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Productivity and R&D: An econometric evidence from Spanish firm-level data

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ABSTRACT

This paper analyses the relationship between productivity growth and R&D investments of Spanish manufacturing firms during the 1990s. The theoretical model is a version of the Cobb-Douglas production function in its growth rate form. The purpose is to estimate the rate of return to R&D expenditures. The econometric specification is a distributed lag model. The estimation applies the GMM method. The main empirical finding is that a positive and significant role is played by R&D expenditures on productivity growth. The rate of return to R&D expenditures is 26.598 per cent.

Key words: Productivity; R&D expenditures; firm panel data; Spanish manufacturing firms.

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1. Introduction.

According to the labour productivity data of the European Union countries (EU25), published by Eurostat and relative to the year 2004, the Spanish's level of GDP per person employed is similar to the EU25 average. However, if only EU15 countries are taken, the Spanish economy is situated between the last positions. If the comparison is made with the United States, almost all the EU25 countries have lower productivity than the U.S. economy, except for Luxembourg.

The productivity gains of the U.S. economy could be explained, in good part, by the technology investments. There is unanimity that the determinants of productivity growth are technology, innovation, and entrepreneurship. The European Union has made a great effort in the last years to achieve an appropriate investment level in research and development (R&D), positioning this expenditure at 1.93 per cent of the GDP in the year 2002 for the EU25 and 1.99 for the EU15.[1] This amount is far from those presented by the United States (2.76 per cent in 2003), and Japan (3.12 per cent in 2002). Moreover, there are important differences between the northern and southern and between western and eastern countries inside the EU. For instance, in Spain, the R&D expenditures are 1.11 per cent of the GDP in 2003, whereas this value is 3.51 in Finland and 0.39 in Latvia.

Since the publishing of the seminal work of Solow (1957), many studies have been made concerning the relationship between technological progress and growth. The difficulty of measuring properly the technological advance pushed

[1] Data extracted from Eurostat.

the economists to centre their attention on the analysis of R&D expenditures. These expenditures contribute to technological improvements and the latter expedite the growth of the economy. So the investment in R&D is considered to have a relevant impact on productivity growth.

The empirical analysis of the relationship between R&D and productivity is made usually through the estimation of a production function in which the technological capital is included as an explanatory variable.[2] This input makes easy into firms the existence of new ideas, which could end up by being to the advantage of a major productivity. Papers that use this approach have a common characteristic. Starting out from a production function, they determine the output elasticity with regard to the technological capital. The underlying problem is that this kind of analyses needs data about research capital stock, which are not available. Thus, it is necessary to make an estimation of the technological capital stock. In order to do so, they usually use the perpetual inventory method. That is, the capital of each period is calculated from the capital of the previous period minus the depreciation and plus the investment in this capital in the period. This process requires to make a hypothesis about the value of capital depreciation rate and to use an initial value of this capital.[3]

These problems could be avoided if what we estimate is some transformation of the production function that only needs to know the R&D expenditures in each

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[2] In this way, see the *technological capital model* from Griliches (1979), which, in addition to the usual productive factors, provides in the production function another differentiated productive factor that could be called research capital, technological capital or R&D capital.

[3] In this approach, researchers usually make different estimates by assuming several values for this depreciation rate.

period, that is, a flow variable. This is the aim of this paper. Instead of estimating production functions in which research capital stock is an additional factor, we relate productivity growth directly to R&D investment over a sample of Spanish manufacturing firms during the 1990s. The goal of the estimation will be to determine the rate of return to the mentioned capital, instead of its elasticity. It implies a certain degree of newness in relation to previous researches made about the Spanish manufacturing sector. According to our knowledge, there are no studies made with Spanish firm-level data in this line of research.

This paper is organised as follows. Section 2 describes previous researches about productivity growth and technological capital. Section 3 describes the used theoretical model. A description of data, variables, and empirical methodology applied in the econometric analysis is presented in section 4. Section 5 contains the estimation results of the Spanish manufacturing industry. The last Section includes the summary and the most important conclusions of the research.

2. Background and previous literature.

According to the preceding section, there are two approaches to deal with the relationship between productivity and technological capital. On the one hand, we can estimate the output elasticity with regard to the technological capital; on the other hand, a rate of return to R&D capital could be estimated. Till now, the former is the approach applied in the Spanish papers concerning this topic.

Thus, Lafuente et al. (1986) estimate the own R&D elasticity using a time series of aggregate data for the period 1966-1981. They calculate the stock of research capital. Fluviá (1990) and Grandón and Rodríguez Romero (1991), using panel data from a survey of large Spanish firms (*Encuesta de Grandes Empresas Españolas*, published by the Ministry of Industry and Energy) for the period 1975-1981, offer evidence on R&D elasticity. García et al. (1998) estimate a production function using a panel from the Business Strategy Survey (*Encuesta sobre Estrategias Empresariales, ESEE*) provided by Fundación SEPI. Their main goal is the estimation of the direct elasticity of employment with respect to innovation. López Pueyo and Sanaú Villarroya (1998), using panel data of thirteen industrial sectors for the years 1986-1992, offer own R&D elasticities. Beneito (2001), using panel data from the *ESEE*, estimates a production function and analyses the effect of R&D capital on productivity, for the period 1990-1996. Finally, López Pueyo and Sanaú Villarroya (2001) estimate production functions for ten countries (nine belonging to the EU and the USA) using panel data for the period 1982-1993. They obtain the own R&D elasticities in each country, taking into account the technological externalities coming from other countries.

However, we use the second mentioned approach. That is, this paper studies the relationship between labour productivity growth and investment in R&D capital for the Spanish manufacturing industry in order to estimate the rate of return to R&D expenditures. We use microdata from the Business Strategy Survey (*ESEE*). Using these panel data allows having a large number of observations, and doing a tracking of the behaviour of individual firms for several periods. The individual firm is the relevant unit of decision relating to R&D investment and, therefore, the dynamic aspects are better studied to this micro level. Everything provides an advantage if compared with other publications that use industry-level data.

There are many studies in other countries that try to estimate the rate of return to R&D expenditures by using firm-level data. In what follows, we will highlight some of the most relevant ones.

Griliches and Mairesse (1983) analyse the influence of R&D expenditures on productivity by using firm-level data for the United States and France between 1973 and 1978. They only consider firms that realise R&D investment in intensive R&D capital industries. For their part, Clark and Griliches (1984) offer results about productivity growth and R&D expenditures for the period 1970-1980. Their sample includes 924 U.S. manufacturing firms. In the work of Lichtenberg and Siegel (1991), panel data were used to estimate the relationship between R&D and productivity growth in the U.S. manufacturing industry from 1972 to 1985. Bessen (2000) uses a sample of 471 U.S. firms between 1983 and 1989 in order to obtain results about the relationship between productivity and R&D expenditures, although the principal aim of his research is measuring the costs of adopting new technology associated with the firm's R&D expenditures.

In what related to Japan, Odagiri and Iwata (1986) estimate the impact of R&D expenditures on productivity growth rate by using firm-level data in two different periods: 1966 to 1973 and 1974 to 1982. Fecher (1990) analyses the influence of R&D expenditures over productivity by using individual data of Belgian firms between 1981 and 1983. For the case of France, Hall and Mairesse

(1995) have updated some results of earlier works that study the relationship between productivity and R&D in the French economy. The sample period extends from 1980 to 1987 and it includes information of 351 individual firms. Wakelin (2001) analyses the relationship between productivity growth and R&D intensity in the United Kingdom by using information of 170 firms between 1988 and 1996. Finally, Parisi et al. (2002) present an empirical evidence of the effects of both productive process innovation and product innovation on productivity in Italy. Likewise, they study the effect of R&D investment over the probability of introducing innovations. The data are extracted, initially, from 941 firms between 1992 and 1997. After carrying out a selection in the sample to eliminate firms with missing values, inconsistencies or extreme values for the variables, authors work with a panel data where are over-represented firms operating in high-technological industries.

The estimates of the rate of return offered by these works are different. It should be noted that the rate of return depends on both, the unit values of the different variables included in the estimations and the data sources used. Later, we will compare the results achieved here for the Spanish case with those of other countries.

3. The theoretical model.

The empirical analysis of the relationship between productivity and R&D expenditures is mainly based on Griliches (1979, 1988) model. His model includes R&D capital as an additional production factor, together with usual productive factors.

In this paper, the starting point in building our model is a Cobb-Douglas production function with three productive factors:

$$Q_{it} = A\, e^{\lambda t}\, C_{it}^{\alpha}\, L_{it}^{\beta}\, K_{it}^{\gamma}\, e^{\mu i}\, e^{\varepsilon it} \qquad [1]$$

where the subscripts *i* and *t* denote the firm and the time, respectively; Q is the output; L represents the labour factor; C measures the physical capital stock; K measures the research capital stock; A is a constant; α,β, and γ are output elasticities with regard to physical capital, labour and R&D capital, respectively; λ is the rate of disembodied technical change (exogenous changes in the productive technology along the time which cause variations in the productivity growth rate that are common to all firms); μ represents a firm-specific unobserved effect, which is constant over time; ε is a random error term.

The use of a Cobb-Douglas function separable in R&D factor allows estimating it as a linear model in first differences. We take equation [1], we make a logarithmic transformation and apply first differences, and then we have the following equations:

$$q_{it} = a + \lambda t + \alpha c_{it} + \beta\, l_{it} + \gamma\, k_{it} + \mu_i + \varepsilon_{it} \qquad [1a]$$

$$\Delta q_{it} = \lambda + \alpha \Delta c_{it} + \beta\, \Delta l_{it} + \gamma\, \Delta k_{it} + \Delta\varepsilon_{It} \qquad [1b]$$

where small-letter symbol denote the logarithm of the corresponding variable and Δ represents the first difference of the pertinent variable. Firm effects, μ, are eliminated when first differences are applied.

The main obstacle of an estimation of this kind is the need to have a proper measurement of R&D capital stock. In order to overcome this obstacle, some transformations could be made to the Cobb-Douglas function. Let us assume that in this function the representative parameter of returns to scale (only considered for the standard inputs: physical capital and labour) it differs from the unitary value in a quantity equal to π. That is, $\pi = 1- \alpha - \beta$. If the coefficient π takes a zero value in the estimation of the empirical model, then it indicates a production function with constant returns on capital and labour.

If we subtract labour logarithm from both sides of expression [1a], we will obtain the following equation:

$$q_{it} - l_{it} = a + \lambda t + \alpha c_{it} + \beta\, l_{it} + \gamma\, k_{it} - l_{it} + \mu_i + \varepsilon_{it}$$

By replacing this value of β by $1 - \alpha - \pi$ and making some operations we get the following result:

$$q_{it} - l_{it} = a + \lambda t + \alpha c_{it} + l_{it} - \alpha\, l_{it} - \pi l_{it} + \gamma\, k_{it} - l_{it} + \mu_i + \varepsilon_{it}$$

Re-ordering terms:

$$q_{it} - l_{it} = a + \lambda t + \alpha\,(c - l)_{it} - \pi l_{it} + \gamma\, k_{it} + \mu_i + \varepsilon_{it} \qquad [2a]$$

By applying first differences to this expression we get:

$$\Delta\,(q - l)_{it} = \lambda + \alpha\Delta\,(c - l)_{it} + \gamma\,\Delta\, k_{it} - \pi l_{it} + \Delta\varepsilon_{it} \qquad [2b]$$

We appointed out earlier that γ is the output elasticity with regard to R&D capital, which could be estimated from the following expression:

$$\gamma = (\partial Q/\partial K)_{it}(K/Q)_{it} \qquad [3a]$$

On the other hand, the growth rate of this kind of capital could be estimated by the expression:

$$\Delta k_{it} = (\partial K/K)_{it} \qquad [3b]$$

If we call ϑ to the marginal productivity of research capital -that is, ϑ=$(\partial Q/\partial K)_{it}$-, we obtain from the expressions [3a] and [3b], the following result:

$$\gamma\,\Delta k_{it} = (\partial Q/\partial K)_{it}(K/Q)_{it}(\partial K/K)_{it} = \vartheta\,(R/Q)_{it} \qquad [4]$$

where R_{it} denotes expenditures on R&D of the firm *i* in the year *t* net of depreciation of the previously accumulated R&D capital. Therefore, R_{it} is a proxy of the net investment in R&D capital.

Taking into account [4], the expression [2b] could be rewritten by the following way:

$$\Delta(q\text{-}l)_{it} = \lambda + \alpha\Delta(c - l)_{it} - \pi\Delta l_{it} + \vartheta\,(R/Q)_{it} + \eta_{it} \qquad [2c]$$

In this expression $\eta_{it} = \Delta\varepsilon_{it}$; $\Delta(q\text{-}l)_{it}$ is the labour productivity growth rate; $\Delta(c - l)_{it}$ is the rate of growth of the capital-labour ratio; Δl_{it} is the rate of growth of the employment; and the ratio $(R/Q)_{it}$ is the R&D intensity or the technological effort. In the estimation of the expression [2c] we only require data of R&D expenditures, instead of R&D capital stock.

If the market is characterized by competitive conditions, ϑ matches with the rate of return to R&D expenditures[4]. It is important, however, to apply some controls on this rate.

First, this rate is the *gross* rate of return. The *net* rate is obtained removing the (unknown) depreciation rate of R&D capital.[5] Therefore, although the problem of measuring the K variable is avoided, some difficulties arise to determine the correct value of the depreciation rate. However, Mairesse and Sassenou (1991) show that, if the R&D capital depreciation rate is small with respect to R&D expenditures growth rate, then ϑ-estimates are enough close to their real value, even though without differentiating between net and gross rate.

[4] See Clark and Griliches (1984) and Griliches and Lichtenberg (1984).
[5] See Hall and Mairesse (1995), for example. They use a depreciation rate of 15 per cent.

Second, some researchers[6] argue that the costsof adoptin g a new technology must be taken into account in order to obtain the true R&D investment rate of return. If each monetary unit spent in R&D requires, for example, another additional monetary unit to implement the technology, then the investment' return equals only half of what could be estimated.

Finally, it is important to differentiate between private and social rate of return. This is because the incomplete appropriation of the research effects causes the disagreement between the private profits and social profits of the activity. The whole economy will be better off with the positive externalities generated by R&D investment of particular firms (spillover effects) because the knowledge can be transferred and utilised by others firms. For instance, it can not be prevented acquired qualifications by research personnel of some firms from passing on to others firms when there is labour mobility between companies. If this spillover effect is taken into account in the estimations, it would be possible, at first, to estimate separately the private and the social rate of return. If this effect is not considered separately, the estimates based on data of individual firms could be reflecting—to an uncertain degree—both the social and the private rate of return.7 Some interesting overviews and papers about spillover effects are those done by Griliches (1992), Nadiri (1993), Mairesse (1995), Aiello and Cardamone (2005) and Chen and Yang (2005). These effects have also been studied in Spain by Fluviá (1990), López Pueyo and Sanaú Villarroya (1998) and Beneito (2001).

[6] See, for example, Bessen (2000).
[7] See Mairesse and Sassenou (1991).

The estimation of equation [2c], which allows the approximation of the value of the technological capital rate of return, ϑ, is the main objective of this paper. Through this specification, which does not take into account the spillover effect, a gross rate of return is obtained and the costs of adopting a new technology are not considered.

4. Data sources, variable definitions, and empirical methodology.

The estimation of the proposed equation will be done using the data included in the Business Strategy Survey (*ESEE*). This survey includes a sample of firms' panel, which is considered representative to the Spanish manufacturing industry. The firms are distributed into 18 industries or branches (energy and mining related activities are excluded).[8] Firms included in the ESEE are those with 10 or more employees. In what follows, we describe the variables used in the econometric specification of the model [2c].

The dependent variable is the rate of growth of labour productivity. The numerator of this productivity variable is the real value added, which is used as a form of measuring the output (Q)[9]. The value added has been deflated using Industrial Price Indexes at two-digit level, which are published by the Spanish Statistics Institute (*Instituto Nacional de Estadística, INE*). The denominator of this productivity variable is the labour variable (L), defined as the number of labour hours that, in average, the firm had during the corresponding year. This

[8] See in the Appendix the industry classification of the two-digit level used by the *ESEE*.
[9] Measuring the output through the value added is frequent in the economic literature. See, for example, Odagiri and Iwata (1986), Hall and Mairesse (1995), Mairesse and Hall (1996) and Rouvinen (2002).

variable is the result of the product of two variables: the average total number of employees and the number of worked hours per full-time employee and year. The average total number of employees is calculated as the sum of the following items: full-time eployees, ½ of the part -time employees (both items at December 31), and the average number of temporary employees during the year.

The labour variable includes all kind of employees (those who work in R&D activities or other activities). This implies a double-counting problem, which also affects other variables, as argued by Mairesse and Hall (1996). In accordance with these researchers, value added, physical capital, and labour should be corrected by taking into account the cost of R&D materials, physical capital used in R&D laboratories, and personnel dedicated to R&D activities, respectively, since these inputs are already included in R&D expenditures. Nonetheless, except for the labour variable, there is a lack of information to carry out these adjustments. The *ESEE* offers details about the number of employees dedicated to R&D. Thus, it might be possible, at first, to deduct these R&D employees from the total number of employees. However, firms offer information about the R&D labour variable once each four years. As a consequence, we decided to use the variable of the average total number of employees in the estimate of the number of labour hours. Despite of not applying the adjustment for the double-counting, the obtained estimates for the rate of return to R&D expenditures could be considered fair.[10]

[10] However, the value of the rate of return is somewhat lower than that obtained by the corrected values. Nonetheless, the difference in the estimates for adjusted and non-adjusted data is practically cancelled if the corrections are only made for the labour variable but not for the rest of variables with a similar problem. For more information, see Hall and Mairesse (1995) or Smith el al. (2004).

The independent variable Δ(c–l) of the equation [2c] represents the rate of growth of the capital-labour ratio. In order to measure the physical capital stock in real terms (C), we used the gross book value of tangible fixed assets adjusted by the deflator for equipment.[11] This deflator is extracted from the Industrial Price Indexes provided by the *INE*. The labour variable is measured as indicated in the previous paragraph (average total number of labour hours).

On the part of R/Q (the technological effort or the R&D intensity), it is the most interesting explanatory variable for the aim of this paper. The R variable is defined as the total R&D expenditures during the year in real terms.[12] The Q variable is measured as indicated previously, and it is the firm's real value added.

Finally, other variables that do not appear explicitly in equation [2c] were also included in the econometric estimation. On the one hand, the specification represented by such equation is mainly based on a long-term perspective by considering R&D expenditures and disembodied technical change, among others, as productivity determinants. However, it is important to control also for short-term phenomena associated with demand fluctuations. Firms partially face temporal demand fluctuations by changing the intensity of using their physical capital stock. This phenomenon involves changes in the productivity of the firms. One way to include these factors in the model is to add as an explanatory variable

[11] The use of the book value of the equipment in real terms as a proxy of the physical capital stock is frequent in the economic literature. See, for example, Clark and Griliches (1984), Hall and Mairesse (1995), Mairesse and Hall (1996), Beneito (2001), Wakelin (2001) and Parisi et al. (2002).

[12] The firms' total R&D expenditures refer to those made by both private funds and public sector subsidies. They are deflated by the aggregate Industrial Price Index provided by the *INE*.

the rate of growth of capacity utilisation (ΔlnCU = Δcu).[13] The *ESEE* provides information about the capacity utilisation (the CU variable).[14]

On the other hand, for the estimations that we make by using equation [2c] it must be taken into account that changes in the firms' productivity might depend on the specific characteristics of the industry to which firms belong. Therefore, dummy variables are included in the model in order to reflect the industry to which each firm belongs. In this way the bias due to sector-specific unobservable heterogeneity is reduced. The 18 industries used in the *ESEE* are summarised in Appendix, as we indicated previously.

The theoretical model presented in equation [2c] must be properly specified in econometric terms in order to estimate it. The possible individual effects were already eliminated because this theoretical model is deduced by applying first differences. Thus, the most important point to take into account is that the impact of investment in R&D over the increase of labour productivity is not used to being immediate one. Meanwhile, such impact, once produced, might not be limited to only one period. As a consequence, these effects will be distributed over time.

The causes of all this might be several. On the one hand, a determined R&D project might have a life of more than a year; thus, their final effects will not be appreciated till the project has reached its end. Besides, in initial steps of the project, the investigation staff will produce ideas, that they do not become immediately into bigger production. On the other hand, even if the project is

[13] See Clark and Griliches (1984).

totally developed, certain time is needed to take the decision of applying it in the productive process; probably, the innovation will be implanted in a gradual way in order not to change traumatically the firm's cost structure. Add to this the learning process at the time of applying in practice the introduced innovation, which surely will be completed in specific details little by little.[15]

Considering the behavior of R/Q variable and the arguments mentioned in previous paragraphs, we have decided to specify equation [2c] econometrically through a distributed lag model. However, the difficulty that entails determining the exact structure of lags with which the variable R&D expenditure operates over the productivity growth rate must be emphasized. To well understand this structure, many (unavailable) data about R/Q variable are needed along time. In addition, the value of the mentioned variable must be independent between several periods, which is not used to being the case: generally, R&D expenditures in a determined period are correlated with those of preceding periods.[16]

Based on all these remarks, in this paper we use the following econometric specification for equation [2c]:

$$\Delta(q\text{-}l)_{it} = \lambda + \alpha\Delta(c - l)_{it} - \pi\Delta l_{it} + \vartheta_1 (R/Q)_{i,t-1} + \vartheta_2 (R/Q)_{i,t-2} + \ldots$$

$$\ldots + \vartheta_n (R/Q)_{i,t-n} + \delta\Delta cu_{it} + \text{industry effect} + \eta_{it} \qquad [2d]$$

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[14] It is defined in the *ESEE* as average percentage of utilisation—during the year—of the firm's standard capacity.

[15] Econometric arguments also support the introduction of lags to the technological effort variable. On the one hand, due to the correlation that might exist between the actual investment in R&D and the value added of the period. On the other hand, the presence of the value added in both sides of the equation might generate biases in the coefficient of the technological effort variable. See Mairesse and Hall (1996).

[16] See, for example, Griliches and Lichtenberg (1984) and Rouvinen (2002).

In this equation all the comments made in the previous paragraphs are already taken into account: we have written the short-term phenomena (Δcu); R/Q variable is lagged for the periods *t-1,t-2,...,t-n*; and we have added the industry effect defined as $\omega_2 IC_2 + \omega_3 IC_3 + ...+ \omega_{18} IC_{18}$; where ω's are parameters and IC's represent industry dummy variables.

In order to estimate the mentioned [2d] model, generalized method of moments (GMM) is applied. This is a robust approach to heteroskedasticity across firms and to correlation of disturbances within firms over time; thus, GMM can be efficient without making very restrictive assumptions. [17]

The used sample in the model estimation is extracted from the *ESEE* panel data between 1993 and 1999. Estimations were done including all firms that provide information for these variables.[18] The firms that fulfil this requirement are 1,312, an unbalanced data panel with a total of 8,636 observations. The panel is unbalanced because of entry and exit of firms. A filter for mergers was also applied.[19]

Most existing models that concern the relationship between productivity and investment in technology have used data for only those firms that make this kind of expenditure at least for a few years. However, from an econometric perspective, it seems reasonable to include also the data offered by remainder

[17] See, for example, Mairesse and Hall (1996) and Wooldridge (2002, especially Chs. 8, 11, and 14).
[18] Significant problems relative to outliers were not found.
[19] A balanced panel would contain an econometrically insufficient number of firms.

firms of the sample (those firms with annual R&D investment that always equals zero). These firms act as a control group and they allow having more complete information as they pick up the changes of labour productivity if no technological effort is made.

5. Empirical results.

In this section we present the results of the estimated rate of return to R&D expenditures. The previous equation [2d] is considered as the starting point of the analysis.

The obtained empirical results are presented in Table 1. Only the results of the model with one lag for R/Q variable are presented, because other lags for this variable are statistically insignificant.[20] The usual tests (C statistic or difference-in-Sargan statistic) allow for the acceptance of the exogeneity hypothesis for the variables Δ(c-l), Δl, and Δuc, but not for the R/Q variable. As a consequence, this latter one has been instrumented. The instruments used in the econometric estimations are enumerated in the mentioned above Table.[21] The overidentifying restrictions are tested by Hansen J statistic, which is consistent in the presence of heteroskedasticity. The results of this test do not reject the validity of the instruments, accepting by that the null hypothesis with p-value of 0.379.

[20] This is similar to the published results of Clark and Griliches (1984), Hall and Mairesse (1995), and Bessen (2000), for example. The empirical results with other lags are available from the authors by request.

[21] Several instruments were analysed and those with the best econometric results were chosen. They are similar to those applied in other studies, which also use three or four lags for some explanatory variables of the model. For instance, see Mairesse and Hall (1996).

According to Wald known tests, industry dummy variables are jointly insignificant (the null hypothesis is accepted: $\chi^2(17)=14.67$, p-value=0.6192);[22] and regressors are jointly significant (the null hypothesis is accepted: without the constant term, $\chi^2(4)=43.10$, p-value=0.0000; with the constant term, $\chi^2(5)=45.49$, p-value=0.0000).

The coefficient of R&D intensity variable is statistically significant and has a positive sign. That means that the technological effort has a positive effect over productivity. The other variables used in the estimation are significant from the statistical viewpoint for some of the usual levels.

In accordance with the estimated econometric model and by taking into account what we pointed out in the previous section, we observe that the rate of return to R&D investment (ϑ) is situated in 0.26598. Thus, for each additional monetary unit invested in R&D, the output would increase by 1.26598 monetary units, *ceteris paribus*.

With regard to the capital-labour ratio, its influence over productivity growth is positive (a positive value of the coefficient α in the equation [2d]). The coefficient of capacity utilisation variable (δ in equation [2d]) also has positive sign, which means that productivity growth rate is also influenced by factors associated with temporary demand fluctuations that firms face. The variable number of labour hours has a coefficient (π in equation [2d]) that is significantly

[22] The inclusion of the capacity utilisation variable might be capturing the different characteristics of each industry and, as a consequence, reducing the significance of dummy variables.

different from zero and with negative sign. This indicates production function with diminishing returns on capital and labour.[23]

The model was also estimated by imposing the assumption of constant returns to scale for capital and labour (zero value for the coefficient π). This constraint does not very substantially change the empirical results, because a similar return rate is obtained (0.26120). In consequence, at the Spanish manufacturing industry the existence of constant returns to scale can be admitted, even though also a light bias toward diminishing returns to scale can be admitted. However, empirical results without the constraint of constant returns to scale were chosen to be presented because they have better econometric properties.

In short, productivity growth in the Spanish manufacturing industry could be explained by innovative effort of firms, capacity utilisation, and capital-labour ratio, in addition to other non-modeled factors.

These empirical results for the Spanish firms could be compared with similar estimates made in other countries. Nonetheless, it must be clarified that, in the economic literature, the estimated values of the rate of return to R&D expenditures (ϑ) change in a wide interval, depending on the used sample, on how the variables have been defined and on the econometric specification.[24] These differences are completely expected because the empirical analysis only provides

[23] This result was also presented by Smith et al. (2004) for Denmark and Wakelin (2001) for the United Kingdom. As it is argued by the latter, one might attribute that result to the exclusion of raw materials and intermediate products from the production function.

estimates of the rate of return, but not necessarily the real value of the mentioned rate. In this way, the estimates are different according to how the variable of technological effort is defined, because R/Q ratio may present in its denominator the value added or the value of sales. There are also some differences depending on, first, if productivity is referred to total factor productivity or labour productivity; second, if representative dummy variables for each industry are or are not included; third, if a lag structure or another is proposed, etc. Therefore, the results presented in this paper could be directly compared, up to a point, to only those results achieved by researches that define the relevant variables by the same way.

The estimate of the rate of return to R&D expenditures obtained in this paper is situated in most usual interval. In most empirical researches existing till now, the estimates of ϑ move in the interval 0.2-0.4, where the values between 0.2 and 0.3 are specially frequent. This is the case of Griliches and Mairesse (1983) for the United States and France, as well as Griliches and Mairesse (1984), Griliches (1986), Jaffe (1986), Jones and Williams (1998), and Bessen (2000); these five later papers refer to the United States. The same holds for the estimates of Odagiri (1983) and Sassenou (1988) for Japan, Griliches and Mairesse (1990) for the United States and Japan, and Wakelin (2001) for the United Kingdom. Nonetheless, we must notice that these works have used different econometric models and estimation techniques, in addition to several forms of defining the relevant variables.

[24] See Mairesse and Sassenou (1991) concerning papers about rate of return to R&D and Atella and Quintieri (2001) in relation to papers about elasticity of total factor productivity with respect

Certainly, in other studies the estimates of the rate of return to R&D investment are positioned in values somewhat lower than those mentioned above. For instance, rates of return below 0.2 appear in studies such as those of Clark and Griliches (1984), Schankerman and Nadiri (1986), Bernstein and Nadiri (1989), and Lichtenberg and Siegel (1991); all of them have used U.S. data. Similar thing holds for papers by Odagiri and Iwata (1986) for Japan and Hall and Mairesse (1995) for France.

Even by comparing ϑ values obtained by models whose explanatory variables are defined by a similar way, we still observe differences between the estimated values. This fact could be due, among others, to several factors. The first factor is that each research concerns different territorial and temporal ambit. Second, the quality of the data used is different. Third, each researcher considers a different functional specification for the empirical estimation (the lag structure for R/Q variable is different). Forth, some analyses use data of the privately financed R&D expenditures, while others include also the R&D investment financed by the public sector. Finally, some studies include the role of spillover effect in productivity growth.

6. Conclusions.

This paper presents a theoretical model that associates labour productivity growth with R&D expenditures. The aim is verify in Spain if a growing investment in R&D generates an increase in the productivity of firms. The model

to R&D capital stock.

allows the estimation of the rate of return to R&D investments by using a flow variable (R&D expenses) without the need to build the (unavailable) research capital stock variable.

The theoretical model was later specified through an econometric model with distributed lags over time. Subsequently, the econometric model has been estimated by means of a panel data extracted from the Business Strategy Survey (*Encuesta sobre Estrategias Empresariales, ESEE)* for the period 1993-1999. The data belong to firms of 18 Spanish manufacturing industries, in which we observe obvious differences with regard to the elements examined here.

In order to estimate the econometric model we used the generalized method of moments (GMM). The empirical results were showed to be consistent to the theoretical perspectives. They indicated that R&D investment by Spanish firms has a positive and statistically significant effect on labour productivity rate of growth, with one lag (the additional lags do not seem to be statistically significant). More specifically, the rate of return of this kind of investment is about 26.598 per cent. En general, this result is in the line of the rate estimated by studies made for other countries.

On the other hand, a positive relationship between labour productivity growth and capital-labour ratio was found. Similar relationship was also found between this productivity growth and capacity utilisation by firms. This indicates that productivity changes are related to short-term factors associated with temporary demand fluctuations that firms face. Lastly, we detected a production function for the Spanish industrial firms with diminishing returns to scale on capital and labour, which is in accordance with results of previous researches. However, the relationship between productivity growth and technological effort does not very substantially change when the constraint of constant returns to scale is imposed.

Of course, the model estimation might be affected by econometric limitations. Griliches and Mairesse (1995) pointed out that estimations of production functions by using micro data show some problems; these problems also appear when a transformed production function is estimated.[25] As a consequence, the empirical results achieved in this paper, even though they are enough reasonable, they must be interpreted with some caution. But, in spite of this, studies of this kind are useful.

Finally, it is important to draw the attention to the weakness of R&D investment in the Spanish firms. At the first glance, the rate of return in the Spanish manufacturing industry seems to be high. This rate of return should enhance the Spanish investment in technological capital. However, in the practice it is shown that this does not occur. The high risk associated with R&D projects and the difficulty of appropriating exclusively all profits derived from innovation can withdraw the firms (specially the small and medium-sized firms) from carrying out this kind of activities, in spite of the high-expected return.[26] Moreover, the Spanish business structure is very focused in the services sector that does not require large efforts in R&D; also the Spanish firms might probably face special problems to finance their R&D investments, mainly because firms

[25] See Mairesse and Sassenou (1991) and Hall and Mairesse (1995).
[26] See Nadiri (1993).

have general financing problems and because government support to the technological innovation is low.

The inadequate stock of R&D capital in Spain is burdening the labour productivity growth. The lack of investment might cause Spanish firms a loss of competitiveness and a slow growth of potentiality of the economy in a context of opening markets where goods with high technological content are exchanged. Therefore, it is worthwhile to stand up and to signal the need for applying some measurements of industrial policy that solve the Spanish economy deficiencies in this scope. In this sense, the company-financed R&D investments should be properly backed up by the public sector because, in Spain, the share of the public sector in R&D activities is majority, in contrast to what occurs in other developed countries. Also the activity of Technology Transference Centres should be enhanced, among other measurements, in order to improve the relationship between firms and universities. Likewise, it would be useful to increase the resources channelled toward research made by government agencies. This one should be accompanied by controls in the allocation of funds and appropriate mechanisms for evaluation of results.

At this moment, in which the Spanish economic conditions are relatively stable, a step forward could be taken in order to solve the mentioned problems. All these measures would be able to create a stable framework for the achievement of technological investment, what would revert in a greater return for this type of investment.

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APPENDIX

Manufacturing industries

Industry 1: Primary Metals

Industry 2: Non-Metallic Mineral Manufacturing

Industry 3: Chemical Products

Industry 4: Metal Manufacturing

Industry 5: Machinery for Agriculture and Industry

Industry 6: Office and Data Machinery

Industry 7: Electrical and Electronic Machinery & Accessories

Industry 8: Autos and Motors

Industry 9: Other Transport Material

Industry 10: Meat and by products

Industry 11: Food and Tobacco

Industry 12: Beverages

Industry 13: Textiles and Clothing

Industry 14: Leather and Footwear

Industry 15: Wood and Wood Furniture

Industry 16: Paper and Printing

Industry 17: Rubber and Plastics

Industry 18: Other Manufacturing

Table 1. Estimation results of empirical model

Dependent variable: $\Delta(q\text{-}l)_t$

Variable	*Coefficient*	*Stand. Error*	*Z*	*Significance*
Constant (λ)	0.03241	0.01771	1.83	0.067
$\Delta(c - l)_t$	0.05228	0.03082	1.70	0.090
Δl_t	-0.31735	0.06273	-5.06	0.000
$(R/Q)_{t-1}$	0.26598	0.12295	2.16	0.031
Δcu_t	0.14354	0.6869	2.09	0.037
No. of firms	1,312	**Period**	1993-1999	
Hansen J statistic	5.312	$[\chi^2(5)]$	Significance	0.37933

Generalized method of moments (GMM). Instruments: $\Delta(c\text{-}l)_t$, Δl_t, Δcu_t, $(c\text{-}l)_{t-1}$, l_{t-1}, $(R/Q)_{t-2}$, $(R/Q)_{t-3}$, $(R/Q)_{t-4}$,, cu_{t-1}. Heteroskedasticity-autocorrelation robust standard errors.