB model allows for overdispersion, it has been noted by Gurmu (1997) that it provides poor fit if there are *excess zeros* in the data, that is to say, when the incidence of zero counts is greater than expected by the Poisson and standard NB distributions. This may occur if the zeros and positive observations are assumed to be generated by the same process when this is not the case. An alternative approach to deal with the likely different nature of the zeros and the positive values is the *zero inflated model*. The zero inflated model gives more weight to the probability that the count variable equals zero. It considers an underlying mechanism to distinguish between what could be named "non-innovators" and "potential innovators" ("*non-users*" and "*potential users*" in other fields of the empirical literature), with probability $q(w_{it}\gamma)$ and $1\text{-}q(w_{it}\gamma)$, respectively, where w_{it} represents the vector of variables to be used for estimating these probabilities. The zero inflated model can be estimated for the Poisson and the NB distribution (ZIP and ZINB models, respectively), and, in estimation, we can use the *Vuong statistic* (Vuong, 1989) to test the non-nested ZIP or ZINB models against their Poisson or NB counterparts.[15]

The probability function for the zero inflated model is defined as:

$$P_{it}^{ZIP}(n_{it}/x_{it}) = 1(n_{it} = 0)q_{it} + (1 - q_{it})P_{it}^{P}(n_{it}/x_{it}) \qquad (10)$$

where $P_{it}^{P}(n_{it}/x_{it})$ stands for the standard Poisson model (the standard NB model in the case of the ZINB model). The zero inflated model jointly estimates two equations: one of them is a binomial probit or logit model to estimate the probability (q_{it}) of a zero against a positive value for the count variable, and the other equation estimates the probability of the observed count according to (10).

[15] The null hypothesis in the Vuong test is that the two models being considered are equally close to the true specification. Rejection of the null hypothesis leads to the acceptance of the zero inflated version of the model.

We have considered that our count data model may be subject to a problem of excess zeros because the mechanism explaining which firms are potential (product) innovators may be different of that explaining the positive number of product innovations. Although in estimation we have selected those firms performing R&D activities at least one year of the sample period, it may be the case that in a given year either the firm is not performing R&D, or its innovation efforts are not aimed at introducing product innovations. In such a case, we will observe a zero count because this firm is not a potential product innovator, which differs from those zero counts of firms that search for product innovations but have not been successful in a given year.

The goal of this paper is to distinguish between the in-house R&D activity carried out by firms, and the externally contracted R&D activities in order to determine if, as expected, in-house R&D activities play relatively a more important role in the achievement of product innovations than externally contracted R&D, given the nature of the accumulation of knowledge associated with each R&D strategy. The basic idea is whether or not the in-house R&D experience has a higher or lower premium than contracted R&D experience in terms of higher chances of introducing product innovations.

As our baseline Model, we start estimating equation (3) for the case where R&D experience in a given year t is measured as the sum of the number of past years the firm has been performing R&D activities, without specifying if these R&D activities are carried out in-house or are externally contracted (we refer to this case as Model I in our table of estimation results). As stated above, the specification given by equation (3) means that the impact of R&D capital on the rate of product innovations is assumed to be a function of the R&D experience of the firm. This function may be non-linear, so in order to allow for a non-linear relationship we assume the following quadratic form:

$$\beta_1(E_{it}) = \alpha_0 + \alpha_1 E_{it} + \alpha_2 E_{it}^2 \qquad (11)$$

Formally, β_1 is defined as the percentage change in innovation output generated by a one percent change in R&D capital. Thus, this elasticity represents the effectiveness of R&D capital, moderated by R&D experience, in obtaining innovation outputs. Note that α_0 would be the standard elasticity parameter if R&D experience would not matter for R&D success. In addition, α_1 captures the impact of firm's R&D experience on R&D effectiveness, and α_2 is the change in the impact of firm's R&D experience on R&D effectiveness. If the estimate of α_2 is significantly positive (negative), then the relationship between R&D effectiveness and firm's R&D experience approximates to a "U-type" (inverted "U-type"). However, if the estimate of α_1 is significantly different from zero but the estimate of α_2 is not significant, then firm' R&D effectiveness is a monotonically increasing or decreasing function of firm's R&D experience.

In order to distinguish between in-house and externally contracted R&D experience, as potential and differentiated sources of accumulation of knowledge and learning, and so as affecting differently to the R&D capital effectiveness, we consider in estimation three approaches. These three approaches may be regarded as three different methods of capturing and distinguishing between in-house and externally contracted R&D experience. In the first approach, we make the hypothesis that the in-house realisation of R&D activities is a condition *sine qua non* to accumulate knowledge and learning, whereas externally contracted R&D activities in isolation do not necessarily create such learning effects. To test this hypothesis, we have split the total number of years of R&D experience into two measures: on the one hand, we consider the number of years of in-house performance of R&D activities, no matter whether or not the firm carries out also externally contracted R&D activities; on the other hand, we have summed up the number of years the firm only contracts R&D activities, but does not carry out in-house these activities. We call IE_{it} and EE_{it} to our measures of in-house

R&D experience and externally contracted R&D experience, respectively, and specify then the R&D capital elasticity as:

$$\beta_1(E_{it}) = \alpha_0 + \alpha_1 E_{it} + \alpha_2 E_{it}^2 = \alpha_0 + \alpha_1^I IE_{t_i} + \alpha_2^I IE_{it}^2 + \alpha_1^E EE_{it} + \alpha_2^E EE_{it}^2 \qquad (12)$$

We refer to this case as Model II in our table of estimation results.

In a second approach, we consider that the contribution of in-house and externally contracted R&D activities to total R&D experience depends on the relative effort devoted to each of these alternatives, measured as the percentage of total R&D expenditure accounted for by each of them. As an example, if a firm allocates in a given year fifty percent of its total R&D investment to in-house R&D activity and fifty percent to contracted R&D, we could say that, in that year, the total R&D experience of that firm is fifty percent in-house R&D experience, and fifty percent contracted R&D experience. Total R&D experience of a firm i in a given year t is computed as a weighted sum as follows:

$$E_{it} = \sum_{\tau=1}^{t} (d_{i\tau}^I \cdot \rho_{i\tau}^I + d_{i\tau}^E \cdot \rho_{i\tau}^E) = \sum_{\tau=1}^{t} d_{i\tau}^I \cdot \rho_{i\tau}^I + \sum_{\tau=1}^{t} d_{i\tau}^E \cdot \rho_{i\tau}^E = IE_{it} + EE_{it} \qquad (13)$$

where $d_{i\tau}^I$ and $d_{i\tau}^E$ are dummy indicators taking value 1 if the firm undertakes in-house and externally contracted R&D activities, respectively, in year τ, and where $\rho_{i\tau}^I$ and $\rho_{i\tau}^E$ are the shares of total R&D expenditures devoted to in-house and externally contracted R&D activities, respectively. To test statistically different effects, we allow the coefficients α_1 and α_2 to vary for in-house and contracted R&D experience, and then (11) takes the form:

$$\begin{aligned}\beta_1(E_{it}) &= \alpha_0 + \alpha_1 E_{it} + \alpha_2 E_{it}^2 = \\ &= \alpha_0 + \alpha_1 \left(IE_{it} + EE_{it}\right) + \alpha_2 \left(IE_{it} + EE_{it}\right)^2 = \\ &= \alpha_0 + \alpha_1^I IE_{it} + \alpha_1^E EE_{it} + \alpha_2^I IE_{it}^2 + \alpha_2^E EE_{it}^2 + \alpha^{I\&E} IE_{it} \cdot EE_{it}\end{aligned} \qquad (14)$$

We refer to this case as Model III in our table of estimation results.

Finally, we follow a third approach for measuring in-house and externally contracted R&D experience. In this case, we classify firms into two groups according to what we consider to be "*mainly an in-house R&D strategy*" or "*mainly an externally contracted R&D strategy*". For this purpose we summed up, on the one hand, the number of years in which a firm performs *mainly* in-house R&D activities, considering as such those years with only in-house R&D spending, and also those years with a higher percentage of in-house R&D spending as compared to contracted R&D spending. On the other hand, we summed up the number of years in which a firm performs *mainly* contracted R&D, considering as such those years with only contracted R&D, and those years with a higher percentage of contracted R&D spending as compared to in-house R&D spending. According to these criteria, a firm is classified into the first group (firms with "*mainly an in-house R&D strategy*") if the number of years doing mainly in-house R&D activities is greater than the number of years doing mainly contracted R&D activities. The firm is classified into the second group (firms with "*mainly an externally contracted R&D strategy*") if the case is the other way around. As a final step, we multiply total R&D experience by a dummy indicator that identifies firms in one or another group. The specification for our R&D-capital elasticity, expression (11), becomes in this case:

$$\beta_1(E_{it}) = \alpha_0 + (\alpha_1^I E_{it} \cdot d_{iI} + \alpha_2^I E_{it}^2 \cdot d_{iI}) + (\alpha_1^E E_{it} \cdot d_{iE} + \alpha_2^E E_{it}^2 \cdot d_{iE}) \quad (15)$$

where d_{iI} and d_{iE} equal one if firm i has been classified into the first or the second group, respectively, as defined above. Note that, in this case, estimated coefficients should be interpreted as the effect of total R&D experience for firms which have mainly in-house R&D experience as compared to the effect of total R&D experience for firms which have mainly externally contracted R&D experience. We refer to this case as Model IV in our table of results.

Finally, from 1998 onwards, the ESEE includes information about firms' recruitment of R&D workforce. In particular, the questionnaire of the ESEE asks firms to respond "*whether or not the firm has recruited* (*during current year) personnel with experience in corporate R&D*". Thus, we construct a dummy variable capturing this information and introduce this variable into the estimation of Model II.[16] The inclusion of this dummy variable leads us to discard more than half of the sample observations since it is available only since 1998, but we find interesting to include it in estimation because is captures the idea we want to test in this paper: that in-house experience, in this case embodied in hired R&D personnel, contributes noticeably to firms innovation success. We refer to this case as Model V in the table of estimation results.

Taking into account the different specifications given to $\beta_1(E_{it})$ in each of the Models presented above, and taking logs in (8), our estimating function takes the form

$$\log \lambda_{it} = \log A(t) + \beta_1(E_{it}) \cdot \log R_{it} + z_{it}\beta_2 \qquad (16)$$

where $\beta_1(E_{it})$ has to be replaced by expression (11), (12), (14) or (15), depending on the Model. As an example, for the particular case of our baseline Model, substituting expression (11) into (3) gives

$$N_{it} = A(t) R_{it}^{(\alpha_0 + \alpha_1 E_{it} + \alpha_2 E_{it}^2)} \exp(z_{it}\beta_2) \qquad (17)$$

and, taking logs,

$$\begin{aligned} \log N_{it} &= \log A(t) + (\alpha_0 + \alpha_1 E_{it} + \alpha_2 E_{it}^2) \log R_{it} + z_{it}\beta_2 = \\ &\log A(t) + \alpha_0 \log R_{it} + \alpha_1 E_{it} \log R_{it} + \alpha_2 E_{it}^2 \log R_{it} + z_{it}\beta_2 \end{aligned} \qquad (18)$$

Control variables in z_{it} include informal innovation-related activities carried out by firms, firm size dummies, firm age and its square, industry dummies accounting for 20 industrial sectors of the NACE-93 classification, and time dummies approximating *log*

[16] We include this dummy variable only in Model II, but conclusions hold irrespective of the model we consider.

A(t). The estimation equation also includes in z_{it} the two variables which account both for the previous number of firms' R&D inactivity spells and for the duration of the last one of these spells. The "zero inflate equation" (which aims at estimating the probability of being a "non-innovator", and which is used to weight the probability of zeros in the data as showed in (10)), includes all the variables that enter z_{it}, as well as a variable that accounts for those firms that follow an R&D strategy based completely on externally contracted activities. This variable has been proved to be a good predictor for zero product innovations in exploratory work.

5. ECONOMETRIC RESULTS

The econometric results from estimation of Models I to V are reported in Table 5. We only present in this table the results corresponding to the ZINB model, that is, the zero inflated negative binomial model, but we have tested all the distributional alternatives described in section 4. In all cases, the parameter capturing overdispersion in the data, ϕ, is statistically significant, indicating the rejection of the Poisson against the NB distribution. In addition, the Voung statistic leads to reject the NB model in favour of the ZINB model. These tests are reported at the bottom of Table 5.

The first column in Table 5 reports the results corresponding to our baseline model (Model I), where a measure of total R&D experience is included without distinguishing between in-house and externally contracted R&D activities. The second, third and fourth columns of Table 5 display the results for our Models II, III and IV described above, respectively, and finally, the fifth column shows Model V, corresponding to the case in which Model II also includes the dummy variable of "*hired personnel in t with corporate R&D experience*". The top half of each column displays the estimation results for our innovation production function and the bottom half of each column presents the results for the zero inflate equation.

Table 5. Estimates of the Innovation Production Function for Product Innovations

	Model I	Model II	Model III	Model IV	Model V
α_0	0.065***	0.064***	0.063***	0.070***	0.033
	(0.015)	(0.015)	(0.015)	(0.019)	(0.029)
α_1	0.009***				
	(0.003)				
α_1	-0.0006***				
	(0.000)				
α_1^I		0.010***	0.014***	0.009***	0.007**
		(0.003)	(0.003)	(0.003)	(0.003)
α_2^I		-0.0007***	-0.0009***	-0.0006***	-0.0005**
		(0.000)	(0.000)	(0.000)	(0.000)
α_1^E		-0.001	-0.011*	-0.0035	-0.005
		(0.007)	(0.006)	(0.004)	(0.008)
α_2^E		-0.001	0.001	0.0002	-0.0002
		(0.001)	(0.001)	(0.000)	(0.001)
$\alpha^I \cdot \alpha^E$			-0.001		
			(0.001)		
Hired personnel in ”t” with R&D experience					0.800***
					(0.217)
Previous number of spells of R&D inactivity	-0.030	-0.012	0.021	-0.033	0.060
	(0.149)	(0.148)	(0.141)	(0.152)	(0.188)
Duration of the last spell of R&D inactivity	-0.074**	-0.069**	-0.067*	-0.061*	-0.080**
	(0.035)	(0.034)	(0.034)	(0.034)	(0.040)
Scient./Tech. Services	0.118	0.121	0.156	0.152	0.095
	(0.114)	(0.114)	(0.108)	(0.119)	(0.172)
Quality control	-0.564***	-0.573***	-0.564***	-0.565***	-0.586***
	(0.137)	(0.137)	(0.133)	(0.137)	(0.166)
Imported technology	-0.095	-0.097	-0.103	-0.074	0.029
	(0.126)	(0.125)	(0.121)	(0.129)	(0.178)
Marketing	0.215*	0.218*	0.225*	0.267**	0.003
	(0.126)	(0.125)	(0.123)	(0.125)	(0.144)
Design	0.397***	0.391***	0.395***	0.472***	0.434***
	(0.117)	(0.116)	(0.115)	(0.120)	(0.155)
Other	-0.324	-0.336*	-0.244	-0.399*	-1.020***
	(0.198)	(0.202)	(0.202)	(0.213)	(0.339)
Age	0.002	0.002	0.002	0.001	0.011
	(0.005)	(0.005)	(0.005)	(0.005)	(0.009)
Age squared	-0.000	-0.000	-0.000	0.000	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Size2	-0.039	-0.039	-0.064	-0.087	0.028
	(0.195)	(0.193)	(0.190)	(0.201)	(0.255)
Size3	-0.032	-0.016	-0.049	-0.109	-0.226
	(0.261)	(0.259)	(0.255)	(0.256)	(0.334)
Size4	0.256	0.249	0.244	0.239	0.158
	(0.254)	(0.253)	(0.246)	(0.264)	(0.325)
Size5	-0.010	-0.008	0.003	-0.013	0.136
	(0.229)	(0.227)	(0.223)	(0.239)	(0.312)
Size6	0.096	0.108	0.084	0.065	0.257
	(0.253)	(0.253)	(0.244)	(0.267)	(0.376)
Constant	-0.173	-0.050	-0.121	-0.264	-0.083
	(0.380)	(0.366)	(0.375)	(0.392)	(0.529)

Zero inflate equation					
Exclusive externally contracted R&D strat.	0.731***	0.685***	0.670***	0.734***	0.674***
	(0.151)	(0.156)	(0.155)	(0.157)	(0.213)
Previous number of spells of R&D inactivity	0.442***	0.439***	0.440***	0.483***	0.463***
	(0.088)	(0.088)	(0.088)	(0.098)	(0.109)
Duration of the last spell of R&D inactivity	0.084***	0.088***	0.088***	0.083***	0.095***
	(0.024)	(0.024)	(0.024)	(0.025)	(0.027)
Scient./Tech. Services	-0.396***	-0.403***	-0.390***	-0.351***	-0.535*
	(0.126)	(0.128)	(0.126)	(0.136)	(0.302)
Quality control	-0.323***	-0.333***	-0.323***	-0.319**	-0.295*
	(0.114)	(0.116)	(0.113)	(0.127)	(0.179)
Imported technology	-0.177	-0.192	-0.200	-0.200	-0.046
	(0.143)	(0.146)	(0.145)	(0.156)	(0.280)
Marketing	-0.467***	-0.472***	-0.461***	-0.407***	-0.570**
	(0.146)	(0.147)	(0.144)	(0.151)	(0.233)
Design	-0.552***	-0.549***	-0.545***	-0.552***	-0.691***
	(0.118)	(0.118)	(0.117)	(0.128)	(0.192)
Other	-0.531*	-0.538*	-0.495*	-0.461	-0.361
	(0.292)	(0.296)	(0.291)	(0.340)	(0.521)
Age	0.013**	0.013**	0.013**	0.013**	0.010
	(0.006)	(0.006)	(0.006)	(0.006)	(0.010)
Age squared	-0.000**	-0.000**	-0.000**	-0.000**	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Size2	-0.215	-0.216	-0.225	-0.280*	-0.487**
	(0.153)	(0.153)	(0.153)	(0.167)	(0.247)
Size3	-0.414	-0.411	-0.433*	-0.555*	-0.714*
	(0.259)	(0.259)	(0.259)	(0.309)	(0.425)
Size4	-0.193	-0.201	-0.199	-0.223	-0.671**
	(0.209)	(0.213)	(0.207)	(0.230)	(0.302)
Size5	-0.006	-0.003	-0.001	-0.057	-0.296
	(0.179)	(0.180)	(0.177)	(0.192)	(0.267)
Size6	0.028	0.037	0.022	0.008	-0.108
	(0.236)	(0.238)	(0.234)	(0.257)	(0.368)
Constant	-0.678*	-0.672*	-0.640*	-0.780*	-0.297
	(0.380)	(0.382)	(0.377)	(0.410)	(0.482)
N. Observations.	12598	12598	12598	11229	5561
Log. pseudo-likelihood	-18480.63	-18471.82	-18452.71	-16920.75	-7832.04
Ho: $\phi = 0$ (test overdispersion)	14.43 (P=0.000)	14.20 (P= 0.000)	14.19 (P=0.000)	13.09 (P=0.000)	11.05 (P=0.000)
Vuong test of ZINB vs. standard NB	4.338***	4.342***	4.282***	4.258***	3.778***
	(0.140)	(0.140)	(0.140)	(0.143)	(0.170)

Robust standard errors in parentheses. * significant at 10%; ** significant at 5%; *** significant at 1%
All estimations include 17 time dummies and 20 industry dummies.

In all regressions, the innovation function equation includes (the log of) our R&D-capital variable and its interactions with R&D experience and with squared R&D experience (see (18)). Depending on the way used to differentiate in-house R&D experience from externally contracted R&D experience, that is to say, depending on whether we look at Model II, Model III or Model IV, the log of R&D capital multiplies expression (12), (14) or (15). For the sake of simplicity, in Table 5 we use the notation $\alpha_1^I, \alpha_2^I, \alpha_1^E$ and α_2^E for the whole set of estimations, taking into account that the interaction terms of the log of R&D capital with in-house R&D experience and contracted R&D experience take different forms in each Model.

If we look at the first column in Table 5, a first result is that both the coefficient α_0 corresponding to the log of R&D capital, and the coefficient α_1 corresponding to the interaction of the log of R&D capital with R&D experience, have positive estimated signs, while the estimated sign of the coefficient α_2 corresponding to the interaction with squared R&D experience is negative. This is a result that confirms previous research by the authors (Beneito *et al.*, 2007), and which suggests that the relationship between R&D capital effectiveness (here expressed in elasticity form) and R&D experience is of an inverted U-type. This means that the effectiveness of R&D capital rises with R&D experience but at a decreasing rate. If we take the (statistically significant) results in this first column, the corresponding R&D-elasticity would be of a magnitude of $\beta_1(E_{it})$= 0.065 + 0.009 · E_{it} - 0.0006 · E_{it}^2. This means that for a value of 4 years undertaking R&D activities (corresponding approximately to the mean of the sample distribution), the value of the R&D-capital elasticity would be of 0.100, which is almost 30% larger than the elasticity of a firm that has been undertaking R&D for only one year. Figure 1 shows this inverted U-type relationship between the elasticity of R&D capital and R&D experience. Our estimated elasticity reaches its maximum value, approximately, for the 8th year of

Figure 1. R&D Capital Elasticity vs. Total R&D Experience

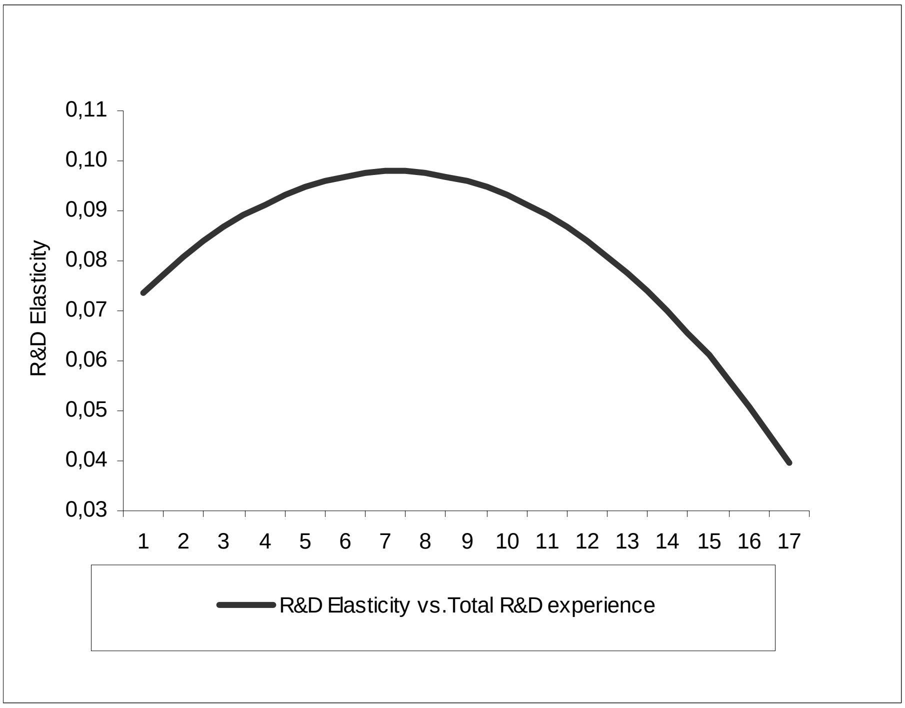
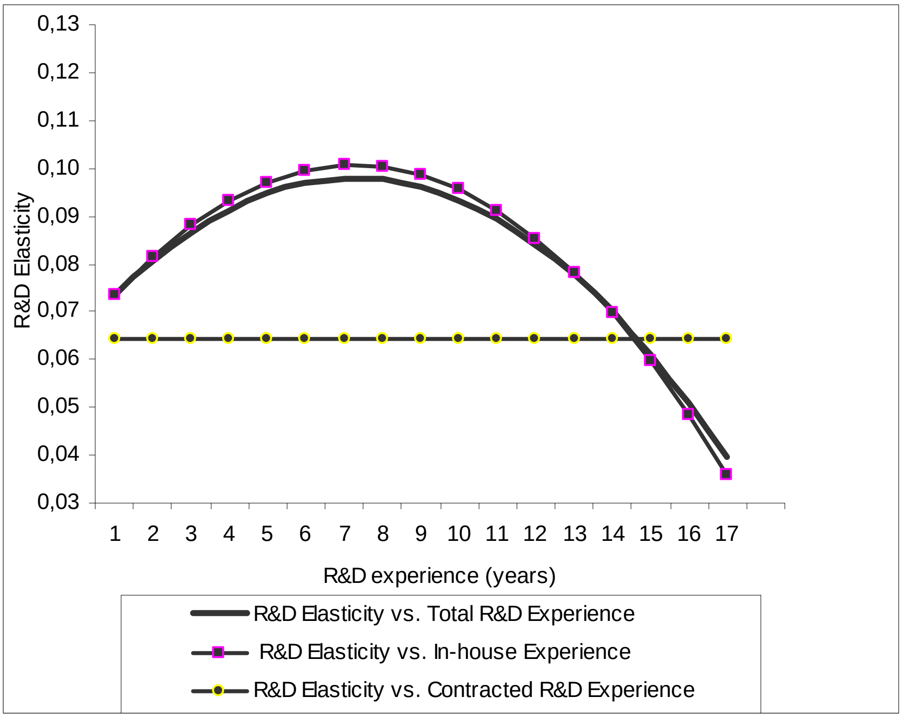


Figure 2. R&D Capital Elasticity vs. In-house and Contracted R&D Experience



R&D experience, and decreases for further years of R&D experience. However, not all points depicted in Figure 1 are equally probable in our sample, and, in particular, by about 85% of the sample distribution lies below a maximum value of 8 years of experience.

Columns II to V show the main results of this paper. The first and main conclusion from these estimations is that, as it has been hypothesized, in-house undertaken R&D activities seem to be the real determinant source for the generation of learning effects during the introduction of product innovations. In Models II and IV the two coefficients that go with the interaction of R&D capital with in-house R&D experience and its square, α_1^I and α_2^I, respectively, are statistically significant and of the same estimated signs as in our baseline model, where total R&D experience was considered. However, the coefficients corresponding to the interaction terms with externally contracted R&D experience, α_1^E and α_2^E, do not render statistical significance in most of the cases. According to the definition of variables in Model II, we could say that only the number of years the firm has been performing in-house R&D counts to explain R&D capital effectiveness, whereas the number of years of externally contracted R&D, if not accompanied by in-house R&D activity, does not seem to help firms to make their R&D capital more productive in terms of product innovations. As for Model IV, we could reach a similar conclusion to the extent that the effectiveness of the R&D capital of firms with "*mainly an in-house R&D strategy*" is affected by their R&D experience, while firms with "*mainly an externally contracted R&D strategy*" do not seem to get any return from the number of years they have been performing R&D.

In Figures 2 and 4 we represent the relationship between the elasticity of R&D capital and the R&D experience arising from both in-house and externally contracted R&D activities, respectively. To facilitate the comparison, in the figures we also present the line corresponding to our estimated baseline Model I in Table 5. The figures show

how similar are the results of Models II and IV both with respect to each other and also with respect to the baseline model, although Model IV renders a somewhat higher value for the estimate of α_0 . If we were to choose between one or another model, it seems that, according to the log of the pseudo-likelihood, Model IV provides a better fit to the data.

Only in Model III, when R&D experience is defined as a weighted combination of years of in-house and years of externally contracted experience, the negative estimated sign of coefficient α_1^E turns out to be statistically significant at a 10% level. In the particular case of Model III, the in-house and externally contracted components of total R&D are, respectively, the sum of the number of years doing in-house and contracting R&D activities multiplied by the shares of total R&D allocated to each of them in each year. Then, for those firms performing both in-house and externally contracted R&D, an increase in the share of contracted R&D spending would imply a lower share of in-house R&D. Then the estimated negative sign of α_1^E may be indicating that those firms which intensify their strategy of outsourcing R&D obtain a lower R&D capital elasticity than those which do not do so. However, the weak statistical significance of the estimated coefficient casts doubt on the confidence we should put on this result. Figure 3 shows the relationship between the R&D capital elasticity and the components of R&D experience as defined in Model III.

The last column of Table 5 displays the results for Model V, which corresponds to Model II including the dummy variable, available only since 1998, that accounts for firms that *have recruited personnel with experience in corporate R&D during the current year*. This variable has a positive and highly significant effect on the achievement of product innovations, a result that reinforces the two main conclusions of our paper: first, that R&D experience is an important source of knowledge which matters to explain innovation results, and second, that it is the in-house performance of R&D activities what allows to exploit the effects of learning through experience.

Figure 3. R&D Capital Elasticity vs. a weighted measure of R&D Experience

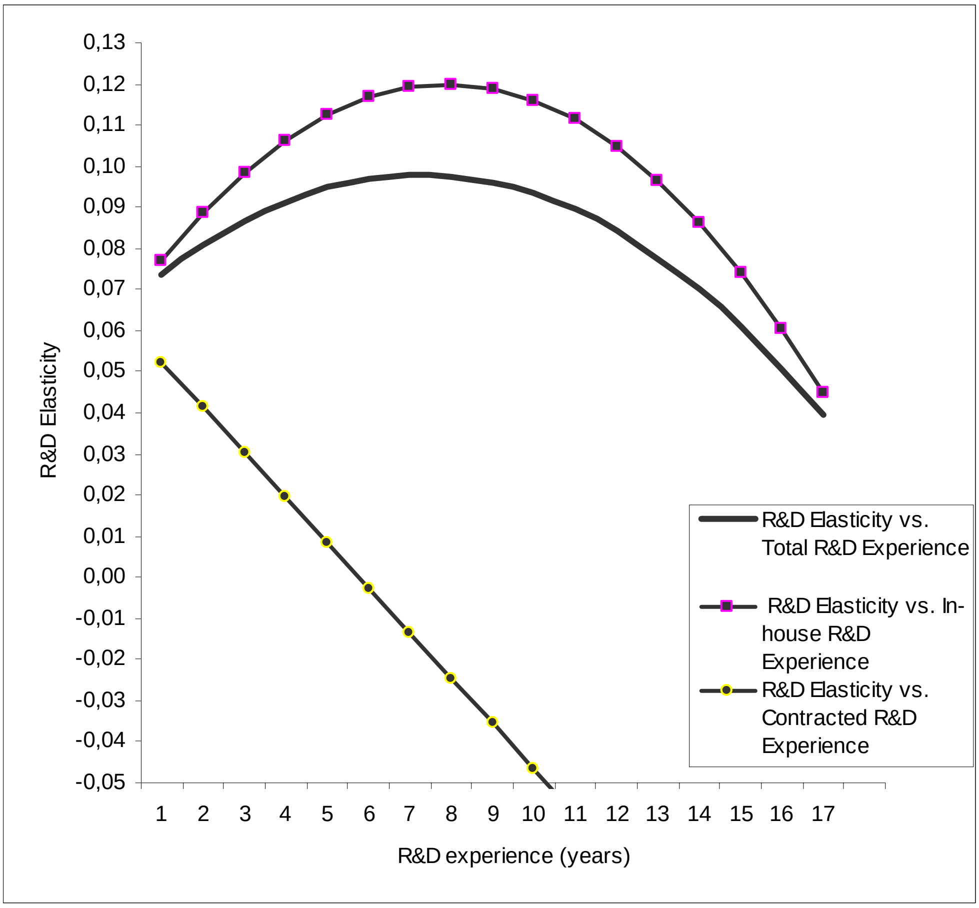
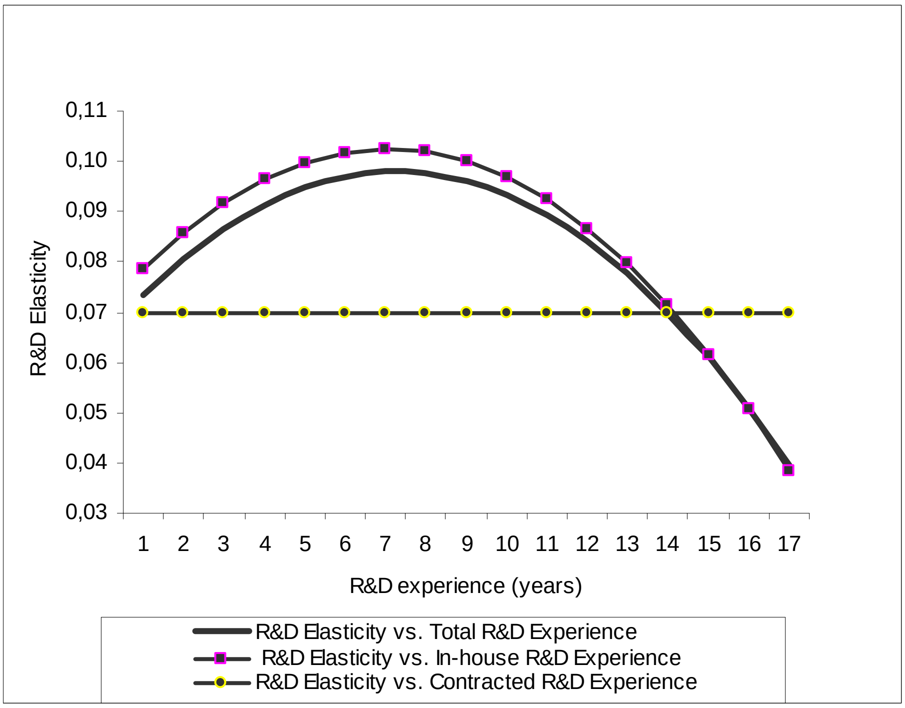


Figure 4. R&D Capital Elasticity for firms with mainly In-house or mainly Contracted R&D Experience



Although the variable accounting for the number of spells of R&D inactivity does not render statistical significance, the negative and significant effect of the variable that accounts for the duration of the last of these spells is noticeable in all our estimation models. To give an example, a firm that accumulates ten years of past R&D experience but stopped previously during three years, obtains a lower number of product innovations than a firm with ten consecutive and uninterrupted years of R&D activity. This result suggests that, not only the continuity in R&D activities is necessary to achieve learning effects through experience, but also that the longer the periods of R&D inactivity, the higher the depreciation of the acquired learning.

Other complementary results in Table 5 are those related to informal innovation-related activities. In the estimation of the innovation production function offered in the top half of Table 5, we observe that both marketing and design activities contribute positively to the achievement of product innovations, whereas quality control activities exhibit a negative and significant sign. Also at a descriptive level, our sample data indicates that quality control activities are negatively correlated with the number of product innovations obtained.

We now turn to comment briefly the results of our zero inflate equation, reported at the bottom half of Table 5. Recall that what we are estimating here is the probability of observing zeros, so that a positive sign of a parameter estimate means a higher probability of a zero, and a negative sign means a higher probability of observing a positive number of product innovations. A first result is that the dummy variable accounting for those firms which base their R&D strategy uniquely on externally contracted R&D helps significatively to predict the event of no product innovations. Also the previous number of spells of R&D inactivity of the firm, and the duration of the last one of these spells are, as expected, positively correlated with the observation of a zero outcome. As for informal innovation-related activities, almost all of them are negatively and significantly correlated with the event of a zero product innovation, reinforcing the hypothesis that these activities correlate positively with the innovative performance of firms. The only exception is imported technology, that it is not statistically significant. Finally, age explains, at a decreasing rate, the probability of zeros, indicating that younger firms are more product innovators than older ones. Firm size, in general, is not significant and, when it is, it indicates a lower probability of a zero outcome for firms of size above the “10 to 20 employees” interval, which is the firm size category left out of the estimation.

6. CONCLUSIONS

In this paper we have tested two hypotheses related to firms' innovation activities using a representative sample of Spanish manufacturing firms (ESEE) for the period 1990-2006. The first one is that, due to knowledge cumulativeness, the period of time during which firms performs R&D activities, which we call R&D experience, is a key determinant of the number of innovations they may achieve. In particular, we have tested the hypothesis that the effect of R&D-capital stock in the achievement of product innovations depends on R&D experience. Our second hypothesis, which constitutes the main aim of this paper, has focused on the investigation of whether firms' R&D effectiveness, i.e., the rate at which R&D investments yield product innovations, depends both upon firms' accumulated in-house and externally contracted R&D experience, respectively. In particular, we have tested the hypothesis that in-house R&D experience, i.e., the number of years devoted to the performance of in-house R&D activities, is more important for the achievement of firms' innovation success (measured as product innovations), than externally contracted R&D experience. To test hypothesis we have estimated, within the framework of a knowledge production function and using count data models, the influence of firms' accumulated R&D experience on their R&D innovative effectiveness, measured as the number of product innovations, distinguishing between the performance of in-house and externally contracted R&D activities.

The results of our empirical analysis indicate that, after controlling for R&D-capital stock and other firms' individual heterogeneity factors, the number of product innovations introduced by firms rises with in-house R&D experience, that is, with the accumulation of technical skills and knowledge that emerges as firms invest in in-house R&D over time. However, the experience that firms accumulate in the performance of externally contracted R&D does not seem to affect the number of product innovations introduced by firms. This result is probably due to the nature of research related to extramural R&D activities, usually of a generic character and not specifically related to the development of new products, which usually requires firm' specific and complex knowledge, arising from a dynamic, cumulative process of in-house R&D activities. Finally, and in addition to past R&D experience, the performance of some informal innovation-related activities and the continuity in the performance of R&D activities have also been found to be important determinants in the achievement of product innovations.

Our results contribute to a better understanding of the channels linking firms' investment in different types of R&D activities and innovation results and thus, of the role of the cumulative process of learning in the effectiveness of R&D investments. These findings may suggest the direction of potential policy measures to be implemented in order to stimulate the production of R&D knowledge. In particular, given that in-house R&D experience positively affects the achievement of product innovations, our results indicate the convenience of implementing policy measures aimed at inducing firms to continuously engage in in-house R&D activities, such as technological policy measures planed within a medium run perspective, or measures aimed at creating a stable institutional framework. More generally, by contributing to understand the heterogeneity across firms regarding the performance of R&D activities and the achievement of innovation results, our findings may be used as a guide for the allocation of R&D subsidies, a major issue in public policy. Finally, our results are also interesting from a strategic management point of view and may also be used to provide managerial recommendations for several key decisions relating the performance of R&D activities, such as the selection of an appropriate schedule for the different types of organising R&D that may be used to achieve innovation results. We have obtained that organising R&D activities in-house positively affects the probability of obtaining product innovations, thus suggesting how better to manage R&D activities to produce innovations. If we consider innovations as closely related to the production of new knowledge, firms that innovate will also be firms concerned with the management of their produced knowledge. This knowledge from innovation may be considered as a firm's asset and therefore should be managed strategically in order to maximize the returns from innovation, as in the case of other assets such as plant, equipment or brand names.

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