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"Does Internationalization Alter the R&D-Productivity Relationship"

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Does Internationalization Alter the R&D-Productivity Relationship?

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ABSTRACT:

R&D investment is an important driver of productivity gains. However, firms differ in their ability to appropriate the returns to their R&D efforts. This paper analyses to what extent firm's internationalization influences the endogenous relation between R&D and productivity. In particular, we assess the contribution of R&D to productivity for a panel of UK firms that differ in their degree of internationalization. We find that, on average, multinationals obtain higher gains from their investment in R&D. However, the influence of internationalization on the contribution of R&D to productivity varies along the distribution of the returns to R&D.

KEYWORDS: R&D, Multinationals, Productivity

JEL CODES: C14, D24, F23

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1. Introduction

R&D is as an important source of firm productivity gains (Griliches 1980). However, there is extensive evidence to show a great disparity among firms in terms of their ability to benefit from their R&D activities (Griliches and Mairesse 1983; Hall et al. 1993; Wakelin 2001). The empirical literature has primarily focused on the role that technological opportunities (Klevorick et al. 1995) and appropriability conditions (Levin et al. 1987) play in driving these differentials. In contrast, and despite the increasing degree of foreign presence in R&D activities (Narula and Zanfei 2005), little attention has been paid to the extent to which differences in firms' degree of internationalization influence the endogenous relation between R&D and productivity. This paper aims to fill this gap in the literature by analyzing the extent to which the ownership advantages of multinational companies (henceforth MNCs) enable them to obtain higher returns to R&D. The analysis is performed for an unbalanced panel of UK firms observed over the period 2002 to 2006.

The degree of internationalization may increase a firm returns to R&D because it increases both a firm's innovative capacity and its ability to exploit and appropriate the innovation outcomes. First, the availability of a broader range of global resources may provide MNCs with a higher capacity to innovate (Kobrin 1991). Second, the geographical expansion that characterizes MNCs may improve their appropriability regime (Teece 1986). However, internationalization is not devoid of problems that may have a detrimental effect on the returns obtained from R&D activities. Among these, several authors point out the possibility of knowledge leakages to competitors (Fish 2003; Sanna-Randaccio and Veugelers 2007) and the high coordination and control costs of a global network of R&D departments (von Zedwitz and Gassman 2002; Gersbach and Schmutzler 2006). It is, therefore, a matter of empirical research to assess what the net effects of internationalization are on the contribution of R&D to a firm's productivity.

In this study we seek to estimate these net effects using a Cobb-Douglas production function and the semi-parametric procedure originally proposed by Olley and Pakes (1996) and later extended by Levinsohn and Petrin (2003). This is a structural approach in the sense that it is ultimately based on a behavioral model of firm dynamics (Ericson and Pakes 1995). In particular, we assume that firms' expectations about their future productivity depend not only on their current productivity but also their R&D expenditures (Buettner 2005; Greenstreet 2007; Yan Aw et al. 2009). This assumption allows us to obtain non-parametric estimates of the return to R&D from the retrieved productivity of individual firms and, therefore, to make inferences for different sets of firms in terms of their degree of internationalization. Namely, we distinguish between domestic firms, domestic-owned MNCs and foreign-owned MNCs. We also distinguish between manufacturing and services firms.

Our approach to assessing the contribution of R&D to productivity differs from that of other studies, which typically estimate the return to R&D directly from the production function coefficients (Griliches 1998). However, this requires making assumptions about the adjustment process that governs the evolution of the stock of R&D. Thus, if we were to follow the classical knowledge capital model of Griliches (1979), as most papers in this area do, we would be imposing a linear accumulation of knowledge with constant-rate depreciation. In contrast, we follow Doraszelski and Jaumandreu (2008) and have considered a more flexible specification of the relation between productivity and R&D that does not impose such assumptions and does not require the initial conditions of the process to be guessed.

This is also a major difference with the previous studies of Kafourus et al. (2008) and Tsang et al. (2008) which, to our knowledge, are the only ones that empirically address the role of internationalization in the R&D-productivity relationship. In particular, Kafourus et al. (2008) estimate a first difference production function by OLS while Tsang et al. (2008) obtain their results from an AR (2) dynamic panel data model estimated in levels by 2SLS (not reported) and GMM using lags as instruments. However, both specifications of the production function are constructed largely ad-hoc. More importantly, their estimates are biased due to the (uncontrolled) presence of unobserved productivity shocks in the production function (Griliches and Mairesse 1998). Lastly, they focus on firms operating in industrial sectors while our data set covers both manufacturing and services firms.

The rest of the paper is organized as follows. In Section 2 we review theories and evidence concerning the superior performance of MNCs and the internationalization process of R&D. In Section 3 we discuss our empirical strategy. In Section 4 we present descriptive statistics as well as estimates of the input coefficients and the (gross rate of) return to R&D. Section 5 concludes.

2. Literature Review

2.1 The Superior Performance of Multinationals

In the international business literature it is often argued that MNCs possess some firm-specific advantages that compensate for the higher costs induced by operating in a foreign market. These advantages may arise from the possession of superior tangible and, particularly, "intangible" assets (Aitken and Harrison 1999), the ability to exploit global scale economies (Dunning 1993), factor price differentials and/or knowledge transfers from the parent firm to its foreign affiliates (Bartlett and Ghoshal 1989). There is also extensive empirical evidence based on firm-level data to show that multinationals, including their foreign affiliates, are on average more productive than domestic firms (Blomström and Kokko 1998). For the US, Doms and Jensen (1998) found that domestic non-MNC plants lag far behind MNC foreign-owned units, while US-owned MNC are the productivity leaders. For Great Britain, Griffith et al. (2004) found that foreign-owned MNCs are on average slightly more productive (in terms of value added per worker) than British-owned MNCs and significantly more productive than British domestic firms. Similarly, Criscuolo and Martin (2008) find that, for the manufacturing sector, British MNCs are as productive as non-US foreign MNCs, while US-owned establishments enjoy a small productivity advantage.

Still, some empirical studies show that domestically owned firms can outperform foreign-owned firms. For instance, Kim and Lyn (1990) found that MNCs operating in the US market are less profitable than randomly selected domestically owned firms. For Great Britain, Griffith (1999) found that, after controlling for factor usage, foreign-owned firms operating in the British car market were not significantly more productive than British-owned firms, with the exception of US-owned establishments. Similarly, Globerman et al. (1994) reported that once the effects of capital intensity and size have been controlled for, MNCs operating in the Canadian market are not significantly more productive than Canadian-owned firms, thus suggesting that the superior performance of MNCs is mostly due to their characteristic high capital intensity and large size.

It is worth noting, however, that these studies exclusively analyze the extent to which multinationality impacts on productivity. That is, they implicitly rule out the possibility that multinationality may also be a determinant of the returns obtained from other business activities, and in particular from R&D activities. This means that the extent to which the MNC's superior performance enables them to obtain higher returns to R&D has hardly been studied. This contrasts with the increasing internationalization of R&D activities over the last two decades. Although the internationalization of innovation activities has not reached the scale of other activities such as sales, marketing or manufacturing (Kuemmerle 1999; Le Bas and Sierra 2002), its potential differential effects upon MNC's performance should definitively be taken into consideration (Kafourus et al. 2008; Tsang et al. 2008).

2.2 Benefits and costs in the internationalization of R&D

Numerous investigations in the innovation and international business literatures have tried to pinpoint the main reasons why MNCs expand their R&D activities abroad –see e.g. Dunning and Narula (1995) for an overview. These reasons can be broadly grouped into two main categories: the exploitation of assets from the parent firm and the acquisition or improvement of assets by exploiting the technological advantages of the host country.[1] In the first case, the internationalization of R&D serves to transfer technology to the foreign subsidiaries in which the technological assets developed in the home country are exploited, usually after some adaptation to the characteristics of foreign markets (Bartlett and Ghoshal 1990). In the second case, multinationals make R&D investments abroad in order to acquire resources only available at foreign locations and augment their stock of knowledge (Florida 1997).

These studies have also identified several reasons why the costs associated with expanding R&D laboratories internationally may outweigh the potential benefits. Arguments for performance disadvantages of multinationality include the liabilities of foreignness (Hymer 1976; Zaheer 1995), i.e. the lack of local knowledge, reputational costs and weak links with the institutional setting of the host country have certain drawbacks. Other factors that may cause the R&D returns from foreign affiliates to be disfavored include the high coordination costs and principal agent problems arising from dispersed R&D locations (Gersbach and Schmutzler 2006), political and foreign exchange risk that may limit the amount of R&D that MNCs can invest (Bae and Noh 2001), and the possibility of knowledge leakages to competitors (Fish 2003).

Therefore, the potential impact of the internationalization of R&D on a firm's productivity remains unclear. However, the two previous empirical studies that address this issue, Kafourus et al. (2008) for Great Britain and Tsang et al. (2008) for Singapore, conclude that the degree of internationalization positively influences the innovation-productivity relationship. In particular, Kafarous et al. (2008) show that firms need to reach a particular threshold of internationalization to be able to benefit from R&D

[1] This last reason has grown in importance during the last decade (Criscuolo et al. 2005).

returns and Tsang et al. (2008) that foreign affiliates obtain higher returns from their R&D investments than their domestic counterparts.

Still, the conclusions drawn by these studies are questionable at least, since their results may be affected by significant bias in the estimation (ad-hoc specification of the production function, existence of unobserved productivity shocks). Additionally, as argued by Doms and Jensen (1998) and Temouri et al. (2008: 33), they do not deal with the important distinction between "subsidiaries of foreign firms (...) and domestic multinationals, on the one hand, and domestic firms, on the other". Therefore, the estimated effects may show the (partial) aggregation of these different categories. In contrast, our empirical strategy does not suffer from these limitations.

3. The Model

3.1 Basic Setting

We assume that firms produce a homogeneous good using a Cobb-Douglas technology:

$$y_{it} = \beta_0 + \beta_a a_{it} + \beta_k k_{it} + \beta_l l_{it} + \omega_{it} + e_{it} \quad \textbf{(1)}$$

where y_{it} is the logarithm of the value added of firm i at time t (in our study, $i = 1,\ldots, 465$ y $t = 1,\ldots, T_i$ with $T_i = 3, 4, 5$), a_{it} is the age of the firm, k_{it} represents the log of capital, l_{it} is the log of labor, ω_{it} is the firm's productivity and e_{it} is a random error term with the classical properties of zero mean and constant variance.

The main problem in estimating (1) is that since ω_{it} is assumed to be observable by the firm but not by the analyst, the correlation between labor and productivity renders the OLS estimator biased and inconsistent

(Griliches and Mairesse 1998). The fixed effects estimator may deal with this correlation, but at the cost of imposing that productivity shocks have no time variation. Similarly, instrumental variables methods have a number of drawbacks (mostly caused by the difficulty of finding appropriate instruments, i.e. variables that are correlated with the endogenous variable but uncorrelated with the productivity term). On the other hand, the semi-parametric method proposed by Olley and Pakes (1996) provides consistent estimates of the parameters of equation (1).[2]

To derive the estimator, Olley and Pakes (1996) consider labor as a freely variable factor. This means that it is an input into the production process that is chosen at t and can easily be adjusted whenever the firm faces a productivity shock. It is also assumed that labor is a non-dynamic factor, that is, it is not an argument of the firm's benefits function. In contrast, age and capital are considered to be fixed and dynamic factors. This means that they are state variables which are costly to adjust but not directly related to current productivity shocks. Rather, they accumulate according to a certain law of motion. Namely, $a_{it} = a_{i,t-1} + 1$ and $k_{it} = (1- \delta)k_{i,t-1} + i_{i,t-1}$, with δ being the discount factor and $i_{it} = i(a_{it}, k_{it}, \omega_{it})$ the demand function of physical investments (e.g. buildings and equipment) derived from the firm's dynamic profit maximization program (Ericson and Pakes 1995). This function is further assumed to be increasingly monotonic in ω_{it} given the other state variables under the firm's control (a_{it} and k_{it}).

As Ackerberg et al. (2007) show, this is a critical assumption in the various empirical strategies for consistently estimating (1), for it makes $i_{it} = i(a_{it}, k_{it}, \omega_{it})$ invertible in ω_{it} for strictly positive investments. As a result, we can now write $\omega_{it} = \omega(a_{it}, k_{it}, i_{it})$ and $\varphi(a_{it}, k_{it}, i_{it}) = \beta_0 + \beta_a a_{it} + \beta_k k_{it} + \omega(a_{it}, k_{it}, i_{it})$, so that (1) becomes:

[2] This estimator also addresses the sample selection bias arising from the endogeneity of the exit decision (see, however, Ackerberg et al. 2007: 4217), although the evidence suggests that the selection bias is much less important than the simultaneity bias –see e.g. Olley and Pakes (1996) and Levinsohn and Petrin (2003). This also seems to be the case in those "studies on innovation [where the] selectivity biases [arise because only] a minority of firms are engaged in (formal) R&D activities" (Crépon et al. 1998: 117).

$$y_{it} = \beta_l l_{it} + \varphi(a_{it}, k_{it}, i_{it}) + e_{it}. \quad \textbf{(2)}$$

The advantage of using (2) rather than (1) to estimate the coefficients of the production function is that specification (2) "allows us to 'observe' the unobserved ω_{it}", thus eliminating "the input endogeneity problem in estimating the labor coefficient" (which, as Ackerberg et al. 2007: 4215 show, it is identified under the timing and dynamic assumptions we made on the input factors). The downside is that the age and capital coefficients are not identified in this partially linear specification. Conditional on survival, these are estimated from the following regression:

$$y_{it} - \mathrm{E}[y_{it} \mid a_{it}, k_{it}, i_{it}] = \beta_l(l_{it} - \mathrm{E}[l_{it} \mid a_{it}, k_{it}, i_{it}]) + e_{it}, \quad \textbf{(3)}$$

under the additional assumption that productivity follows an exogenous first-order Markov process such that, for some function $f(\cdot)$, $\omega_{it} = E[\omega_{it} \mid \omega_{i,t-1}] + \xi_{it} = f(\omega_{i,t-1}) + \xi_{it}$, where ξ_{it} is an innovation shock (uncorrelated with the state variables, but not necessarily with labor).

Since the survival function is estimated non-parametrically using a_{it}, k_{it} and i_{it} as covariates, this results in a semi-parametric three-step method. However, if sample selection is not a major concern, the percentage of zero-investment observations is high and/or intermediate inputs data are available (as in our case), the related work of Levinsohn and Petrin (2003) can be followed. These authors suggest an alternative estimation approach under the assumption that $\varphi = \varphi(a_{it}, k_{it}, m_{it})$, where m_{it} is the value of intermediate inputs of firm i in year t. Thus, the idea is to use intermediate inputs (energy, materials, etc.) rather than investment to control for the correlation between labor and productivity.

More specifically, Petrin et al. (2004) suggest the following procedure for the case in which the dependent variable is a measure of value added. In the first stage, an OLS estimate of β_l is obtained from (2) with

$\varphi(a_{it}, k_{it}, m_{it})$ proxied with a third-degree polynomial estimated by OLS ($\hat{\varphi}_{it}$). In the second stage, the loss function $(y_{it} - \hat{\beta}_l l_{it} - \hat{\beta}_k k_{it} - \hat{f}(\omega_{i,t-1}))^2$ is minimized with respect to $\hat{\beta}_k$, $\hat{\beta}_l$ being the first-step estimate of β_l and $\hat{f}(\omega_{i,t-1})$ the predicted third-degree polynomial regression of $\hat{\omega}_{it}$ on its lag. Lastly, standard errors are obtained using bootstrapping methods that take into account the longitudinal nature of the data. In essence, this is the procedure followed in this study, so we will refer to this as the "Extended Petrin-Poi-Levinsohn (ExtPPL) procedure" in the discussion of the empirical results.[3]

3.2 The Role of R&D

However, the ultimate goal of this study is not to analyse the coefficient estimates of the production function. Rather, we seek to assess the influence of internationalization in the contribution of R&D to productivity. This raises the question of how to introduce R&D and the degree of internationalization in the basic model defined by (1). A natural way to proceed is to include the stock of R&D as an additional factor input and (cross products of the) dummy variables that proxy for the degree of internationalization (Tsang et al. 2008). However, this approach requires some assumptions to be made about how this knowledge capital accumulates and a method to deal with the potential endogeneity problem (Hall and Mairesse 1995).

These difficulties have recently been addressed in the studies by Greenstreet (2007) and Doraszelski and Jaumandreu (2008) using alternative assumptions about the dynamic stochastic process that governs productivity behavior. In particular, in this paper we follow Doraszelski and Jaumandreu (2008) and

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[3] "Extended" because the procedure proposed by Petrin et al (2004) does not include firm age among the explanatory variables of the production function (neither does that of Levinsohn and Petrin 2003; see, however, Olley and Pakes 1996), so the second stage requires a search algorithm for a single dimensional loss function (namely, a Stata program called "linemax"). Since this algorithm is not appropriate for our setting we have used instead a search algorithm to minimize a multidimensional function (a Stata program called "amoeba") described in Ferall (1997). This "extended" version of the program written by Petrin et al. (2004) is available upon request —see also Yasar et al. (2008) for an alternative approach based on Olley and Pakes' original procedure (1996).

assess the impact of R&D on productivity by estimating (1) under the assumption that $\omega_{it} = E[\omega_{it} \mid \omega_{i,t-1}, r_{i,t-1}] + \xi_{it}$, where $r_{it} = r(a_{it}, k_{it}, \omega_{it})$ is the demand function for investment in knowledge derived from the firm's dynamic profit maximization program. This assumption allows us to endogenously consider the link between R&D and productivity in a way that captures "the uncertainties in the R&D process" and does not require the stock of R&D to be included as an additional covariate.[4]

One interesting feature of this approach, which we will refer to in the discussion of the results as the "Levinsohn-Petrin-Doraszelski-Jaumandreu (LP-DJ) procedure", is that it is easy to implement in the estimation methods described above. In practice, all we need to do is to use $\varphi(a_{it}, k_{it}, m_{it}, r_{i,t-1})$ instead of $\varphi(a_{it}, k_{it}, m_{it})$ in the first step of the procedure and a third degree polynomial of the lags of $\hat{\omega}_{it}$ and $r_{i,t}$ (instead of lags of $\hat{\omega}_{it}$ only) in the series approximation to $E[\omega_{it} \mid \omega_{i,t-1}, r_{i,t-1}]$ of the second step.[5] The downside is that since R&D does not enter directly in the specification of the production function we cannot estimate its marginal or partial effect with respect to the firms' output.

Still, following Doraszelski and Jaumandreu (2008) we can compute two alternative measures of the return to R&D. First, we can obtain the partial derivative of the conditional expectation of the productivity with respect to the (lagged) R&D. To do this we use a numerical approximation based on a three-point formula and a bandwidth parameter calculated using lagged R&D as the upper bound of the fourth derivative (Judd 1998). As Doraszelski and Jaumandreu (2008) point out, if $f(\omega_{i,t-1}, r_{i,t-1})$ "can be interpreted as the expected percentage change in total factor productivity", then $\frac{\partial f(\omega_{it-1}, r_{i,t-1})}{\partial r_{i,t-1}}$ "is the elasticity of output with respect to R&D expenditures". Second, we can compute the (weighted average)

[4] Yan Aw et al. (2009), for example, use an analogous assumption in a dynamic model that relates R&D investment and exports.

[5] As Doraszelski and Jaumandreu (2008) show, to guarantee identification we need to further assume that either the demand function for investment in knowledge is not invertible in the capital of the firm (see also Buettner 2005) or, if invertible, that there exist some variables that shift "the costs of the investments in physical capital and knowledge over time".

net rate of return to R&D, $(1/T)\Sigma_t\ \Sigma_i(R_{i,t-2}/\Sigma_i R_{i,t-2})(Y_{i,t}/R_{i,t-1})[f(\omega_{i,t-1},\ r_{i,t-1}) - \omega_{i,t-1})]$, as well as its two components: the gross rate of return, $(1/T_i)\Sigma_t\ \Sigma_i(R_{i,t-2}/\Sigma_i R_{i,t-2})(Y_{i,t}/R_{i,t-1})[f(\omega_{i,t-1},\ r_{i,t-1}) - f(\omega_{i,t-1},\ \underline{r})]$, and the compensation for depreciation, $(1/T)\Sigma_t\ \Sigma_i(R_{i,t-2}/\Sigma_i R_{i,t-2})(Y_{i,t}/R_{i,t-1})[f(\omega_{i,t-1},\ \underline{r}) - \omega_{i,t-1}]$.[6] "The first term (…) reflects the change in expected productivity that is attributable to R&D expenditures $r_{i,t-1}$, [whereas] the second term (…) is attributable to depreciation of already attained productivity". Notice that since these measures of the return to R&D depend ultimately on the values of the (estimated) productivity and (lagged) R&D, estimates can be obtained for different points of the sample distribution (for example, the mean as well as the quantiles) and/or for different groups of firms (for example, manufacturing and service firms as well as foreign and domestic firms).

4. Results

4.1 Sample, variables and statistical sources

The initial sample of firms was drawn from the 2007 *R&D Score-Board* and consists of 850 UK firms that reported data on R&D expenditures in 2007. However, our final sample is an unbalanced panel consisting of 465 manufacturing and service firms (utilities and mining companies were excluded) observed over the period 2002 to 2006. The panel is unbalanced due to the existence of missing observations in critical variables. In particular, to construct the final sample we selected firms that provided information for three or more consecutive periods on value added, turnover, number of employees, value of tangible assets, cost of sales and R&D expenditures. Table 1 shows the main descriptive statistics from the sample finally used in this study.

[6] As it is common in this literature, variables in levels are denoted in capital letters (that is, R denotes R&D expenditures and Y denotes turnover). Also, following Doraszelski and Jaumandreu (2008) $\underline{r}$ is the fifth percentile of R&D expenditures (although it is interesting to note that most results largely hold when using the first percentile of R&D expenditures) and the net rate of return is inferred from calculations of the gross rate of return and the depreciation rate in which 2.5% of observations were trimmed at each tail of the distribution of these rates, as well as at each tail of the distributions of the terms in square brackets (results largely hold, however, if we only trim 2.5% of observations at each tail of the distribution of both rates).

[Table 1 here]

Four out of five of these firms have more than a hundred employees, about two thirds are more than ten years old and practically 85% can be considered to be multinationals. Therefore, our sample consists mostly of large, mature and internationalized firms. Also, the distribution by sectors shows that roughly one-third of the firms in our sample are in services. Finally, these firms spend on average around £25 million per year on R&D. However, there are statistically significant differences in terms of R&D effort between manufacturing and service firms: the former spend more than twice as much as the latter. Similarly, both foreign and domestic MNCs spend much more on R&D than their domestic counterparts (on average four and fifteen times more, respectively).

Information on R&D expenditures comes from the 2007 R&D *Score-Board*, a register published by the *Department for Innovation, Universities & Skills* (DIUS) and the *Department for Business, Enterprise & Regulatory Reform (*BERR) on an annual basis. The remaining variables were obtained from the accounting information provided by Bureau van Dijk's data base FAME (*Financial Analysis Made Easy*). In particular, the definition of the variables is the following:

- Value Added (y): (Turnover – Cost of Sales) / (Producer Price Index).[7]
- Firm's Age (a): Years since foundation.
- Capital (k): Value of Tangible Assets / Investment Price Index.
- Labor (l): Number of Employees.
- Intermediate Materials (m): Cost of Sales / Intermediate Inputs Price Index.
- R&D (r): R&D Expenditures / Intermediate Inputs Price Index.

[7] Notice that we use single deflated not double deflated value added –see Francis and Stoneman (1994) for a discussion of the pros and cons of using each method.

As for the distinction between domestic and foreign companies, we use information on the ultimate owner of the firm (direct and indirect share of equity larger than 25%) reported in FAME in 2006. Also, we distinguish between foreign and domestic MNCs depending on whether the firm reports to have subsidiaries abroad or not in 2006. Lastly, we use a price index calculated at the three-digit SIC level to deflate all nominal values (originally in thousands of pounds). This was provided by the data base EUKLEMS.

4.2 Empirical Results

Table 2 provides estimates of production function (1) using alternative estimation methods: OLS, fixed effects, and the semi-parametric approach described in the previous section (with and without R&D in the Markov process that defines productivity, i.e. using the "ExtPPL procedure" and the "LP-DJ procedure", respectively). Results are similar to those obtained in previous studies, such as Olley and Pakes (1996) and Griliches and Mairesse (1998). In particular, figures in Table 2 show that OLS and fixed effects estimates tend to overestimate the effect of labor and underestimate that of capital. Also, the effects of age are ambiguous, with changes in sign across the different specifications and with very small coefficients. In fact, the age of the firm is statistically non-significant when the semi-parametric (consistent) estimation procedures are used.

[Table 2 here]

In any case, our main interest is to estimate not the coefficients of the production function but the elasticities with respect to R&D, which are reported in Table 3, and the net, gross and depreciation rates of return to R&D, which are reported in Table 4. Before discussing the main conclusions drawn from these figures, however, it is important to highlight that "a firm may invest in R&D to the point of driving returns below zero for a number of reasons including indivisibilities and strategic considerations such as a loss of an early-mover advantage" (Doraszelski and Jaumandreu 2008: 28). Therefore, "negative returns to R&D are legitimate and meaningful in our setting, although some of them may be an artifact of the nonparametric estimation" of *f(·)*. Still, trimming the tail of the sampling distributions seems to be enough to guarantee positive values in our estimates.

[Table 3 here]

Estimates presented in Table 3 show, firstly, that British multinationals obtain on average higher returns from their R&D investments than other foreign multinationals operating in Britain, and that both are superior to purely domestic firms. These results are consistent with those obtained by Kafourus et al. (2008) and Tsang et al. (2008) who used specifications and estimation methods other than those used here.

Nonetheless, the estimated sample distribution of the R&D elasticities reveals that foreign firms in the first quantile obtain higher returns from their R&D investments than British firms, and that domestic firms are particularly inefficient. While the differential between domestic and MNC is very significant in the lower bounds of the distribution, it narrows as we move up toward the higher quantiles. Thus, the values of the third quantile show that the apparent superiority of foreign multinationals over domestic multinationals vanishes when we analyze the most efficient firms. In this case, British multinationals stand out, with foreign MNCs and domestic firms obtaining similar returns from R&D.

In Table 3 we also present the elasticities with respect to R&D for both manufacturing and service firms. Interestingly, service firms obtain on average greater gains from their investments in R&D than manufacturing firms. In fact, this relationship is maintained throughout the distribution. However, the differential seems to reach a maximum at the median firm.

[Table 4 here]

In Table 4 we report a weighted average of the net rate of return for each type of firm and its decomposition into the net rate and the composition for depreciation. As Doraszelski and Jaumandreu (2008) argue, this can be seen as an alternative measure of the returns to R&D. The gross rate of return exceeds the net rate, suggesting that part of a firm's investment in R&D is devoted to maintain its attained productivity instead of advancing it. We also show that the net rate of return differs across types of firms, with UK MNEs obtaining an average higher net rate (15.2%) followed by foreign multinationals (13%). On the other hand, domestic firms obtain, on average, the lowest net rate of return (2%). The difference between manufacturing and service firms is also considerable, with services obtaining a net rate of return to R&D of 5% compared to the 25.6% obtained by manufacturing companies.

To conclude, it is interesting to observe that our estimates are more modest that those obtained by Doraszelski and Jaumandreu (2008) for a sample of Spanish firms, but more in line with other studies for the UK. For instance, the mean value of the net rate in Doraszelski and Jaumandreu varies from 0.066 to 0.549 for the different industries considered. Therefore, these differences could come from institutional divergences between Spain and the United Kingdom. As Añón Higón (2007) shows in a review of previous empirical studies for the UK (most of which only deal with the manufacturing sector), the values obtained for the elasticity to R&D range between 0.02 and 0.37, while the estimated rate of return to R&D is between 0.12 and 0.27.

5. Conclusion

There is a vast empirical and theoretical literature on the superior performance of MNCs. However, few studies have analysed the returns to R&D as a source of the comparative success of MNCs in terms of higher productivity. This paper addresses this issue by analyzing to what extent a firm's degree of internationalization influences the endogenous relation between R&D and productivity. In particular, we assess the contribution of R&D to productivity for a panel of UK manufacturing and services firms that differ in their degree of internationalization (domestic, British multinationals and foreign multinationals) using a structural approach to the estimation of production functions.

Previous related studies have ignored endogeneity concerns, imposed a linear accumulation of knowledge with linear depreciation and/or reduced the degree of internationalization to the simple distinction between "national" versus "foreign" firms. In contrast, our measures of the returns to R&D are based on a consistent estimation of the production function coefficients that allows for a flexible accumulation of the stock of knowledge. Moreover, on the basis of these estimates we can easily make inferences for the different degrees of internationalization we consider.

The empirical results indicate that multinationals are on average more efficient than purely domestic firms as far as contributions of R&D to productivity are concerned, with the largest difference being at the lower bounds of the distribution. In other words, of the most productive firms, the returns to R&D of British-owned domestic firms are similar to those of their foreign counterparts. However, British-owned multinationals are superior to foreign multinationals, in terms of the estimated elasticity both at the mean point and at the different quantiles of the distribution, except for the lower ends, where foreign firms tend to stand out. Therefore, our results suggest that the effect of multinationality is not constant but varies over the distribution and is particularly important within the most inefficient firms. Finally, our estimates of the net rate of return seem to be similar to those already obtained in previous literature for the UK and confirm previously reported results.

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Table 1: Descriptive Statistics.

	Mean	Std. Dev.	Min.	Max.
Value Added*	10.06	2.06	-0.12	16.69
Age	28.80	30.29	1	123
Capital*	9.72	2.38	2.53	17.74
Labor*	6.41	1.83	1.79	12.67
Intermediate Inputs*	10.54	2.55	-0.13	18.42
R&D*	8.14	1.56	2.74	14.91
Foreign Multinational	0.45	0.49	0	1
British Multinational	0.39	0.48	0	1
Domestic Firm	0.15	0.36	0	1

Notes: Asterisks denote variables in logs. Nominal values are in thousands.

Table 2: Production Function Estimates.

	OLS	Fixed Effect	Semiparametric (ExtPPL)	Semiparametric (LP-DJ)
Age	-0.0015**	0.0707***	0.0291	0.0251
	(0.0007)	(0.0078)	(0.0212)	(0.0229)
Capital	0.1737***	0.1022***	0.1849**	0.2480***
	(0.0205)	(0.0299)	(0.0774)	(0.0888)
Labor	0.7930***	0.7929***	0.6063***	0.5772***
	(0.0270)	(0.0473)	(0.0745)	(0.0734)

Notes: The dependent variable is (log) value added. Standard errors in brackets. Level of significance: *** 1%, ** 5%, * 10%.

<u>Table 3: Estimates of the elasticities of output with respect to R&D.</u>

	Mean	Q1	Q2	Q3
Foreign Multinational	0.0486	0.0105	0.0314	0.0683
British Multinational	0.0504	0.0089	0.0331	0.0713
Domestic Firm	0.0388	0.0008	0.0265	0.0628
Service Firms	0.0550	0.0096	0.0432	0.0839
Manufacturing Firms	0.0440	0.0089	0.0289	0.0631

<u>Notes</u>: Q1, Q2 y Q3 represent the first, second (i.e. the median) and third quartile of the sample distribution.

Table 4: Estimates of the rates of return to R&D.

	Gross Rate	Depreciation	Net Rate
Foreign Multinational	0.2617	0.1316	0.1301
British Multinational	0.4019	0.2496	0.1523
Domestic Firm	0.0291	0.0091	0.0200
Service Firms	0.1306	0.0840	0.0466
Manufacturing Firms	0.5622	0.3063	0.2559

Notes: Weighted averages using the two-period lags of R&D expenditures as weights. As explained in Section 3.2, values correspond to samples where around 20% of the observations were trimmed.