Productivity, adjustment costs and R&D investment prices
An analysis of a panel of Spanish manufacturing companies[1]

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Summary: This study analyses the role played by adjustment costs and R&D investment prices in total R&D productivity. The results show that on average, for each monetary unit increase in adjustment costs produces a fall in productivity of 0.034 monetary units.

Key words: R&D, productivity, adjustment costs

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1. Introduction

A common way of measuring the productivity of investment in R&D is to use a ratio which compares output and R&D stock (Total Factor Productivity, TFP). In this study we are interested in analysing this measurement of productivity. In particular, we want to analyse the role which adjustment costs and price variations in R&D investment play. Specifically, adjustment costs imply a loss of revenue because of the time lapse between the moment at which the investment occurs and the period in which the results of R&D (if they eventually arise) are utilised in the company. Little attention has been paid in the literature to these questions (see, for example, Schankerman and Nadiri, 1982; and, Nadiri and Kim, 1996).[2]

2. Model and econometric specification

The current value of the company is determined in the following way:

$$Max E_0 \sum_{t=1}^{n} \left[\prod_{s=0}^{n} \beta_{is} \right] \pi_{it} \tag{1}$$

where E is the expectations operator, π_{it} the cash flow (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 equations which define cash flow (2) and the R&D stock (3):

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

$$R_{it} = I_{it}^{R} + (1 - \delta_R) R_{i,t-1} \tag{3}$$

[2] In contrast to what happens with adjustment costs for investments in fixed productive assets.

where μ is the rate of corporation tax, F (.) are revenues[3], H(.) represents the adjustment costs of investment in R&D, I^R is investment in R&D, R is the R&D stock I+D, C(.) is other intermediate costs (for example, raw materials) and, finally, p^R is the effective price (net of taxes) of investment in R&D. In Spain, approximately 85% of R&D expenditure is personnel costs. For this reason, R is a mixture of technological capital (for example, laboratories) and of the know-how of scientists and engineers who are involved in R&D tasks.[4] Deriving the first order conditions with respect to R&D we obtain the following Euler equation:

(4)

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

Operating and simplifying appropriately we obtain:

(5)

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

[3] The revenues in period t depend on the R&D accumulated at the end of period t-1.

[4] The R&D stock for the first year of the sample (1990) is calculated in accordance with the method proposed in Beneito (2001). In this study we use a value for δ_R of 15% (see Beneito, 1997, 2001). However, estimations have been made for δ_R values between 0.01 and 0.20 with the results showing little sensitivity to these rates of depreciation.

Where λ_{it} is the shadow price for an additional unit of external financing and $(1+\lambda_{it})/(1+\lambda_{i.t+1})$ is the degree of financial restriction. For simplicity, we assume that the financial restriction, if there is one, remains constant, that is to say, $\lambda_{it} \cong \lambda_{i,t+1}$. Dividing by $(1-\mu)$, we obtain:

$$F_R(R_{i,t-1},\cdot)\frac{1}{1-\delta_R} + \beta_{i,t+1}F_R(R_{it},\cdot) = H_I(I_{it}^R, R_{i,t-1}) - \beta_{i,t+1}H_I(I_{i,t+1}^R, R_{it})(1-\delta_R)$$
$$+ H_R(I_{it}^R, R_{i,t-1})\frac{1}{1-\delta_R} + \beta_{i,t+1}H_R(I_{i,t+1}^R, R_{it}) + P_{it}^R - \beta_{i,t+1}P_{i,t+1}^R(1-\delta_R) \qquad (6)$$

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

$$P_{it} = \frac{Y_{it} - C_{it}}{R_{i,t-1}} + \beta_{i,t+1}\frac{Y_{i,t+1} - C_{i,t+1}}{R_{i,t+1}}\frac{1}{1-\delta_R} \qquad (7)$$

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

$$H(\cdot) = \frac{1}{2}\left(\frac{I_{it}}{R_{i,t-1}} - v\right)^2 R_{i,t-1} \qquad (8)$$

The greater the rate of investment $(I_{it}/R_{i,t-1})$ is, the greater are 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. From (8) we derive the corresponding adjustment costs:

$$H_I\left(I_{it}^R, R_{i,t-1}\right) = \left[\frac{R_{i,t-1} + I_{it}^R \frac{1}{1-\delta_R}}{\left(R_{i,t-1}\right)^2} \right] R_{it-1} - \frac{1}{2}\left(\frac{I_{it}^R}{R_{i,t-1}}\right)^2 \frac{1}{1-\delta_R} \tag{9}$$

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

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

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

As can be seen, there are two types of adjustment costs: $H_I(.)$ and $H_R(.)$. The first of these can be interpreted as the costs of the facilities necessary for the researchers to perform their work. For example, the purchase of a computer, laboratory instruments, etc. The second corresponds to the loss of revenues because of changes in the workforce (stock) of researchers. For example, the time which elapses between the incorporation of a scientist or engineer into the workforce (earning a salary) until his or her activity begins to bear fruit.[5] In this study we have assumed that the personnel employed takes a year to produce positive results from their research –these advances would represent an improvement in the company's productivity.[6]

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[5] This interpretation of adjustment costs is based on Whited (1992).

[6] Estimations have been performed for two years with minimal changes in the outcomes.

3. Results and conclusions

From expressions (6) to (12) we can write the model to be estimated as:

(13)

$$P_{it} = c - a\left[2\beta_{i,t+1}\left[(1-\delta_R) + \frac{I^R_{i,t+1}}{R_{it}} + \left(\frac{I^R_{i,t+1}}{R_{it}}\right)^2\right]\right] + b\left[p^R_{it} - \beta_{i,t+1}\,p^R_{i,t+1}\right] + \phi\, d_i + \varepsilon_{it}$$

As we can see, the model to be estimated is not linear, having as regressors the intercept (parameter c), the loss of revenues associated with adjustment costs (parameter a) and the evolution of the prices of investment in R&D (parameter b). We also control the estimation of the model using a set of dummy variables (d_i). Firstly, with respect to the number of patents obtained in other sectors (z). This dummy variable could help us to capture the spillovers generated by the R&D expenditure of other industrial companies. Secondly, with respect to the size of the company (h1) –greater or less than 200 employees. Thirdly, we consider whether it is listed on the stock exchange (h2). Fourthly, we take into account whether it is a public or private company (h3). Finally, using the parameters associated with the dummy variable s*0* (companies with a low level of R&D investment) and *s1* (companies with an average level of R&D investment) the difference in productivity are captured in relation to companies with a high level of investment in R&D.

The results of the estimation of (13) are presented in Table 1. The estimation procedure used was the *SUR* (*Seemingly unrelated regression*) method for non-linear models. The data base used in this study is the Survey on Company Strategies (ESEE)[7]. The EESE is an

[7] However, only data for the years 1991 to 2000 are used for two reasons. Firstly, because the estimation method for the R&D stock used for the first year (1990) is different to that used for the other years. To avoid

annual representative survey of manufacturing companies carried out in Spain since 1990 for the Ministry of Industry. For this study, we have taken into account solely the 125 companies who have taken part in all of the years in which the survey has been performed.

The White and Breusch-Pagan test performed on the initial estimation of the model allow the existence of the homocedasticity hypothesis to be rejected. To correct this problem the model has been estimated weighting for the *t* variable. As can be seen in Table 1, the Durbin-Watson test allows the first order serial correlation to be rejected. Similarly, the Godfrey test indicates that there is no first, second and third order serial correlation.

The parameters a and b present a significance which is greater than 99%. The sign of the adjustment and prices costs parameter is negative which indicates that they have a negative affect on the level of productivity. However, the influence of prices on this variable is much greater than that exercised by adjustment costs. Specifically, on average, for each monetary unit increase in adjustment costs produces a fall in productivity of 0.034 monetary units. In other words, adjustment costs have a negative effect on the productivity of the R&D activity although its effect is limited. The other parameters are not significant. In other words, the dummy variables used in the estimation have very little influence on the level of productivity. In this respect, Table 2 shows the results of different contrasts of joint significance. As can be seen, the null hypothesis is only rejected for prices and adjustment costs.

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spurious relationships therefore the data for 1990 are omitted. Secondly, as the costs have been defined (see

Table 1
Results of the weighted SUR estimation

Parameters	Value	Pr > |t|
c	-77.6834	0.7499
a	-0.03478	<.0001
b	-37.8291	0.0014
z	2.785E-6	0.7313
h1	61.04574	0.1939
h2	-65.4215	0.6272
h3	-58.4668	0.7126
s0	-93.4674	0.8428
s1	-632.577	0.7481

Durbin Watson test	2.0169
Godfrey serial correlation test (first order)	(p-value) 0.7641
Godfrey serial correlation test (second order)	(p-value) 0.9328
Godfrey serial correlation test (third order)	(p-value) 0.9793
Adjusted R square	0.1967

Table 2
Verification of parameter hypotheses

Specification	Wald test	P-value
a1+a2=0	10.22	<0.0014 (Rejected)
(z+h1+h2+h3+s0+s1)=0	0.10	<0.7471 (Accepted)
(s0+s1)=0	0.09	0.76600 (Accepted)

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(3)), the last year is lost in the calculations.

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