FURTHER CONSIDERATIONS ON THE LINK BETWEEN ADJUSTMENT COSTS AND THE PRODUCTIVITY OF R&D INVESTMENT: EVIDENCE FOR SPAIN

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De conformidad con la base quinta de la convocatoria del Programa de Estímulo a la Investigación, este trabajo ha sido sometido a evaluación externa anónima de especialistas cualificados a fin de contrastar su nivel técnico.

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Further considerations on the link between adjustment costs and the productivity of R&D investment: evidence for Spain (1, 2, 3)

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Summary: This paper constructs a dynamic model to estimate the impact of adjustment costs on the productivity of investment in R&D. In order to take into account the possible endogeneity of adjustment costs, the model is estimated by means of Instrumental Variables (IV), using a panel of Spanish companies. The results show that the elasticity of the productivity of R&D investment with regard to adjustment costs is high, with a value close to 1 (-0.96). This confirms that it is essential to include adjustment costs in the empirical analysis of R&D productivity, as suggested by Jones and Williams (1998) and Comin (2003, 2004).

Keywords: R&D, productivity, adjustment costs, companies
JEL code: O30, L60, C23

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1. Introduction

Economists have made enormous efforts to evaluate the impact of R&D investment on growth and productivity (see the surveys undertaken by Griliches, 1992, Nadiri, 1993 and CBO, 2005). The evidence indicates that a positive relationship between these variables exists, although the range of elasticities is very wide (CBO, 2005). This breadth may be the result of various factors e.g. the type of data utilised in the empirical analysis, the definition of R&D, the econometric procedures used, etc. In recent years, certain authors, such as Jones and Williams (1998) and Comin (2003, 2004), have argued that the regressions habitually performed have omitted certain variables which simultaneously affect both productivity and investment in R&D. One factor frequently omitted in empirical research is that of adjustment costs (for some exceptions, see Schankerman and Nadiri, 1984, Nadiri and Kim, 1996 and Nishimura *et al.*, 2005). Broadly speaking, adjustment costs, H(.), show the potential loss of output occurring during the maturation period of an investment project such as R&D. The sum of these costs is positively related to two factors: (i) the quantity of expenditure on R&D and (ii) the quantity of time elapsing from the beginning of the project until the results are fully incorporated into the production process.

Two principal arguments justify the incorporation of adjustment costs into the analysis of R&D productivity. Firstly, in an intertemporal setting, the optimal behaviour of the investor is determined by matching marginal costs and marginal benefits over the useful life of the investment. Obviously, dynamics can be rationalised by the existence of adjustment costs (apart from other factors, such as expectations). Secondly, adjustment costs are the result of multiple factors that enhance disembodied productivity, such as managerial and organisational practices, learning-by-doing mechanisms or the degree of commitment to the organisation on the part of white-collar workers (see Comin, 2004). In fact, since a portion of overall company knowledge is lost when white-collar workers leave or are dismissed, firms may make a strategic decision to spread their R&D expenditure over time (see Hall, 2002). This implies that spending on R&D at company level may entail high adjustment costs (for a discussion, see Hall *et al.,* 1986, Lach and Schankerman, 1988, Bessen, 2002, 2003 and Comin, 2000, 2002).

Our contribution to this research field is twofold. Firstly, using Euler's equations as a basis, we construct a dynamic model for the estimation of R&D productivity regarding adjustment costs H(.). Secondly, we model two types of adjustment costs: H_I(.) represents the costs of the necessary equipment for researchers to perform their work i.e. the purchase of computers, acquisition of laboratory instruments, etc., while H_R(.) depicts the loss of revenues due to changes in research staff membership i.e. the time which elapses between the incorporation of a scientist or engineer into the workforce (earning a salary), and the moment his or her activity begins to produce results.

The evaluation of the model is performed using a panel of Spanish manufacturing companies for the time period 1990-2001. The Spanish case is interesting for two reasons: firstly, because until today little analysis of this field has been performed in Spain and, secondly, because the proportion of Spanish company investment in R&D is one of the lowest in the EU-15. It may well be that the high adjustment costs in Spanish R&D investment explain such low levels.

This paper takes the following format. In Section 2 the model and the econometric specification are presented. The data utilised and the results of the estimation are given in Section 3, and the conclusions are described in Section 4.

2. Model and econometric specification

Under traditional assumptions, the present value of a given company is determined as follows:

$$MaxE\sum_{t=1}^{n}\left[\prod_{s=0}^{n}\beta_{is}\right]\pi_{it} \tag{1}$$

where E is the expectation operator, π_{it} is the after-tax dividends of the firm (throughout this article, the subindex *i* represents the company and *t* the time period), and β_{it} is the discount factor. The optimisation problem is subject to the restrictions inherent in the following equations (2), (3) and (4), which define the firm's dividends and the R&D stock (see Whited, 1992):

$$\pi_{it} = (i-\mu)\left[F\left(R_{i,t-1,}\ \cdot\right) - H\left(I_{it}^{R}, R_{i,t-1}\right) - C(\cdot)\right] - p_{it}^{R} I_{it}^{R} \tag{2}$$

$$\pi_{it} \geq 0 \tag{3}$$

$$R_{it} = I_{it}^{R} + (1-\delta_{R})R_{i,t-1} \tag{4}$$

where μ is the nominal tax rate of corporation tax, F (.) are revenues, H(.) represents the adjustment costs of investment in R&D, I^{R} is the market value of the investment in R&D, R is the value of stock, C(.) represents other intermediate costs (such as raw materials) and, finally, p^{R} is the "fiscal" price per unit of investment in R&D. Specifically, $p_{it} = (1-\Phi_{it})$ where Φ_{it} is the present value of tax credits and tax depreciations for R&D investment (see Appendix)[4]. Deriving the first order conditions with respect to R&D stock, we obtain the following Euler equation:

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[4] In Spain, approximately 60% of R&D expenditure is constituted by personnel costs, 25% by capital expenditure and the remaining 15% by other current expenditure (INE, 2001). Thus, *R* is a

$$(1+\lambda_{it})\left\{(1-\mu)\left[\frac{\partial F(R_{i,t-1};\cdot)}{\partial R_{i,t-1}}\cdot\frac{\partial R_{i,t-1}}{\partial R_{it}}-\frac{\partial H(I_{it}^{R},R_{i,t-1})}{\partial I_{it}^{R}}\cdot\frac{\partial I_{it}^{R}}{\partial R_{it}}-\frac{\partial H(I_{it}^{R},R_{i,t-1})}{\partial R_{i,t-1}}\cdot\frac{\partial R_{i,t-1}}{\partial R_{it}}\right]-p_{it}^{R}\frac{\partial I_{it}}{\partial R_{it}}\right\}+$$
$$+(1+\lambda_{i,t+1})\beta_{i,t+1}E_1\left\{(1-\mu)\left[\frac{\partial F(R_{it};\cdot)}{\partial R_{it}}-\frac{\partial H(I_{i,t+1}^{R},R_{it})}{\partial I_{i,t+1}}\frac{\partial I_{i,t+1}^{R}}{\partial R_{it}}-\frac{\partial H(I_{i,t+1}^{R},R_{it})}{\partial R_{it}}\right]-p_{i,t+1}^{R}\frac{\partial I_{i,t+1}^{R}}{\partial R_{it}}\right\}=0 \tag{5}$$

Following the appropriate operations and simplifications, we obtain:

$$(1+\lambda_{it})\left\{(1-\mu)\left[F_R(R_{i,t-1},\cdot)\frac{1}{1-\delta_R}-H_I(I_{it}^{R},R_{i,t-1})-H_R(I_{it}^{R},R_{i,t-1})\frac{1}{1-\delta_R}\right]-p_{it}^{R}\right\}$$
$$+\beta_{i,t+1}(1+\lambda_{i,t+1})E_1\left\{(1-\mu)\left[F_R(R_{it},\cdot)+H_I(I_{i,t+1}^{R},R_{it})(1-\delta_R)-H_R(I_{i,t+1}^{R},R_{it})\right]-p_{i,t+1}^{R}(1-\delta_R)\right\}=0 \tag{6}$$

where λ_{it} is the Lagrange multiplier associated to the constraint (3). Under the null hypothesis of no capital-market frictions, $\lambda_{it}\cong\lambda_{i,t+1}$ (see Hubbard *et al.*, 1995). In addition, we assume the existence of rational expectations. Dividing (6) by $(1-\mu)$, we obtain:

$$F_R(R_{i,t-1},\cdot)\frac{1}{1-\delta_R}+\beta_{i,t+1}F_R(R_{it},\cdot)=H_I(I_{it}^{R},R_{i,t-1})-\beta_{i,t+1}H_I(I_{i,t+1}^{R},R_{it})(1-\delta_R)$$
$$+H_R(I_{it}^{R},R_{i,t-1})\frac{1}{1-\delta_R}+\beta_{i,t+1}H_R(I_{i,t+1}^{R},R_{it})+p_{it}^{R}+\beta_{i,t+1}p_{i,t+1}^{R}(1-\delta_R) \tag{7}$$

The left-hand side of expression (7) represents the total ~~amount of the~~ current value of marginal productivity of the R&D stock valued at period *t*. For estimation purposes, we define P_{it} as follows:

$$P_{it}=\frac{Y_{it}-C_{it}}{R_{i,t-1}}\frac{1}{1-\delta_R}+\beta_{i,t+1}\frac{Y_{i,t+1}-C_{i,t+1}}{R_{i,t}} \tag{8}$$

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mixture of technological capital (for example, laboratories) and of the know-how of scientists and engineers involved in R&D tasks.

where *Y* is the level of output and *C* represents intermediate costs. To obtain the values for $H_I(.)$ and $H_R(.)$, we use a convex quadratic adjustment costs function in *R*:

$$H(\cdot)=\frac{1}{2}\left(\frac{I_{it}}{R_{i,t-1}}-v\right)^{2}R_{i,t-1} \tag{9}$$

For each firm, the greater the rate of investment ($I_{it}/R_{i,t-1}$), the greater the monetary costs associated with this investment. The parameter *v* can be interpreted as the specific level of investment required to minimise H(.). For simplicity's sake, we assume that v is zero for all firms. From (9) we derive the corresponding adjustment cost functions:

$$H_I\left(I_{it}^{R},R_{i,t-1}\right)=\left[\frac{R_{i,t-1}+I_{it}^{R}\dfrac{1}{1-\delta_R}}{\left(R_{i,t-1}\right)^{2}}\right]R_{it-1}-\frac{1}{2}\left(\frac{I_{it}^{R}}{R_{i,t-1}}\right)^{2}\frac{1}{1-\delta_R} \tag{10}$$

$$H_I\left(I_{i,t+1}^{R},R_{it}\right)=\left[\left[\frac{R_{it}+I_{i,t+1}^{R}\dfrac{1}{1-\delta_R}}{\left(R_{it}\right)^{2}}\right]R_{it}-\frac{1}{2}\left(\frac{I_{i,t+1}^{R}}{R_{it}}\right)^{2}\frac{1}{1-\delta_R}\right] \tag{11}$$

$$H_R\left(I_{it}^{R},R_{i,t-1}\right)=\left[\frac{-\left(1-\delta_R\right)R_{i,t-1}-I_{it}^{R}}{\left(R_{i,t-1}\right)^{2}}\right]R_{i,t-1}+\frac{1}{2}\left(\frac{I_{it}^{R}}{R_{i,t-1}}\right)^{2} \tag{12}$$

$$H_R\left(I_{i,t+1}^{R},R_{it}\right)=\left[\left[\frac{-\left(1-\delta_R\right)R_{it}-I_{i,t+1}^{R}}{\left(R_{it}\right)^{2}}\right]R_{it}+\frac{1}{2}\left(\frac{I_{i,t+1}^{R}}{R_{it}}\right)^{2}\right] \tag{13}$$

Thus, from expressions (7) to (13) we can rewrite the model as:

$$P_{it} = \alpha - \gamma\left[\beta_{i,t+1}\left[2\left[(1-\delta)+\frac{I^{R}_{i,t+1}}{R_{it}}\right]+\left(\frac{I^{R}{}_{i,t+1}}{R_{it}}\right)^{2}\right]\right]+\eta\left[p_{it}+\beta_{i,t+1}p_{i,t+1}(1-\delta_{t})\right] \qquad (14)$$

The term on the far right-hand-side includes the relation between productivity growth and adjustment costs. As can be observed, the expected relation between both magnitudes is negative. The second term from the right includes the effect of the taxation of investment on productivity. In this case, we expect the sign associated with parameter η to be positive. Taking the logarithms in expression [14], we attain the model to be estimated:

$$LnP_{it} = \alpha - \gamma\, LnX_{it} + \eta LnZ_{it} + \sum_{i=1}^{4}\lambda_{1,i}D_{i} + \sum_{t=1}^{9}\lambda_{1,t}D_{t} + u_{i} + v_{it} \qquad [15]$$

where X_{it} is the vector of the adjustment costs linked to the process of R&D investment, which is allowed to be correlated with v_{it}. The variation in effective "fiscal" prices is denoted by Z_{it}. In addition, two sets of dummies have been included in the model. The first of these is a proxy for time effects, D$_t$., while the second captures company characteristics i.e. if the company has at least 200 wage-earners (D$_1$), if it is quoted on the stock exchange (D$_2$), if it is constituted by public capital (D$_3$) and if it belongs to a technology-intensive sector (D$_4$).

Lastly, u_i are the fixed-effects (with σ_u standard deviation) which may be correlated with the variables in X_{it}, and v_{it} is the error component (with zero mean and σ_e standard deviation) which is uncorrelated with the variables in X_{it}.

3. Data and results

The database used in this study is the Survey of Company Strategies (ESEE). The ESEE, an annual representative survey of manufacturing companies, was undertaken in Spain for the Ministry of Industry during the period 1990-2000. A subsample of 125 companies (which fulfilled the condition of full and complete participation for all the years the survey was performed) was then extracted. The definition of the variables used, whether raw or derived, is explained in detail in the Appendix.

Table 1 shows the estimation results of equation (14). The model has been estimated by means of the within estimator in order to capture unobservable heterogeneity (see Hsiao, 1986); thus, the bias generated by the potential omission of variables in the regression has been avoided. Estimations have been carried out in logarithmic form, in order to control for the possible existence of heteroskedasticity. Column II includes the estimation of the model by Instrumental Variables (IV), in order to take into account the potential endogeneity of adjustment costs with regard to R&D productivity (for a discussion on this subject, see CBO, 2005). Estimation using IV makes it possible to obtain an unbiased estimation which is consistent with the parameters (see Wooldridge, 2006). The instrument used was the same variable, but one-period lagged. Figure 1 shows that the adjustment of the residuals to normal standardised distribution is greater when we use instrumental variables (right-hand graph).

As Table 1 shows, the F statistic demonstrates that the significance of both estimations is high. If the results obtained in Column II are examined, it is clear that the instrumentation of adjustment costs reinforces the negative sign of the coefficient. Likewise, the estimation with IV increases the significance of parameter γ to 95%. The results indicate that if adjustment costs increase by 1%, growth in productivity will be reduced by 0.96%. The parameter associated with taxation of R&D, η, displays the correct sign but is nevertheless not significant.

On this point, it should be noted that the coefficients of the dummy variables maintain their sign and significance in the two estimations. The size and degree of technological intensity of companies have a positive effect on the productivity of R&D investment, while the public ownership of companies exerts a negative influence. The temporal dummies refer to each year of this study in the time period 1991-1999. Lastly, the high percentage of variance displayed by the fixed effects should be emphasised.

4. Final remarks

The present study evaluates the role of R&D adjustment costs. The results show that the elasticity of productivity with respect to R&D adjustment costs is approximately 1 (-0.96). This confirms that adjustment costs should be included in the empirical analysis of R&D productivity; otherwise, as Jones and Williams (1998) and Comin (2003, 2004) have suggested, R&D productivity could be incorrectly measured.

Table 1: Determinants of R&D Investment Productivity

Dependent Variable: LnP_{it}

Panel data model with fixed effects

Parameters	I Without Instrumental Variables	II With Instrumental Variables
Constant	1.34(3.21)**	2.07(3.23)**
LnX_{it}	-0.04(-0.98)	-0.96(-2.03)**
LnZ_{it}	-0.01(-2.12)**	0.01(0.73)
D_1	0.23(2.50)**	0.24(1.98)**
D_2	-0.00(-0.00)	-0.06(-0.52)
D_3	-0.43(-3.28)**	-0.47(-3.27)**
D_4	0.06(1.55)*	0.07(1.44)*
1991	0.72(8.85)**	-
1992	0.46(6.36)**	1.12(3.20)**
1993	0.40(5.74)**	0.84(3.59)**
1994	0.28(4.11)**	0.59(3.34)**
1995	0.24(3.64)**	0.45(3.50)**
1996	0.14(2.06)**	0.31(2.75)**
1997	0.08(1.19)	0.17(2.10)**
1998	0.06(0.86)	0.04(0.63)
σ_u	1.14	1.21
σ_e	0.50	0.53
ρ	0.84	0.84
F-test of significance	F(14,986) = 14.91	F(138,862) = 8.10
Observations	1.125	1.000

ρ : is the percentage of variance displayed by the fixed effects.

t-statistic in parentheses

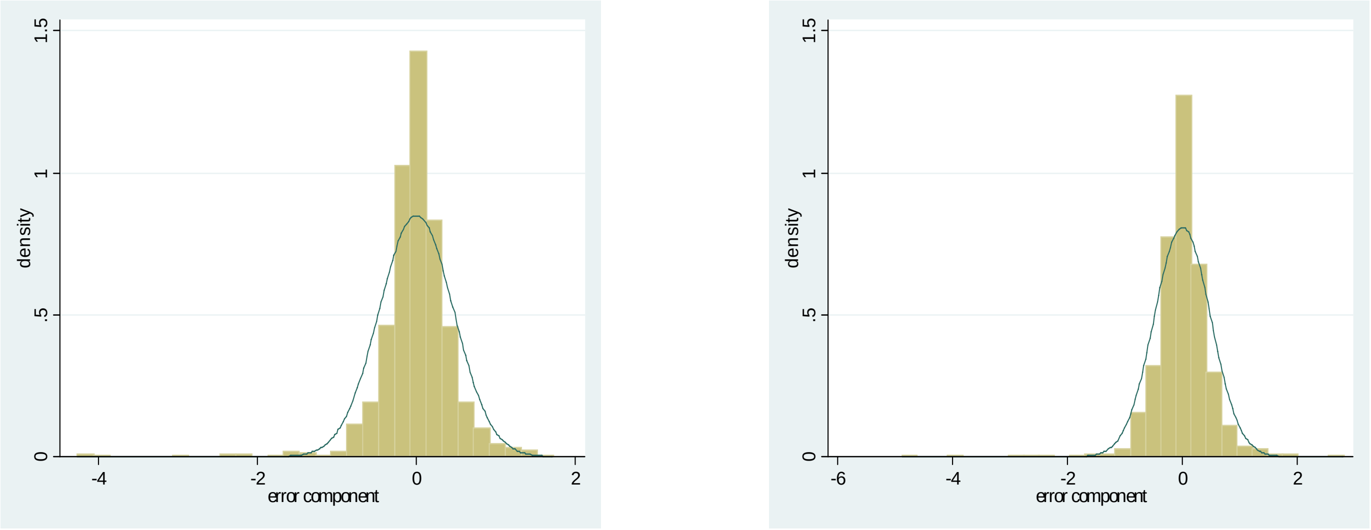
* Parameter significant at 90%

** Parameter significant at 95%

Figure 1: Residual Analysis

Without instrumental variables

With instrumental variables



Std.Dev.: 0.469

Mean: 2.19e-09

N: 1125

Std.Dev.: 0.494

Mean: 2.97e-09

N: 1000

Appendix

Construction of variables

Production (Y)

The value of production (in 1990 pesetas) has been calculated as the monetary value of production (sales plus variation of stocks) divided by a deflator of production d_{it}^{Y}. This deflator has been constructed for each company, based on the available information concerning the variation in annual sales prices π_{it}^{S}.

Intermediate inputs (C)

Annual expenditure on intermediate inputs has been constructed as the sum of the purchases of energy and fuel, raw materials and payment for external services. As a deflator of this variable, the National Statistics Institute's *Index of Industrial Prices* has been used. If we divide annual monetary expenditure on intermediate inputs by the deflator, we obtain the value of such inputs in 1990 pesetas. Unfortunately, the information provided by the ESEE does not itemise the expenditure assigned to R&D activities. Consequently, this variable is affected by a problem of double accounting.

Technological capital stock (R)

Technological capital stock, R_{it}, is defined as the accumulation (net of depreciation) of annual expenditure on R&D. Such expenditure is aimed at the development of new materials, products or productive processes, as well as the improvement of existing production systems. Included in this variable is expenditure earmarked for external research contracts signed with, for example, universities and specialist companies. The stock of technological capital has been constructed for each company by means of the permanent inventory method referred to in equation (3). As in the majority of existing studies for the case of Spain (see Marra, 2004), in this paper a constant rate of depreciation of 15% is used. In order to calculate the stock of technological capital for the first year of the sample, we have used the procedure proposed by Beneito (2001):

$$R_1 = I_1(1+m)\left[\left(1-\eta^{T}\right)/\left(1-\eta\right)\right] \qquad [A.1]$$

$$\eta = (1 - m)(1 - \delta) \qquad \text{[A.2]}$$

where R_1 is the investment in year 1, m is the average growth rate of companies which undertake R&D, T is the number of years since the founding of the company and δ is the (constant) rate of depreciation of R&D stock.

Effective "fiscal" price of technological capital (p)

The effective "fiscal" price, per unit of R&D investment, is defined as follows:

$$p_{it} = (1 - h_{it} - uz_{it}) \qquad \text{[A.3]}$$

where h_{it} is the instantaneous tax credit on R&D investment and uz_{it} is the present value of tax savings from the depreciation of assets related to R&D activities.

For the years 1990 to 1992, the percentage of h_{it} is 30%. From 1993 onwards, there are two percentages of deduction: one is applicable to the total investment of the fiscal year analysed h_1 and the other is applicable to the incremental base B_{it}. The incremental base is the difference between the investment during the fiscal year analysed and the average investment of the two preceding fiscal years. Thus, tax savings derived from credit for R&D investment are defined as follows:

$$B_{it} h_1 + \theta B^*_{it} h^* \qquad \text{[A.4]}$$

being:

$$B^*_{it} = B_{it} - \frac{1}{2} \sum_{i=1}^{2} B_{i,t-1} \qquad \text{[A.5]}$$

with the following restrictions:

$$\theta \begin{cases} \theta = 0 \quad \text{si} \quad B^*_{it} \leq 0 \\ \theta = 1 \quad \text{si} \quad B^*_{it} > 0 \end{cases} \qquad \text{[A.6]}$$

For the years 1993 to 1995, the percentage applicable to the incremental base is 45%. During the period 1996 to 1999, a 20% deduction is applied, with an additional 40% on the incremental base. In the period 2000 to 2001 percentages of 30% and 50% are applied respectively.

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