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# Does history matter for the relationship between R&D, Innovation and Productivity?

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## *Abstract*

This paper analyzes the relationship between R&D expenditures, innovation and productivity growth, taking into account the possibility of persistence in firms' behaviour. We study this relationship for a sample of Spanish manufacturing firms between 1990 and 2005, estimating a model with four equations: participation in technological activities, R&D intensity, the generation of innovations and the impact of these technological outputs on total factor productivity growth. Our results reflect the existence of true state dependence both in the decision of R&D investment and in the production of innovations. The omission of this persistence leads to an overestimation of the current impact of innovations on productivity growth. However, the presence of persistence in technological inputs and outputs entails current R&D activities having long–run effects on a firm's productivity.

**Keywords***:* CDM model, productivity growth, persistence in R&D and innovation.

**J.E.L. Classification:** D24, L6, O3

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# 1. Introduction

The analysis of productivity growth and its determinants is a classic topic in Industrial Economics. There is a large number of papers that study this question from an empirical point of view, pointing out the performance of technological activities as an essential source of firms' growth. Following the method proposed by Griliches (1979), some authors include a stock of knowledge capital as an additional input in the firm's production function. Recently, the idea that the growth of firms is more related to the results of technological activities than to the inputs used in them has generated some studies that directly analyze the impact of technological outputs (process and/or product innovations, patents…) on firms' productivity. Specifically, Crepon, Duguet and Mairesse (1998) developed a multi-equational model (hereafter the CDM model) that explains productivity growth by technological outputs and the latter by technological effort. Since the appearance of this seminal paper, many researchers have applied the same methodology to different European countries using essentially cross-sectional data from the Community Innovation Surveys (CIS Data)[1].

However, only a few studies have used panel data to perform the analysis, mainly due to information availability, and therefore there is little evidence about these decisions that take into account the dynamics in a firm's behaviour. Some exceptions are the papers by Cefis and Orsenigo (2001), Cefis (2003), Raymond et al. (2009), Mañez-Castillejo et al. (2009) and Peters (2009), which empirically analyze the persistence of R&D activities or technological outputs with different methodologies and results.

In this line, the objective and the main contribution of the present paper is to consider the existence of persistence both in the R&D investment decision and in the achievement of innovations when estimating the recursive model that reflects the relationship between R&D, innovations and productivity. With this aim, we adapt the CDM model to analyze this relationship for a panel of Spanish manufacturing firms between 1990 and 2005. Our econometric results suggest the existence of true state dependence both in the decision of

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[1] See, for example, Mairesse and Mohnen (2002, 2005) and Mohnen *et al*. (2006) using French CIS1 and CIS3 data, Parisi *et al*. (2006) for Italian manufacturing firms, Lööf and Heshmati (2006) using Swedish manufacturing data, Van Leeuwen and Klomp (2006) and Van Leeuwen et al. (2009) for Dutch manufacturing firms, and Griffith et al. (2006) using firm-level data from the internationally harmonized CIS3 for France, Germany, Spain and the UK. Two examples for non-European countries are Benavente (2006) for Chile and Jefferson et al. (2006) about China.

R&D investment and in the production of innovations. The omission of this persistence in the analysis leads to an overestimation of the current impact of innovations on productivity growth. However, the existence of true state dependence in technological inputs and outputs entails current innovation activities having long–run effects on a firm's productivity. This is especially important when analyzing the relevance of technological policy as an instrument to induce productivity increases.

Following this introduction, the next section presents the theoretical framework and the empirical multi-equational model. Section 3 describes the database and the variables included in the specification. The results of the estimation of the model are presented in Section 4 and, finally, Section 5 summarizes the main conclusions.

## 2. Theoretical framework and empirical model

As we explain in the introduction, the model to be estimated is an adaptation of the CDM model, which reflects the sequence of a firm's decision. The first equation describes the firm's decision to engage in technological activities or not. The second one refers to the intensity of technological inputs (measured basically by the intensity of the R&D expenditure). The third equation deals with the generation of innovations on the basis of both internal and external technological inputs and, finally, the fourth equation shows the impact of these innovations on productivity growth, measured by the Solow residual.

Unlike the CDM model, which circumscribes the analysis of innovative firms, in this paper we also take into account those firms that do not declare R&D expenditures. Following the approach of Griffith et al. (2006), we consider that to some extent all firms make some innovative effort. However, below a certain threshold, the firm is not capable of picking up explicit information about this effort and will not report on it. Thus, we estimate a selection model for the observed R&D intensity.

Additionally, instead of considering a static framework, we model the firm's decision to engage in R&D activities and the equation for the generation of innovations taking into account the possible persistence in these stages. As Heckman (1981) points out, there are two explanations for persistent behavior: the true state dependence and the spurious dependence.

The first one implies a real causal effect: the probability of investing in $t$-1 increases the probability of investing in $t$. There are some theoretical explanations for this real true dependence in the case of innovation activities (Peters, 2009): the sunk cost associated with the performance of R&D activities, the "success breeds success" hypothesis and the existence of dynamic increasing returns. Alternatively, some firm characteristics can positively affect the decision to engage in R&D activities or the generation of innovations and, if they are correlated over time, could also create a spurious relation between current and future status (spurious dependence). Some of them can be observables, like size, and it is possible to control them in the empirical analysis. However, there are other characteristics, like managerial ability, technological opportunities and risk attitudes that are unobservable. If these characteristics are persistent over time and they are not properly treated in the estimation, they can generate a spurious state dependence in R&D activities.

According to these theoretical explanations for real state dependence, it is not clear whether persistence is more related to technological inputs or outputs. Under the sunk cost hypothesis, R&D decisions are modeled in a long-term horizon, given that sunk costs could represent not only a barrier to entry for new firms, but also a barrier to exiting for incumbent firms that have not recovered their investments. In this case, an input measure would be desirable. However, the "success breeds success" and the "learning by doing" hypotheses are more associated with technological results. Additionally, if we assume that innovation outputs are basically determined by innovation inputs, input persistence should be translated partially into output persistence.

The empirical evidence about this question is mixed. Máñez et al. (2009) study the persistence in the firm R&D status, i.e., in the decision to engage in R&D activities, while Peters (2009) analyzes whether firms innovate persistently, defining an innovator as a firm which exhibits positive innovation expenditure in a given year. In contrast to these studies, Duguet and Monjon (2004) and Raymond et al. (2010) examine the persistence in innovation outputs, although, as they use CIS data, their indicators as to whether a firm has introduced an innovation are related to a 3–year period, which could induce an artificial persistence due to overlapping time periods and double counting (Peters, 2009). However, Raymond et al. (2010) find that there is only true persistence of innovation in high-technology industries. For low-technology industries, past process and product innovations and past shares of innovative

sales do not affect current process and product innovations and innovative sales[2]. In a later paper, Raymond et al. (2009) study the dynamics in innovation inputs and outputs, estimating a dynamic panel data bivariate Tobit model. They obtain persistence in both a lagged effect of innovation input on innovation output in the high-tech industry and a feedback effect of innovation output on innovation input in all industries.

Our paper differs from previous ones in the sense that we analyze the persistence in both input and output R&D activities in a recursive model[3]. Nevertheless, we do not consider the dynamics of the R&D intensity (R&D expenditures over employment), but only in the decision to engage in R&D activities.

In particular, our empirical model is as follows. The first equation describes the R&D effort of firm $i$ in year $t$ in terms of the latent variable $id_{it}^*$:

$$id_{it}^* = z_{it}'\beta + e_{it} \qquad [1]$$

, where $z_{it}$ is a vector of determinants of the innovation effort. We consider that we can measure the R&D effort $id_{it}^*$ by the intensity of the R&D expenditure $id_{it}$ only if the firm makes and reports that expenditure. To represent this decision to perform and report R&D expenditures, we assume the following selection equation:

$$r_{it} = \begin{cases} 1 & \text{si} \quad r_{it}^* = \gamma \cdot r_{it-1} + x_{it}'\beta + \mu_i + \varepsilon_{it} > 0 \\ 0 & \text{si} \quad r_{it}^* = \gamma \cdot r_{it-1} + x_{it}'\beta + \mu_i + \varepsilon_{it} \le 0 \end{cases} \qquad [2]$$

, where $r_{it}$ is a binary variable that takes the value 1 when the firm invests in (and reports) R&D, and 0 otherwise. If the latent variable $r_{it}^*$ is bigger than a constant threshold (which can be zero), we then observe that the firm engages in (and reports) R&D activities. In this equation, $r_{it-1}$ captures the previous innovation experience (true state dependence), $x_{it}$ is a vector of observable explanatory variables (time-variant and time-invariant variables which can differ from those that explain the R&D effort) and the permanent unobserved heterogeneity is captured by $\mu_i$. Finally, $\varepsilon_{it}$ is an idiosyncratic error (which refers to other unobservable time-variant determinants).

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[2] Although their objective is not properly the analysis of persistence, Piva and Vivarelli (2007) also consider lagged R&D expenditures as an explanatory variable when studying the effect of demand evolution on R&D expenditures according to different groups of firms.
[3] With the aim to jointly analyze the dynamics of trade and innovation, Esteve and Rodríguez (2009) present estimations for R&D performance, product and process innovations as "alternative" measures of the innovation status. Their results indicate the existence of true state dependence in both export and innovation.

To estimate this dynamic equation, we have to solve two theoretical and empirical problems: how to treat the unobservable heterogeneity ($\mu_i$) and the treatment of initial conditions ($r_{i0}$). With respect to the first problem, a fixed effects (FE) or a random effects (RE) model can be used to model $\mu_i$. However, the problem with the FE model is that there is no transformation to eliminate the unobserved effects in non-linear models. For this reason, we use a random effects model. The second problem arises because the first observation of each firm (initial condition) is affected by the same generation process and for this reason is endogenous. There are three different ways to solve this problem. The first one is to assume that the initial condition is a non-random constant and therefore is uncorrelated with the unobservable heterogeneity. However, this assumption is very unrealistic. The second solution considers $r_{i0}$ to be random and tries to estimate the joint density for $r_{i0}$ and for all $r_{it}$ conditioned to the strictly exogenous variables. Although Heckman (1981) proposes a method for approximating the conditional distribution, this function can only be found in some special cases. The third solution also assumes that $r_{i0}$ is random, but in this case a distribution of $\mu_i$ conditional on $r_{i0}$ and $x_{it}$ is specified. This method was suggested by Wooldridge (2005), who develops an estimator for dynamic non-linear RE models where it is necessary to model the unobservable heterogeneity[4].

We follow this last methodology. Specifically, we assume that this unobserved individual heterogeneity depends on the initial conditions and the strictly exogenous variables:

$$\mu_i = \alpha_1 + \alpha_2 \cdot r_{i0} + \overline{x}_i{'} \alpha_3 + a_i \qquad [3]$$

, where $\overline{x}_i$ is the time-average of $x_{it}$ and where $r_{i0}$ is the initial value. The assumptions about $a_i$ are $a_i \cong i.i.d.\ N(0,\sigma_a^2)$ and $a_i \perp (r_{i0},\overline{x}_i)$. In this context, $\rho_a$ is $\dfrac{\sigma_a^2}{1+\sigma_a^2}$ and shows the percentage of total variance explained by the unobserved heterogeneity.

In the original estimator proposed by Wooldridge (2005), instead of the average of the exogenous variables, he uses all the time observations of the variables. However, he shows that time-averages can be used to reduce the number of explanatory variables.

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[4] This method was proposed by Chamberlin (1980) for a linear AR(1) model without covariates.

Therefore, under this parameterization, the probability of being a firm which engages in (and reports) R&D activities is:

$$r_{it} = \begin{cases} 1 & \text{si} \quad r_{it}^* = \gamma \cdot r_{it-1} + x_{it}'\beta + \alpha_1 + \alpha_2 \cdot r_{i0} + \overline{x}_i'\alpha_3 + a_i + \varepsilon_{it} > 0 \\ 0 & \text{si} \quad r_{it}^* = \gamma \cdot r_{it-1} + x_{it}'\beta + \alpha_1 + \alpha_2 \cdot r_{i0} + \overline{x}_i'\alpha_3 + a_i + \varepsilon_{it} \le 0 \end{cases}$$ [2']

Conditional on the performance (and reporting) of R&D activities, we can observe the quantity of resources allocated to this purpose; that is,

$$id_{it} = \begin{cases} id_{it}^* = z_{it}'\beta + e_{it} & \text{si} \quad r_{it} = 1 \\ 0 & \text{si} \quad r_{it} = 0 \end{cases}$$ [4]

Therefore, to capture the true impact of R&D intensity on knowledge production, we estimate a selection model for the observed intensity and to use the predicted value as a proxy of the innovation effort in the production function of knowledge or innovations. However, to our knowledge, there is not any accepted econometric procedure that integrates the intensity equation [4] and Wooldridge's (2005) approach for estimating a dynamic RE model for equation [2'] in a selection model.

For this reason, we start with the estimation of a Heckman model where a static pooled model for the first decision is considered. That is, we implicitly assume that there is not state dependence ($\gamma = 0$) and the unobservable individual heterogeneity is not parameterized. Secondly, we consider a dynamic pooled Probit for the decision whether to engage in R&D activities or not, where the individual heterogeneity is parameterized as in Wooldridge (2005). In both cases, we assume that the error terms $e_i$ and $\varepsilon_i$ follow a bivariate normal distribution with a mean equal to 0, variances $\sigma_\varepsilon^2 = 1$ and $\sigma_e^2$, and correlation coefficient $\rho_{e\varepsilon}$ (Rho). Finally, as a robustness check, we compare the results for the selection equation in the second case with the estimation of a dynamic RE Probit model where individual heterogeneity is parameterized following Wooldridge (2005).

The third equation of the model corresponds to the estimation of the new knowledge production function, $g_i$, generated from firms' technological effort. This new knowledge is measured alternatively by three dummy variables that capture, respectively, the achievement

of product innovations, process innovations, and any of them[5]. Given that the investment intensity is a public good within the firm, it can be used to produce different outputs without depletion. Therefore, we can model $g_{it}$ as a vector of technological outputs:

$$g_{it} = \gamma \cdot g_{it-1} + \lambda \cdot id_{it}^* + y_{it}'\delta + \zeta_i + u_{it} \tag{5}$$

, where the latent investment intensity $id_{it}^*$ appears as an explanatory variable joint with the vector $y_{it}$, which includes other determinants of the knowledge production (time-variant and time-invariant variables). We also add the dependent variable lagged one period, $g_{it-1}$, in the specification to reflect whether the firm has previously generated new knowledge capturing the innovation output experience.

As in equation [3], following Wooldridge (2005), we model the unobserved heterogeneity $\zeta_i$ as dependent on the initial conditions and the average of the explanatory variables:

$$\zeta_i = \pi_1 + \pi_2 \cdot g_{i0} + \overline{y}_i'\pi_3 + \upsilon_i \tag{6}$$

We assume that $\upsilon_i \cong i.i.d.\ N(0, \sigma_v^2)$ and $\upsilon_i \perp (g_{i0}, \overline{y}_i)$. In this context, $\rho_v$ is $\dfrac{\sigma_v^2}{1+\sigma_v^2}$ and shows the percentage of total variance explained by the unobserved heterogeneity. Therefore, the new knowledge production function can be expressed as:

$$g_{it} = \gamma \cdot g_{it-1} + \lambda \cdot id_{it}^* + y_{it}'\delta + \pi_1 + \pi_2 \cdot g_{i0} + \overline{y}_i'\pi_3 + \upsilon_i + u_{it} \tag{5'}$$

Given that our measures of new knowledge generation are binary variables for process or product innovation, the last equation will be estimated by a dynamic RE Probit model.

Finally, firms produce goods using the following production function (in growth rates):

$$y_{it} = a(g_{it}) + \varepsilon_{y,l}l_{it} + \varepsilon_{y,k}k_{it} + \varepsilon_{y,m}m_{it} + v_{it} \tag{7}$$

where $y, l, k$ and $m$ stand respectively for the logarithmic differences in production and in the quantities of labor, physical capital and intermediated inputs, $\varepsilon_{y,l}, \varepsilon_{y,k}$ y $\varepsilon_{y,m}$ are the output

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[5] Other measures of innovation outputs have been used in complementary estimates of the knowledge production function. Specifically, we have considered dummy variables for the joint generation of product and process innovations, for only process and for only product innovators. The results confirm those presented in this paper and are available from the authors upon request.

elasticities with respect to the above inputs, and *a* is the productivity growth, which in part will be determined by the technological output *g*.

Rearranging terms, it is possible to explain the last expression as a total factor productivity equation:

$$\theta_{it} = y_{it} - (s_l l_{it} + s_k k_{it} + s_m m_{it}) = \pi_\varpi \varpi_{it} + \pi_g g_{it} + v_{it} \qquad [8]$$

, where $\theta_{it}$ is the well-known Solow residual and $\varpi_{it}$ is a vector that includes the variables reflecting the non-fulfillment of the assumptions associated with this kind of model (constant returns to scale, instant adjustment of the inputs), along with other control variables. In the estimation of this last equation, we will take into account the potential endogeneity of the technological output *g*.

To summarize, our model consists of equations [2], [4], [5] and [8]. Following the CDM methodology, we assume a recursive model where feedback from productivity growth to technological effort is not allowed, and therefore we apply a three-stage estimation procedure.

## 3. Data and variables definition

Estimations are carried out with an unbalanced panel of Spanish manufacturing firms for the period 1990-2005. The variables are obtained from the *Encuesta Sobre Estrategias Empresariales* (ESEE), a survey that is sponsored by the Spanish Ministry of Industry and carried out by the Fundación SEPI[6]. The sampling scheme of this survey is conducted for each manufacturing NACE class (two-digit) level. Companies employing between 10 and 200 employees are chosen by a random sampling scheme and the rate of participation is around 4%. For firms employing more than 200 employees, the rate of participation is about 60%. The sample considered is about 2000 manufacturing firms that have ten or more employees each year.

Table 1 shows the main characteristics of the database distinguishing between small and medium-sized firms (SME) (with fewer than 200 workers) and large firms (more than 200 employees). To analyze the dynamics of R&D activities, it is required that the firms answer

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[6] See a more detailed description of the database in http://www.funep.es/esee/en/einfo_que_es.asp

consecutively. In this sense, only those firms that have at least eight consecutive observations, which is the average period of our sample, have been taken into account. As can be seen in Table 1, in our unbalanced panel the average number of consecutive years per firm is around 12. We could restrict the analysis to the balanced panel, but due to attrition in this case we lose two thirds of the observations.

**Table 1**
Characteristics of the sample

|  | Firms with at least eight consecutive observations | | |
| --- | --- | --- | --- |
|  | SME | Large Firms | All Firms |
| No. of observations | 8052 | 4251 | 12303 |
| No. of firms | 709 | 363 | 1072 |
| Average no. of consecutive observations by firm | 12.0 | 12.3 | 12.1 |

Although the ESEE is not specifically designed to analyze technological activities, it includes a relevant set of indexes about this subject and has information not only for firms engaged in technological activities but also for firms without R&D expenditures. In fact, for the analysis we have 12,303 observations and 7,548 of them correspond to firms that do not perform formal R&D. This is especially suitable in this case, given that we assume that all firms make some innovative effort, although not all reflect this effort in their answer to the survey. That's why we estimate the model for the whole sample, and not only for firms with positive R&D expenditures. As a measure of the R&D investment intensity, we use the total R&D expenditure per employee (in logs), assuming that a firm decides to perform technological activities if its expenditures are positive.

Table 2 presents the transition probabilities of engaging in R&D activities or not over the period 1990-2005. Notice that the status in $t$-1 is positively correlated with the status in $t$. Almost 90% of firms which perform R&D activities in one year persist in the following year. Additionally, more than 93% of non-performing firms in $t$-1 are also non-performers in $t$, while 7.3% engaged in R&D activities. This implies that the probability of undertaking R&D in $t$ is 82 percentage points higher for performers than for non-performers in $t$-1[7].

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[7] When the balanced panel is considered, the transition probabilities of the R&D status are almost the same.

Following theoretical models (Arvanities and Hollenstein, 1994, Klepper, 1996), the variables to be included in the participation and the intensity equations relate basically to the technological environment, demand and market conditions, appropriability of the benefits derived for technological investments[8], financial restrictions and size (to capture the existence of economies of scale in R&D).

**Table 2**
Transition probabilities of the R&D status

|  | | Performer in t | |
|---|---|---|---|
|  | Performer in t-1 | Yes | No |
| SME | Yes | 83.2 | 16.8 |
|  | No | 5.0 | 95.1 |
| Large Firms | Yes | 92.7 | 7.3 |
|  | No | 15.5 | 84.5 |
| All Firms | Yes | 89.1 | 11.0 |
|  | No | 6.9 | 93.2 |

In this line, given the available information in the database, to capture environmental and demand conditions, we have introduced, as explanatory variables, one indicator of the firm's export character and a variable reflecting whether the market evolution perceived by the firm each year was expansive or recessive with respect to the previous year.

Following Schumpeterian tradition, we include a qualitative measure of the number of a firm's rivals to capture the degree of market competition.[9] A negative impact of this variable on the participation decision would be coherent with the hypothesis that the more competitive the market, the less capacity firms have for appropriating the benefits of their investments, and therefore have fewer incentives to make these investments. To indicate appropriability conditions, we have also used the proportion of engineers and graduate employees in the firm. We can think that those firms with more qualified personnel are more capable of assimilating new knowledge, whether it is developed internally or externally. Piva and Vivarelli (2009) provide evidence that supports this hypothesis for a panel of Italian firms.

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[8] See, in Cohen and Levin (1989), a discussion about the effect of technological opportunities, appropriability conditions and market evolution on R&D activities.
[9] The concentration ratio CR4 is also available in the database, but with a very low response.

With respect to financial restrictions, we use a categorical variable that shows whether the firm obtained public support during the year. The evidence about the impact of financial restrictions on investment effort is mixed. Hall et al. (1999) find that during the period 1978-1989, R&D in the American high-tech sector was sensitive to cash flow, while the results are not so clear in the case of France and Japan. Bond, Harhoff and Van Reenen (1999) find that the cash flow affects the decision to perform R&D more than the levels of expenditure. Previous works for Spanish economy point out that, irrespective of firm size, the investment effort since 2000 has been superior in firms that won public support than in those who apply for it without success, and greater in the latter than in firms that did not apply for it.

Along with the above variables, the model includes indicators to capture differences in the firms' investment behavior in terms of the time of permanence in the market. International evidence suggests that entrants are among the most innovative and that the growth rate post-entry depends on their innovative behavior, the probability of survival being tied to the existence of technological opportunities.[10] Therefore, we introduce the firm's age and two dummies reflecting whether the firm was an entrant or an exiting firm during the period. The set of mobility indicators is fulfilled with two event dummies for mergers and scissions.

Finally, we include sets of time, size, and industry dummies as control variables in both equations, and two factors related to firms' organizational aspects: belonging to a society and the degree of services subcontracting. As Raymond et al. (2009) point out, firms that are part of a group can be more innovative because they benefit from internal financing, knowledge spillovers and marketing synergies.

As for the knowledge production function, the ESEE provides qualitative information about the achievement of process and product innovations. In particular, a product innovation is assumed to have occurred when the firm answers the following request in the affirmative: "Please indicate if during the year 199x your firm obtained product innovations (completely new products or products with such important modifications which made them different from the old ones)". In a similar way, a process innovation is assumed to have occurred when the firm answers the following request positively: "Please indicate if during the year 199x your firm introduced some significant modification in the production process (process innovation).

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[10] See, for example, Audretsch (1995) and, for Spanish industry, Huergo and Jaumandreu (2004).

If the answer is yes, please indicate the way: a) introduction of new machines; b) introduction of new methods of organization; c) both."

Table 3 shows the transition probabilities for the generation of product or process innovations during the sample period. In both cases, the status in *t*-1 is positively correlated with the status in *t*, although the persistence seems to be slightly higher for product innovations. Almost 70% of firms which innovate in one year persist in innovating the following year, while more than 82% of non-innovative firms in *t*-1 are also non-innovators in *t*. This confirms the interest in taking persistence into account when analyzing the generation of new knowledge.

**Table 3**
Transition probabilities of the innovator status

|  |  | Innovator in t | | | |
|  |  | Process Innovator | | Product Innovator | |
| | *Innovator in t-1* | Yes | No | Yes | No |
| Small and medium firms | Yes | 60.3 | 39.7 | 65.9 | 34.1 |
|  | No | 14.8 | 85.2 | 8.5 | 91.5 |
| Large Firms | Yes | 75.6 | 24.4 | 73.7 | 26.3 |
|  | No | 23.7 | 76.3 | 15.9 | 84.1 |
| All Firms | Yes | 67.6 | 32.4 | 69.7 | 30.3 |
|  | No | 17.2 | 82.8 | 10.7 | 89.3 |

With respect to the explanatory variables in the knowledge production function, in the case of process innovations, given that these can be obtained by buying new machines, along with investment effort we include physical capital intensity (in logs). In addition, irrespective of the type of innovation, the set of variables also comprises specific industry characteristics. Notice that, along with internal inputs, it is also necessary to take into account other elements that do not depend completely on the firms' decision but can affect their generation of innovations. In particular, the incentives to allocate resources can change depending on demand price elasticity. In markets where the product supplied by the firm is highly standardized, product innovations are a better mechanism for reducing competitive pressure. In the estimations, we use a binary variable reflecting the degree of product homogeneity as a "naive" proxy of demand price elasticity. This index takes the value one if the product sold by the firm is highly standardized. The specification also includes industry dummies to capture the possibility of technological spillovers and different life cycles and technological regimes (Klepper, 1996, and Utterback, 1994).

As for productivity growth (the dependent variable in equation [8]), the available information allows us to compute a cost-based Solow residual in terms of a Tornqvist index[11]. In this equation, together with the control variables (mobility, time, size and industry dummies), we introduce the change in the capacity utilization to pick up the impact in the degree of inputs used in the presence of quasi-fixed factors. In addition, we include the weighted input variation to capture the potential bias by the non-fulfillment of the constant returns to scale assumption[12].

Table 4 shows the descriptive statistics of the main variables in our model. Except the degree of services subcontracting[13], all of them can vary across firms and time.

### Table 4
Descriptive Statistics

| | Mean | Standard deviation | | | Min | Max |
| --- | --- | --- | --- | --- | --- | --- |
| | | Overall | Between | Within | | |
| Age | 24.781 | 12.297 | 12.077 | 3.038 | 1 | 40 |
| Belonging to a group | 1.324 | 0.468 | 0.427 | 0.197 | 1 | 2 |
| Capacity utilization variation (%) | 0.077 | 15.739 | 2.591 | 15.539 | -230.259 | 289.037 |
| Demand evolution | 2.113 | 0.689 | 0.367 | 0.588 | 1 | 3 |
| Degree of product homogeneity | 0.636 | 0.481 | 0.429 | 0.226 | 0 | 1 |
| Degree of services subcontracting | 47.013 | 11.215 | 11.345 | 0.000 | 0 | 93.4 |
| Proportion of engineers and graduates | 4.165 | 6.512 | 6.308 | 2.244 | 0 | 78.9 |
| Exporter in t-1 | 0.640 | 0.480 | 0.425 | 0.227 | 0 | 1 |
| Export intensity in t-1 (in logs.) | 6.226 | 4.861 | 4.473 | 1.933 | 0 | 13.637 |
| Physical capital intensity (in logs.) | 9.746 | 0.948 | 0.885 | 0.367 | 7.118 | 12.644 |
| Process innovation | 0.352 | 0.478 | 0.295 | 0.377 | 0 | 1 |
| Product innovation | 0.266 | 0.442 | 0.300 | 0.325 | 0 | 1 |
| Public support in t-1 | 0.100 | 0.300 | 0.217 | 0.205 | 0 | 1 |
| Number of competitors | 1.787 | 1.113 | 0.884 | 0.692 | 1 | 4 |
| R&D intensity | 2.683 | 3.509 | 3.059 | 1.720 | 0 | 11.142 |
| R&D performer | 0.387 | 0.487 | 0.414 | 0.255 | 0 | 1 |
| Size (number of employees) | 216.2 | 463.5 | 463.5 | 103.9 | 3 | 9043 |
| Total factor productivity growth (%) | 0.810 | 14.435 | 2.907 | 14.154 | -208.197 | 170.461 |
| Weighted inputs variation (%) | 2.873 | 21.327 | 6.355 | 20.427 | -161.171 | 310.349 |

Notes: The period used is 1991-2005. For lagged variables the reference period is 1990-2004.

Note that, for almost all explanatory variables to be used in the selection equation, the variation across firms ("*between*" variation) is bigger than the time variation ("*within*"). See, for example, the age, the degree of services subcontracting, the proportion of engineers and

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[11] In the ESEE, firms report the price changes on their output and inputs, which makes it possible to construct Paasche-type firm individual indices to deflate output and intermediate consumption real changes.
[12] See the Appendix for a more detailed explanation of the variable definitions.
[13] In the survey, firms only answer the question referring to this information every four years.

graduates and the number of competitors. For this reason, we are going to treat them as time constant in equation [2'].

## 4. Econometric results

In this section, we present the results of the estimation of the model depicted in Section 2. As equations [2], [4], [5] and [8] point out, we assume a recursive model where feedback from productivity growth to technological effort is not allowed. Taking this into account, we apply a three-stage estimation procedure.

In the first stage, the decision to engage in R&D activities is jointly estimated with the R&D intensity (equations [2] and [4]) using the Generalized Tobit model. We investigate the possibility of persistence in the selection equation but we do not consider any dynamics in the R&D effort. In particular, we use Wooldridge's (2005) approach to parameterize the unobserved individual heterogeneity.

In the second stage, we estimate the knowledge production function [5], introducing the predicted value of the R&D intensity as an explanatory variable. As we indicate in Section 2, the technological effort can be used to obtain new products and/or processes. Therefore, we consider both types of innovations to be technological outputs. Additionally, we study whether the probability of obtaining a process or product innovation is positively affected by previous success in the generation of innovations. Given the binary character of our innovation indexes, we estimate this equation as dynamic RE Probit models. As in the first stage, Wooldridge's approach is used to parameterize the unobserved individual heterogeneity.

Finally, in the last stage, the productivity growth equation [8] is estimated taking into account the potential endogeneity of the technological factor in the production function.

*R&D investment intensity*

Table 5 shows the results of the estimation associated with equations [2] and [4] explained in Section 2. We start with the estimation of a pooled and static RE Probit model, implicitly

assuming no state dependence in the selection equation ($\gamma = 0$). In columns (1) and (4), we present the results of the Generalized Tobit model where the participation and the intensity equations are estimated consistently by maximum likelihood. .

Secondly, in column (2), we investigate the persistence of the decision whether to engage in R&D activities or not by estimating this equation as a dynamic RE Probit model (equation [2']), following Wooldridge's approach for taking into account the unobservable individual heterogeneity. Finally, given that we confirm the existence of true state dependence in the selection equation, a Generalized Tobit model is estimated, parameterizing the individual unobserved heterogeneity in terms of the initial conditions and the exogenous variables (columns (3) and (5)) as in the dynamic RE Probit model.

The three first columns exhibit the marginal effects of the Probit model for the participation decision, while the coefficients showed in columns 4 and 5 correspond to the R&D intensity for the static and dynamic pooled model, respectively. Notice that the correlation term rho ($\rho_{e\varepsilon}$) is significant in both estimations, pointing out the necessity of estimating a selection model for the observed intensity.

We tried almost the same set of explanatory variables for both equations ($x_{it} = z_{it}$), but eventually we included only those variables that turn out to be statistically significant in each equation in the specification. There are four variables, the proportion of engineers and graduates, the firms' age, the degree of services subcontracting and the number of competitors, which present a very small *within*-firm variation. For these reason, we consider them to be time-constant specific variables in the estimation for the participation equation. This implies that these variables cannot be included in the parameterization of the individual effects[14].

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[14] Due to the high collinearity between them and their time-averages, when we introduce the last ones in the parameterization of the individual heterogeneity, all are not significant. Specifically, we have tried with the age and the proportion of engineers and graduates. We find the same result when we introduce each variable separately.

**Table 5**
R&D intensity

| | Propensity to engage in R&D (0/1) | | | R&D Intensity | |
|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) |
| *Estimation method* | *Pooled Probit* | *Dynamic RE Probit* | *Dynamic Pooled Probit* | *Generalized Tobit (selection from (1))* | *Generalized Tobit (selection from (2))* |
| R&D performer in t-1 | | 0.586*** | 0.638*** | | |
| | | (0.016) | (0.012) | | |
| Exporter in t-1 | 0.196*** | 0.039 | 0.032 | | |
| | (0.012) | (0.029) | (0.028) | | |
| Export intensity in t-1 | | | | 0.031*** | 0.016*** |
| | | | | (0.006) | (0.006) |
| Public support in t-1 | 0.534*** | -0.022 | -0.066** | 0.685*** | 0.624*** |
| | (0.018) | (0.032) | (0.029) | (0.048) | (0.050) |
| Demand evolution | 0.048*** | 0.040*** | 0.037*** | 0.067*** | 0.083*** |
| | (0.008) | (0.012) | (0.011) | (0.028) | (0.028) |
| Proportion of engineers and graduates | 0.012*** | 0.004*** | 0.004*** | 0.050*** | 0.047*** |
| | (0.001) | (0.002) | (0.001) | (0.003) | (0.003) |
| Degree of services subcontracting | 0.001*** | 0.000 | 0.000 | | |
| | (0.000) | (0.001) | (0.001) | | |
| Number of competitors | -0.046*** | -0.018 | -0.016* | | |
| | (0.007) | (0.011) | (0.009) | | |
| Age | 0.002*** | 0.001 | 0.001 | -0.004*** | -0.007*** |
| | (0.001) | (0.001) | (0.001) | (0.002) | (0.002) |
| Belonging to a group | | | | 0.061 | 0.016 |
| | | | | (0.042) | (0.041) |
| *Initial conditions* | | | | | |
| M_Exporter in t-1 | | 0.067* | 0.063* | | |
| | | (0.039) | (0.035) | | |
| M_Public support in t-1 | | 0.618*** | 0.617*** | | |
| | | (0.075) | (0.063) | | |
| M_Demand evolution | | 0.037 | 0.032 | | |
| | | (0.028) | (0.023) | | |
| R&D performer in 0 | | 0.390*** | 0.317*** | | |
| | | (0.023) | (0.015) | | |
| Rho | | | | 0.104*** | -0.203*** |
| | | | | (0.044) | (0.031) |
| Wald test – Industry dummies | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 |
| Wald test – Time dummies | 0.059 | 0.000 | 0.000 | 0.000 | 0.000 |
| Wald test – Size dummies | 0.000 | 0.000 | 0.000 | | |
| $\rho_a$ | | 0.119 (0.025) | | | |
| lnL | -5155.8 | -2773.8 | -2789.5 | -13069.2 | -10684.1 |
| Observed Probability | 38.6 | 38.6 | 38.6 | | |
| Predicted Probability | 38.6 | 38.4 | 38.6 | | |
| Correct predictions | 79.9 | 91.5 | 91.6 | | |
| Correct predictions: 1 / 0 | 82.0/ 78.7 | 91.1 / 91.7 | 90.7 / 92.2 | | |
| No. observations | 12303 | 12303 | 12303 | 4755 | 4755 |

Notes: Marginal effects (standards errors in brackets) are showed. ***, ** and * indicate significance on a 1%, 5% and 10% level, respectively. All regressions include a constant and 19 industry and 14 time dummies. Regressions (1) to (3) also include 5 size dummies. To avoid multicolinearity, the dummy variables corresponding to year 1991, industry 1 and size up to 20 employees are excluded. The estimates also include four dummies to capture the firm's mobility (merger, scission, entry and exit). Rho is the correlation coefficient, $\rho_{e\varepsilon}$, and $\rho_a$ is the percentage of total variance explained by the unobserved heterogeneity.

Additionally, the dynamic RE Probit model requires the strict exogeneity of the explanatory variables. Although it is possible to assume that most variables are exogenous, the indicators for being an exporter and for the winning of public support are introduced with a lag in the decision equation to control for endogeneity.

With respect to the decision to engage in (and report) R&D activities, the estimation in column (2) confirms that it is relevant to consider the existence of persistence. Even after controlling for individual unobserved heterogeneity, previous behavior as an R&D performer has a positive effect on the probability of engaging in R&D activities at present. That is, conditional on other firms' characteristics, a firm which performs R&D in $t$-1 is almost 60 percentage points more probable to undertake R&D activities in the next period.

The initial conditions are also significant, which suggests the existence of a high correlation between the initial value and the unobserved heterogeneity. In particular, the achievement of public support and being an exporter in the previous period have a positive impact on the probability of innovating. Additionally, the coefficient of correlation $\rho_a$ at the bottom of column (2) indicates that the unobserved heterogeneity explains 12% of the total variance of the dependent variable[15].

Comparing the first and the second columns, the results show that, when the persistence in the decision to perform R&D activities is taken into account, some explanatory variables which are strongly significant in the pooled Probit estimation lose their effect. For example, the number of rivals that exhibits a negative coefficient in column (1) - which is coherent with the Schumpeterian hypothesis - is non-significant in column (2). The same result occurs with the degree of services subcontracting and the firms' age. All of them are variables with a small time variation and their effect is probably captured by the lagged dependent variable.

However, there are some explanatory variables which still are significant and increase the probability of carrying out R&D expenditures. Specifically, the proportion of engineers and graduates (as a proxy of skilled employees) confirms the relevance of having qualified workers in the firm to more easily assimilate new knowledge. In addition, firms which operate

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[15] When estimating the equation through a Static RE Probit model, unobserved heterogeneity is relatively more important: almost 75% of the variance is explained by it.

in markets with an expansive demand present a higher probability of engaging in R&D activities.

As can be seen at the bottom of Table 5, the Wald tests confirm that the control variables are jointly significant. From the coefficients of the size dummies[16], a positive relationship between a firm's size and the decision of carrying out R&D is established. This is consistent with the hypothesis that large firms are more capable of exploiting economies of scale or scope in technological activities, but also with the idea that these firms have advantages in appropriating the results of them and obtaining external funding.

Due to the fact that estimation in column (2) confirms the existence of true state dependence in the innovation activity and that we are interested in the prediction of the R&D intensity for the second step of the CMD model, we proceed to estimate a Generalized Tobit model with dynamic in the participation equation. Again we parameterize the unobservable heterogeneity following Wooldridge (2005). The results in column (3) are quite similar to the ones in column (2), although the coefficient of the lagged dependent variable is slightly bigger and the number of competitors as a proxy of market competition is now significant as in the pooled Probit.

As can be seen in columns (4) and (5), once the firm has decided to invest, the proportion of engineers and graduates, the winning of public support in the previous period, and the export intensity stimulate the intensity of R&D investment, while the firm's age has the opposite effect. These results are in accordance with Hall et al. (2009) and Griffith et al. (2006). However, unlike this last paper, we find that the demand evolution has a positive effect not only on the participation decision but also on the R&D intensity. Additionally, belonging to a group of companies does not affect the amount of R&D expenditures.

*The knowledge production function*

The second stage of the model corresponds to the estimation of the new knowledge production function (equation [5]) generated from the firm's technological efforts. In Table 6, we show the results of this estimation for three alternative measures of innovation outputs,

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[16] The coefficients are available from the authors upon request.

using the predicted value of R&D intensity (obtained from the estimations in columns (3) and (5) in Table 5) as an explanatory variable. Notice that the R&D intensity equation can be interpreted as an instrumental variables equation, in which innovation effort is presumably endogenous to the innovation production function – that is, there can be unobservable (to the econometrician) firm characteristics that make firms invest more in R&D and, at the same time, make them more productive in the use of this effort. This could generate spurious correlation and upward bias in the coefficients of the knowledge generation equation.

Both for product and process innovation equations, the estimations in columns (2) and (4) also confirm in this case the existence of true state dependence. Conditional on other firm characteristics, a firm which innovates in $t$-1 is around 35 percentage points more likely to innovate in the next period. The last two columns in Table 6 show the results when we do not distinguish between product and process innovation. That is, we consider that a firm obtains a technological result independently of the kind of innovation[17]. As can be seen, the coefficient of the lagged dependent in column (6) is quite similar to those obtained in columns (2) and (4), supporting the existence of persistence.

As we expected, the predicted investment intensity has a significant positive impact on the generation of process and product innovations, even when we consider the dynamics in the generation of innovations. Nevertheless, its impact is smaller when persistence is taken into account. The quantitative effect of this variable is quite similar for process and product innovations. In addition, physical capital intensity is also positively related to the achievement of process innovation, which is coherent with the fact that part of these innovations are attained through the purchase of new machinery. This variable is also significant when the dependent variable does not distinguish between process and product innovations.

The degree of product homogeneity, used as a proxy of demand price elasticity, presents the correct sign according to theoretical predictions, positive for product innovations and negative for process innovations. However, it loses its significance as a determinant of any type of technological innovation (columns (5) and (6) of Table 6), which can be explained by its opposite effect on product and process innovations.

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[17] According to this variable, almost 50% of firms have obtained technological results over the period.

**Table 6**
The knowledge production function

| | Process innovation | | Product innovation | | Process or Product innovation | |
|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) |
| *Estimation method* | *Static RE Probit* | *Dynamic RE Probit* | *Static RE Probit* | *Dynamic RE Probit* | *Static RE Probit* | *Dynamic RE Probit* |
| R&D intensity[a] | 0.098*** | 0.047*** | 0.110*** | 0.055*** | 0.139*** | 0.068*** |
| | (0.017) | (0.016) | (0.016) | (0.013) | (0.024) | (0.019) |
| Process Innovation in t-1 | | 0.350*** | | | | |
| | | (0.012) | | | | |
| Product Innovation in t-1 | | | | 0.371*** | | |
| | | | | (0.014) | | |
| Process or Product Innovation in t-1 | | | | | | 0.374*** |
| | | | | | | (0.012) |
| Physical capital intensity | 0.110*** | 0.077*** | | | 0.107*** | 0.076*** |
| | (0.011) | (0.015) | | | (0.012) | (0.017) |
| Demand evolution | 0.050*** | 0.043*** | 0.009 | 0.008 | 0.043*** | 0.035*** |
| | (0.008) | (0.008) | (0.006) | (0.007) | (0.009) | (0.009) |
| Degree of product homogeneity | -0.034** | -0.018 | 0.040*** | 0.042** | -0.014 | 0.003 |
| | (0.017) | (0.013) | (0.013) | (0.011) | (0.019) | (0.016) |
| *Initial conditions* | | | | | | |
| M_Physical capital intensity | | -0.031* | | | | -0.038* |
| | | (0.017) | | | | (0.020) |
| M_Demand evolution | | 0.061*** | | 0.050*** | | 0.076*** |
| | | (0.021) | | (0.018) | | (0.024) |
| Process Innovation in 0 | | 0.241*** | | | | |
| | | (0.015) | | | | |
| Product Innovation in 0 | | | | 0.293*** | | |
| | | | | (0.018) | | |
| Process or Product Innovation in 0 | | | | | | 0.304*** |
| | | | | | | (0.016) |
| Wald test – Industry dummies | 0.006 | 0.439 | 0.000 | 0.007 | 0.000 | 0.359 |
| Wald test – Time dummies | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Wald test – Size dummies | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 |
| $\rho_v$ | 0.412 | 0.122 | 0.538 | 0.155 | 0.467 | 0.151 |
| | (0.017) | (0.015) | (0.018) | (0.018) | (0.016) | (0.016) |
| lnL | -6392.9 | -5825.7 | -5196.1 | -4536.5 | -6559.2 | -5934.6 |
| Observed Probability | 35.2 | 35.2 | 26.6 | 26.6 | 45.5 | 45.5 |
| Predicted Probability | 31.6 | 34.2 | 19.6 | 25.1 | 43.8 | 45.0 |
| Correct predictions | 66.5 | 76.5 | 70.6 | 81.4 | 65.0 | 76.7 |
| Correct predictions: 1 / 0 | 57.0 / 71.6 | 74.7 / 77.5 | 48.1 / 78.7 | 79.0 / 82.2 | 61.5 / 68.0 | 76.7 / 76.7 |
| Number of observations | 12303 | 12303 | 12303 | 12303 | 12303 | 12303 |

[a] - The prediction of the R&D intensity is obtained from estimations (3) and (5) in Table 5.
Notes: Marginal effects (standards errors in brackets) are showed. ***, ** and * indicate significance on a 1%, 5% and 10% level, respectively. All regressions include a constant and 19 industry and 5 size and 14 time dummies. To avoid multicolinearity, the dummy variables corresponding to year 1991, industry 1 and size up to 20 employees are excluded. The estimates also include four dummies to capture the firm's mobility (merger, scission, entry and exit). $\rho_v$ is the percentage of total variance explained by the unobserved heterogeneity.

The Wald tests show that, when persistence is taken into account, there are no significant differences between the probabilities of obtaining process innovations among industries. The size dummies again reflect the advantages of large firms to innovate, and the time dummies denote an increase in the achievement of both types of innovations until 2003, but stagnation during the last two years of the period.

*The Total Factor Productivity growth*

Finally, in Table 7 we present the results of estimating productivity equation [8]. All estimates are carried out considering the information to be a pool. To control for unobserved heterogeneity, we also made complementary estimations, taking into account the panel structure of the data. However, the test for the null hypothesis that all fixed effects are equal to zero cannot be rejected, as is showed at the bottom of the table.

To take into account the potential endogeneity of the technological factor in the production function, instead of observed technological outputs, we include the predicted values for the generation of innovations obtained from the estimations in Table 6 in the specification. The results show that the omission of the persistence in the analysis of the generation of knowledge leads to an overestimation of the impact of innovations on productivity growth. Specifically, when the predictions from the static RE Probit model are considered (columns (1) and (3) in Table 7), the impact of innovations on the PTF growth is clearly significant, and the quantitative effect is quite similar for both types of innovations. However, when the persistence of innovations is taken into account - columns (2) and (4) - the effect of process innovations on productivity growth is reduced more than fifty percent and the effect of product innovations disappears. Firms which obtain process innovations during the period show a TFP growth significantly higher than non-innovators. In this sense, it seems relevant to consider the true state dependence in the generation of knowledge if we want to capture the real effect of technological outputs on growth.

**Table 7**
Total Factor Productivity Growth

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) |
|---|---|---|---|---|---|---|---|
| *Estimation method* | *IV regression* | *IV regression* | *IV regression* | *IV regression* | *IV regression*[c] | *IV regression* | *IV regression* |
| Process innovation[a] | 7.251*** | 2.663*** | | | 2.825*** | | |
| | (1.275) | (0.573) | | | (0.605) | | |
| Product innovation[b] | | | 6.686*** | 0.380 | -0.460 | | |
| | | | (1.842) | (0.526) | (0.556) | | |
| Process or Product innovation[d] | | | | | | 6.866*** | 1.722*** |
| | | | | | | (1.303) | (0.519) |
| Weighted inputs variation | -0.196*** | -0.195*** | -0.194*** | -0.193*** | -0.195** | -0.196*** | -0.195*** |
| | (0.006) | (0.006) | (0.006) | (0.006) | (0.006) | (0.006) | (0.006) |
| Capacity utilization variation | 0.082*** | 0.082*** | 0.082*** | 0.082*** | 0.082*** | 0.082*** | 0.082*** |
| | (0.008) | (0.008) | (0.008) | (0.008) | (0.008) | (0.008) | (0.008) |
| Merger | 5.462*** | 5.921*** | 5.854*** | 6.081*** | 5.922*** | 5.715*** | 6.030*** |
| | (1.151) | (1.146) | (1.148) | (1.147) | (1.146) | (1.148) | (1.146) |
| Scission | -7.559*** | -7.373*** | -7.296*** | -7.356*** | -7.379*** | -7.364*** | -7.339*** |
| | (1.657) | (1.657) | (1.658) | (1.659) | (1.658) | (1.657) | (1.658) |
| Entry | 0.242 | 0.407 | 0.517 | 0.479 | 0.394 | 0.382 | 0.461 |
| | (0.359) | (0.357) | (0.357) | (0.358) | (0.358) | (0.357) | (0.357) |
| Exit | -0.384 | -0.706 | -0.150 | -0.839 | -0.745 | -0.066 | -0.696 |
| | (0.574) | (0.569) | (0.602) | (0.570) | (0.571) | (0.588) | (0.570) |
| Wald test – Industry dummies | 0.188 | 0.069 | 0.001 | 0.012 | 0.080 | 0.006 | 0.022 |
| Wald test – Time dummies | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Wald test – Size dummies | 0.002 | 0.236 | 0.030 | 0.378 | 0.276 | 0.002 | 0.351 |
| Fixed effects test: $F_{(1071,11212)}$ | 0.53 | 0.52 | 0.54 | 0.53 | 0.51 | 0.53 | 0.52 |
| Number of observations | 12303 | 12303 | 12303 | 12303 | 12303 | 12303 | 12303 |

[a] - Predictions used in columns (1) and (2) are obtained from estimations (1) and (2) in Table 6, respectively.

[b] - Predictions used in columns (3) and (4) are obtained from estimations (3) and (4) in Table 6, respectively.

[c] – Predictions of process/product innovation used in column (5) are obtained from estimations (2)/(4) in Table 6.

[d] - Predictions used in columns (6) and (7) are obtained from estimations (5) and (6) in Table 6, respectively.

Notes: All estimates include a constant, 19 industry dummies and 14 time dummies. To avoid multicolinearity, the dummy variables corresponding to year 1991 and industry 1 are excluded. Standards errors (in brackets) are showed. ***, ** and * indicate significance on a 1%, 5% and 10% level, respectively. The estimates also include four dummies to capture the firm's mobility (merger, scission, entry and exit).

These results are confirmed when we jointly introduce the predictions for process and product innovations as explanatory variables, as can be seen in column (5) of Table 7. In addition, when we use the prediction for innovation, irrespective of its type, as the only measure of technological output –columns (6) and (7)-, the impact is lower than in columns (1) and (2), in which we consider only process innovations. Unlike most previous empirical papers, which obtain a significant effect of product innovations on the growth of labor productivity, the PTF growth seems to be affected only by process innovations. In that respect, our findings show that the choice of the productivity measure is relevant to properly studying the effect of knowledge generation on growth.

The rest of the variables are included in the estimations to control for the non-fulfillment of the assumptions associated with the Solow residual models (constant returns to scale, instantaneous adjustment of the inputs) and the firm's mobility (entry, exit, merger, scission) during the period. In this sense, the capacity utilization variation is positively related to growth and the negative sign of the weighted inputs variation supports the existence of decreasing returns to scale. In addition, all the mobility dummies show the expected signs but only merger and scission are statistically significant. They have a similar quantitative impact on productivity growth, positive (negative) for mergers (scissions). Although the signs of the dummies for entrants and exiters support the predictions of industry dynamic models, the coefficients are non-significant. Notice that this result can be affected by the fact that we have restricted the sample to firms with more than 7 consecutive observations and therefore we are not capturing all the entries and exits during the period in a suitable way.

## 5. Conclusions

Since the mid-1990s, productivity in Spanish manufacturing industry has greatly decelerated. This phenomenon, shared with the majority of EU members, keeps European countries away from American firms that have been able to use the new telecommunication and information technologies to improve the efficiency in sectors not directly related to them.

With the objective of clarifying the relationship between technological activities and productivity growth, many researchers have empirically tested, with data from different European countries, the recursive CDM model that explains productivity growth by

technological outputs and these outputs by R&D effort. In this line, we estimate an adaptation of the CDM model for a panel of Spanish manufacturing firms during the period 1990-2005. Our main contribution consists of the consideration of persistence both in the R&D investment decision and in the achievement of innovations when estimating the model that reflects the relationship between R&D, innovations and productivity.

The results reflect that the R&D investment status and the production of innovations in one period strongly influence these variables in the next period. The omission of this persistence leads to an overestimation of the effect of the current impact of innovations on productivity growth. Additionally, our paper shows that the choice of the productivity measure is relevant to studying the effect of knowledge generation on growth. Specifically, unlike most previous empirical evidence that finds a positive effect of product innovation on labor productivity growth, in our analysis, only firms which obtain process innovations increase their TFP growth.

These empirical regularities hide important differences in firms' behavior according to their size. Large firms present advantages in exploiting economies of scope and scale in R&D activities. However, they have more difficulties improving their productivity.

Furthermore, the paper shows that the evolution of markets plays a relevant role not only for the probability of engaging in R&D expenditures but also for the effectiveness in obtaining process innovations. Both of them rise when firms perceive their market as expansive.

The estimations also point out the relevance of technological policy as an instrument for increasing productivity. In particular, public funding seems to stimulate R&D investment intensity and improvements in workers' level of education increase both the probability of carrying out R&D activities and the technological effort. In that respect, public support and private R&D investment seem to be complementary rather than substitute activities. In addition, the evidence of persistence in R&D inputs and innovation outputs suggests that the effects of technological policy can also persist in the long term.

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**Appendix:** *Variable definitions*

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

*Capacity utilization variation:* Variation in the percentage of utilization of installed capacity reported by the firm.

*Capital intensity*: Ratio of capital stock in equipment goods to employees.

*Capital stock of equipment goods:* Net stock of capital for equipment goods in real terms. It is calculated by using the perpetual inventory formula: $K_t = (1-d)K_{t-1}(P_t/P_{t-1}) + I_t$, where $P$ is the price index for equipment, *d* is the depreciation rate, and *I* is the investment in equipment.

*Degree of product homogeneity:* Dummy variable which takes the value 1 if the product supplied by the firm is highly standardized.

*Degree of services subcontracting:* Variable which indicates the degree of the subcontracted services by the firm not related to its productive activity like legal and fiscal advice, auditing, administration, personal selection and training, computer programming, installing of software packages, courier service, machinery hire, security, cleaning and packing and labeling.

*Effective hours of work:* Normal hours plus overtime hours minus lost hours.

*Demand evolution:* Each firm identifies the behavior of market demand in its main market during the year with respect to previous years according to three different categories: recession, stability and expansion. A value of 1, 2 and 3 is assigned respectively to each category.

*Export intensity:* Ratio of exports over total employment.

*Exporter:* Dummy variable which takes the value 1 if the firm has exported during the year.

*Firm's age:* Difference between the current year and the constituent year reported by the firm. We have assigned 40 to firms older than forty years old.

*Foreign capital participation*: Percentage of foreign capital in the social capital of the firm.

*Number of competitors:* Discrete variable which takes the values 1, 2, 3 and 4 when the number of competitors reported by the firm is up to 10, from 11 to 25, more than 25, and in an atomized market, respectively.

*Process Innovation:* Dummy variable which takes the value one if the firm has obtained a process innovation during the year.

*Product Innovation:* Dummy variable which takes the value one if the firm has obtained a product innovation during the year.

*Proportion of engineers and graduates:* Ratio of engineers and graduates over total employment.

*Public support:* Dummy variable which takes the value 1 if the firm has obtained public funding during the year.

*R&D expenditures per employee:* Ratio of total expenditures in R&D (including technology imports) over total employment.

*Total factor productivity (Solow residual)*: It is calculated using the Tornqvist index: $TFP = y - s_L l - s_K k - s_M m$, where the output and the inputs are in logarithmic differences and the weights $s$ in t are the cost shares of each input in the year $t$. Intermediate consumption variation ($m$) includes raw materials, services purchases and energy and fuel cost. Output and intermediate consumption are deflated using Paasche-type firm individual indices, constructed starting from the price changes in output and inputs reported by firms. Labor input variations ($l$) are the changes in total effective hours of work. The user cost of capital is calculated as the long-run debt interest rate paid by the firm plus equipment good depreciation minus the rate of change of a capital goods price index.