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Multinationals, R&D and productivity: Evidence for UK Manufacturing firms†

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ABSTRACT:

In this study we analyze multinationality (domestic-based firms *vs.* multinationals) and foreignness (foreign *vs.* domestic firms) effects in the returns of R&D to productivity. We follow a two-step strategy. In the first step, we consistently estimate firm's productivity by GMM and numerically compute the sample distribution of the R&D returns. In the second step, we use stochastic dominance techniques to make inferences on the multinationality and foreignness effects. Results for a panel of UK manufacturing firms suggest that multinationality and foreignness effects operate in an opposite way: whilst the multinationality effect enhances R&D returns, the foreignness diminishes them.

Key words: multinationals, foreignness, R&D, productivity

JEL classification: C14, D24, F23

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1. Introduction

Economists and policy makers have emphasized the key role of research and development (R&D) efforts in driving long-term economic growth. Nevertheless, the empirical evidence suggests that, in comparison with other leading economies, the UK's corporate R&D as a percentage of GDP is relatively and persistently low (Rogers, 2009). Furthermore, the aggregate statistics show a small decline in the UK's ratio of business expenditure on R&D (BERD) in the 1990s, whereas other leading economies have experienced rises. In response to this evidence, the UK government undertook some policy initiatives addressed to increase R&D investment. In 2000, the UK government introduced a fiscal incentive in the form of R&D tax credits for SMEs and extended the scheme in 2002 to include large firms. In addition, the Science and Innovation Investment Framework (SIIF) 2004-2014 set the ambition of raising UK spending on R&D to 2.5% of GDP by 2014.[1]

Another distinctive feature of the UK's corporate R&D is that a substantial share of the investment in R&D is undertaken by multinational enterprises (henceforth MNEs). Also, the share of the corporate investment in R&D directly undertaken by foreign-owned affiliates has been increasing in the UK. Particularly, UK's BERD funded from overseas increased from 15% in 1992 to 27% in 2003 (ONS, 2001), while other European economies showed substantially lower ratios (for example, 2% in Germany and 10% in France). Further, UK-owned MNEs have increased the amount of R&D investment abroad, particularly to the US in the Pharmaceutical industry. These trends point to increasing internationalization of R&D in the UK.

From a micro perspective, is widely admitted that R&D is one of the main drivers of firm's productivity growth (Griliches, 1980). Nevertheless, empirical studies show a great disparity among firms in terms of their ability to benefit from their R&D efforts (Hall *et al.*, 2009). These differentials in rates of return have

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[1] The Department of Business, Innovation and Skills (BIS) 2009 Annual Report on the SIIF retains the 2.5% goal as a key challenge.

been explained, among others, by technological opportunities (Klevorick *et al.*, 1995) and appropriability conditions (Levin *et al.*, 1987). In contrast, and despite the increasing degree of internationalization in R&D activities, little attention has been paid to the extent to which multinationality influences 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 MNEs enable them to obtain higher returns to R&D. The analysis is performed for an unbalanced panel of UK manufacturing firms extracted from the 2007 *R&D Scoreboard* and observed for the period 2002-2006.

Few studies have previously analyzed the role the multinational character plays on the firm's ability to appropriate the returns to the R&D investments.[2] In particular, these few exceptions are the studies by Tsang *et al.* (2008), which show evidence for Singapour, and Kafourus *et al.* (2008) for the UK. Nevertheless, these studies suffer from serious methodological problems (among them, the use of an ad-hoc production function specification and the uncontrolled presence of unobserved productivity shocks), which may cause estimation biases and, therefore, cast doubt on the reliability of their findings (Ackerberg *et al.*, 2006; Ackerberg *et al.*, 2007). In contrast, we provide consistent and efficient estimates of the production function coefficients (Wooldridge, 2009). Also, none of these studies deal with the important distinction between "subsidiaries of foreign firms (...) and domestic multinationals, on the one hand, and domestic firms, on the other" (Doms and Jensen, 1998; Temouri *et al.*, 2008). Therefore, their conclusions arise from the (partial) aggregation of these different categories. In contrast, we analyze the role of R&D as a source of comparative success of MNEs in terms of higher productivity taking explicitly into account the distinction between subsidiaries of foreign MNEs and domestic-owned MNEs.

[2] It is worth mentioning a related stream of studies which, instead of explicitly analysing the R&D-productivity relationship, focus on the innovation process as a whole (see Molero and Garcia, 2008; Criscuolo *et al.*, 2010).

More specifically, we seek to analyze the effects of multinationality (domestic-based firms *vs.* MNEs) and foreignness (foreign *vs.* domestic-owned firms) on the contribution of R&D to firm's productivity in the UK manufacturing sector using recent methodological innovations that allow us to overcome some of the shortcomings of previous studies. In particular, we follow a two-step strategy. In the first step, we use a GMM approach to consistently estimate the input coefficients of a Cobb-Douglas production function under the assumption that firms' expectations on future productivity depend on their current productivity as well as on their current R&D spending (Doraszelski and Jaumandreu, 2009). We also obtain estimates of the firm's (non-observable) productivity, which we use to compute the sample distribution of the R&D returns using a numerical approximation (Judd, 1998). In the second step, we use a stochastic dominance approach (Delgado *et al.*, 2002; Mañez *et al.*, 2010) to make inferences about the role of multinationality and foreignness in shaping the distribution of the R&D returns.

Our results reveal that both multinationality and foreignness are important drivers of the R&D returns. However, they operate in an opposite way: whilst the multinationality effect enhances R&D returns, the foreignness effect diminishes them. Thus, the R&D returns of domestic-owned MNEs (not affected by the negative foreignness effect) are higher than those of domestic-based firms and foreign-owned MNEs, while there are no significant differences between the R&D returns of domestic-based firms and foreign MNEs (for which the foreignness negative effect seems to compensate the positive multinationality effect).

The rest of the paper is organized as follows. In the following section we review theoretical arguments and empirical evidence concerning the role that multinationality and foreignness play in driving the returns to R&D. In Section 3 we discuss the empirical strategy and in section 4 we present the data. The principal results of the empirical analysis are presented and discussed in section 5, while the conclusions are presented in section 6, together with the main implications of this study.

2. Multinationals, R&D and Productivity

The relationship between multinationality and firm performance has been studied both from the theoretical (Caves, 1974) and empirical perspectives (Doms and Jensen, 1998; Criscuolo and Martin, 2009). A detailed survey of this literature is, however, beyond the scope of our study. Since our main interest lies on the analysis of the differential effect in the relationship between productivity and R&D that imply being a domestic-based firm, a domestic-owned MNE and a foreign MNE, we initially focus on the theoretical arguments which would predict the sign of this differential and next present a review of previous empirical studies that look at the impact of multinationality and foreignness on the R&D-productivity relationship.

2.1 Theoretical Arguments

The international business literature contends that MNEs (both domestically and foreign-owned) enjoy some kind of advantages over domestic-based firms, which compensate for the higher costs induced by operating in a foreign environment. These advantages may be the result of their possession of firm-specific assets, particularly intangibles, and capabilities (Aitken and Harrison, 1999); their ability to exploit scale economies (Dunning, 1993); the cost differential; and/or the transfer of proprietary assets, in the form of superior managerial expertise or technological capabilities, from the parent firm to the foreign subsidiary (Bartlett and Ghoshal, 1989). However, do these advantages extent to the particular case of R&D activities?

In principle, MNEs are in a position to obtain higher returns from their innovation efforts.[3] This is due to both a greater capacity to innovate and a stronger appropriability regime (Hitt *et al.*, 1997). The greater

[3] Most researchers divide the motives to undertake R&D in foreign countries into two categories: knowledge exploiting and knowledge augmenting (Kuemmerle, 1997). In the knowledge exploiting strategy, the internationalization of R&D serves as

innovation capacity relates to the fact that the multinational firm is able to access a broader range of global resources at lower cost (Kobrin, 1991). Also, the MNE possesses a greater opportunity (and capacity) to learn from the global knowledge stock stemming from a wide range of international sources –suppliers, consumers, universities, research centers and competitors (Hitt *et al.*, 1997). Lastly, Teece (1986) argues that the internationalization process improves the firms' appropriabiltiy regime by raising the possibility of obtaining strategic complementary assets (e.g. through international alliances), which may provide the opportunity for innovating MNEs to outperform their local competitors. These characteristics, together with the ability to benefit from scale economies and risk diversification that confers the process of globalization, suggest that MNEs should be able to obtain greater returns from their R&D efforts (in terms of productivity) than domestic-based firms.

However, the literature has also identified several reasons why the costs associated with expanding R&D laboratories internationally may outweigh the potential benefits. Factors that may cause the R&D returns of MNEs 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 risks that may limit the amount of R&D that MNEs can invest (Bae and Noh, 2001), and the possibility of knowledge leakages to local competitors (Fish, 2003). All in all, there are no conclusive theoretical arguments that allow us to establish *a priori* hypothesis about the effect of multinationality in the returns to the firm's R&D efforts.

In principle, domestic-owned MNEs share the same advantages than foreign affiliates: both are part of multinational networks and this enables them to benefit from advantages of scale and specialization within the network and from access to resources worldwide. In contrast, the literature points out at

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a process of technology transfer towards the foreign subsidiaries in which the technological assets developed in the home country are exploited, usually after a certain adaptation to the characteristics of foreign markets. In contrast, MNEs following knowledge augmenting strategies perform R&D investments overseas in order to profit from the acquisition of unique resources available at foreign locations and consequently augment the current stock of knowledge (Florida, 1997). The number of knowledge augmenting R&D units has recently increased with the development of global innovation networks, but still are a minority compared to knowledge exploiting laboratories (Sachwald, 2008) asymmetries between foreign and domestic-based firms in terms of costs. Arguments for performance disadvantages of foreign-owned firms include the drawbacks caused by the lack of local knowledge by foreign affiliates, reputational costs and weak links with the institutional setting of the host country (Hymer, 1976; Zaheer, 1995). This "liability of foreignness" suggests that domestic-based firms and domestic-owned MNEs should be able to obtain greater returns from their R&D efforts (in terms of productivity) than foreign-owned MNEs.

In summary, the expected sign of the multinationality effect, defined as the effect of being a MNE on R&D returns, seems undetermined. However, we expect the foreignness effect, defined as the effect of being a foreign firm on R&D returns, to be negative.

2.2 Empirical Evidence

There is sound empirical evidence that affiliates of foreign MNEs outperform purely domestic-owned firms (Barba Navaretti and Venables, 2005). It is worth noting, however, that most of these studies focus exclusively on the extent to which multinationality impacts on productivity, without exploring 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 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 MNE's performance should definitively be taken into consideration.

The empirical evidence that analyses the extent to which MNEs are able to obtain a higher return from their R&D investment is scarce. Previous studies have focused primarily on the role that multinationality plays on the firm's innovation behavior. More specifically, most previous studies, relying on CIS data, have analyzed whether the patterns of innovation behavior displayed by MNEs differ from that of domestic-owned firms. In this line, Criscuolo *et al.* (2010), for a sample of firms in the UK, find that MNEs are more innovative than non-globally engaged firms. Also, Sadowski and Sadowski-Rasters (2006) show that foreign affiliates seem to be more innovative that domestic firms, although this superior performance is primarily based on imitations. In contrast, Molero and Garcia (2008) conclude that the innovation process of foreign affiliates in Spain show noticeable coincidences with that of domestic enterprises.

As for the few studies that focus exclusively on the return to R&D investment, Kafourus *et al.* (2008) and Tsang *et al.* (2008) show that the degree of internationalization impacts positively in the R&D-productivity relationship. In particular, Kafourus *et al.* (2008) show that British firms need to reach a particular threshold of internationalization to be able to benefit from R&D and Tsang *et al.* (2008) find that foreign affiliates obtain higher returns from their R&D investments than their domestically-owned counterparts. Still, the conclusions drawn by these studies are questionable at least. Firstly, they may be affected by significant bias in the estimation (see Ackerber *et al.*, 2007). Secondly, they do not consider the important distinction between domestic-based firms, domestic-owned MNEs and foreign-owned MNEs (Doms and Jensen 1998; Temouri *et al.*, 2008). In contrast, our empirical strategy does not suffer from these limitations.

3. Empirical Strategy

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

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

where y_{it} is the logarithm of the value added of firm *i* at time *t*, a_{it} is the age of the firm, k_{it} is the log of capital, l_{it} is the log of labor, e_{it} is a standard error term and ω_{it} is the firm's productivity, which is assumed to be observable by the firm but not by the analyst. It is also assumed that age and capital evolve following a certain law of motion that is not directly related to current productivity shocks (i.e. they are state variables), whereas labor is an input that can easily be adjusted whenever the firm faces a productivity shock (i.e. it is a freely variable factor). This correlation between labor and productivity complicates the estimation of (1), for it makes the OLS estimator biased and the fixed-effects and instrumental variables methods generally unreliable (Ackerberg *et al.*, 2007).

In light of the difficulties faced by traditional solutions to the endogeneity problem, Olley and Pakes (1996) and Levinsohn and Petrin (2003) propose an alternative approach that is based on using investment and materials, respectively, to "proxy" for the unobserved firm's productivity. This means that they assume that, for some general function $g(\bullet)$ and some proxy variables p_{it}, we can write $\omega_{it} = g(a_{it}, k_{it}, p_{it})$. Under this assumption, expression (1) becomes:

$$y_{it} = \beta_0 + \beta_a a_{it} + \beta_k k_{it} + \beta_l l_{it} + e_{it} + g(a_{it}, k_{it}, m_{it}) = \beta_l l_{it} + h(a_{it}, k_{it}, m_{it}) + e_{it} \qquad (2),$$

where $h(a_{it}, k_{it}, p_{it}) = \beta_0 + \beta_a a_{it} + \beta_k k_{it} + g(a_{it}, k_{it}, p_{it})$. The advantage of using (2) rather than (1) is that there is no endogeneity problem, so that we may estimate semi-parametrically both the labor coefficient and the composite term $h(a_{it}, k_{it}, p_{it})$. The downside is that we cannot obtain an estimate of the age and capital coefficients. Still, these can be estimated in an additional step assuming that productivity evolves following an exogenous first-order Markov process.

Mathematically, $\omega_{it} = E[\omega_{it} \mid \omega_{it-1}] + \xi_{it} = f(\omega_{it-1}) + \xi_{it}$, with $f(\bullet)$ being a general function and ξ_{it} a random shock (uncorrelated with the state variables but not necessarily with labor). Also, since $\omega_{it-1} = g(a_{i-1t}, k_{i-1t}, p_{it-1})$, then plugging $\omega_{it} = f(\, g(a_{it-1}, k_{it-1}, p_{it-1})\,) + \xi_{it}$ into (1) gives

$$y_{it} = \beta_0 + \beta_a a_{it} + \beta_k k_{it} + \beta_l l_{it} + f(\, g(a_{it-1}, k_{it-1}, p_{it-1})\,) + \xi_{it} + e_{it} \qquad (3).$$

We may then use the estimates of β_l and $h(a_{it}, k_{it}, p_{it})$ obtained in the first step of the procedure to rewrite (3) as

$$y_{it} - \hat{\beta}_l l_{it} = \beta_0 + \beta_a a_{it} + \beta_k k_{it} + f(\hat{h}(a_{it-1}, k_{it-1}, p_{it-1}) - \beta_a a_{it} - \beta_k k_{it}) + \xi_{it} + e_{it} \qquad (4).$$

Expression (4) can easily be estimated, for example using polynomials to approximate f(•) and a GMM or NLLS procedure. However, this two-step procedure may be flawed. Ackerberg *et al.* (2006) discuss at length what assumptions on the timing of the input choices guarantee the identification of the parameters of interest and conclude that there may be severe collinearity problems in the first step. In particular, they show that the labor coefficient is nonparametrically unidentified unless "l_{it} varies independently of the non-parametric function" $h(a_{it}, k_{it}, p_{it})$. Consequently, they suggest an alternative two-step procedure under the assumption that the demand of the proxy variable (investment, materials) depends on labor. This assumption is consistent with labor choices having dynamic effects, i.e. with the existence of firing, hiring or training costs of labor.

Still, these two-step estimation methods are not efficient and require constructing the standard errors by bootstrap. In contrast, Wooldridge (2009) combines the moment conditions of both stages into a single set and obtains efficient GMM estimates and standard errors in one step. That is, he considers the estimation of equations (2) and (3) simultaneously while allowing for different instruments for each equation. This is the approach followed in this study.

In particular, Wooldridge (2009) suggests using polynomials of order three or less to approximate functions *g(•)* and f*(•)*. Here we use a polynomial of order 3 for *g(•)* and a polynomial of order 1 for f*(•)*.[4] As for the instruments, we use labor, age, capital and a third-degree polynomial of age, capital and materials in the first equation of the model (which corresponds to expression (2) above) and lagged labor, age, capital and a third-degree polynomial of lagged age, lagged capital and lagged materials in

[4] We obtain similar results using polynomials of order 2.

the second equation of the model (which corresponds to expression (3) above). We implement this setting in *Stata* using the GMM routines of Baum *et al.* (2007). This procedure allows us to obtain both coefficient estimates of the production function (reported in the third column of Table 2) and estimates of the firm's productivity.

Since our ultimate goal in this study is to obtain the elasticity of output with respect to R&D expenditures taking into account the possible influence of multinationality and foreignness (distinguishing between subsidiaries of foreign MNEs and domestic MNEs), we might then proceed to apply this procedure to an alternative specification of the basic model (1) that includes the stock of R&D as an additional input and (cross products of the) dummy variables for domestic-based firms, domestic-owned MNEs and foreign-owned MNEs (see e.g., Tsang *et al.,* 2008). However, this way to proceed would require strong assumptions about the accumulation of knowledge capital and a method to deal with the endogeneity of R&D (Hall and Mairesse, 1995). We circumvent these problems by using a simple version of the model developed by Doraszelski and Jaumandreu (2009). These authors show that we may assess the impact of R&D on productivity by estimating (1) under the assumption that the impact of R&D on productivity occurs through the function $f(\bullet)$. That is, if we denote by r_{it} the demand for investment in knowledge derived from the firm's dynamic profit maximization program (a function that depends on age, capital and productivity), then we will be assuming that $\omega_{it} = E[\omega_{it} \mid \omega_{it-1}, r_{it-1}] + \xi_{it} = f(\omega_{it-1}, r_{it-1}) + \xi_{it}$.

This assumption allows us to endogenously consider the link between R&D and productivity without explicitly modeling how the knowledge capital accumulates and does not require the stock of R&D to be included as an additional covariate. Moreover, this is easy to implement in the GMM setting described above (results are reported in the fourth column of Table 2). In practice, all we need to do is to include as additional instruments the lagged log of R&D in the third-degree polynomial of the first equation and the twice-lagged log of R&D in the third-degree polynomial of the second equation. 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.

However, we may compute the sample distribution of the (lagged) R&D returns using a numerical approximation to the derivative and the estimates of the firm's productivity (Judd, 1998). In particular, we use a three-point formula with a bandwidth parameter calculated using lagged R&D as the upper bound of the fourth derivative and trim 2.5% of observations at each tail of the distribution to avoid outliers.

In a second step, we pairwise compare the R&D elasticity distributions of purely domestic firms, domestic-owned MNEs and foreign-owned MNEs using the concept of first-order stochastic dominance. These pairwise comparisons will allow establishing a ranking of the R&D distributions of the three groups of firms considered. In particular, we follow Delgado *et al.* (2002) to undertake the stochastic dominance analysis.

Thus, let us assume that we have two independent and random R&D elasticity samples, $z_1,\ldots, z_n$ and $z_{n+1}, \ldots, z_{n+m}$, with sizes n and m, drawn from the cumulative distribution functions $F(\cdot)$ and $G(\cdot)$, respectively. These distributions correspond to two comparison groups of firms with different multinationality/foreignness status. First order stochastic dominance of F with respect to G is defined as $F(z) - G(z) \leq 0$ uniformly in $z \in \Re$, with strict inequality for some z. Since this comparison considers all moments of the distribution it is a stronger test of R&D elasticity differences between groups of firms than just comparing the mean or the median R&D elasticity values.

In particular, we apply the one-sided and two-sided Kolmogorov-Smirnov (KS) tests.[5] The two-sided test indicates whether the two distributions are significantly different whereas the one-sided test allows

[5] See Delgado *et al.* (2002) for a description of the KS statistics used to evaluate the one and two-sided tests. Notice that in the design of the KS tests carried out along this paper we take into account that a proper application of the KS tests using

determining which distribution dominates the other. Thus, if we reject the null hypothesis for the two sided test and do not reject the null for the one sided test, we can conclude that *F* stochastically dominates *G*. Mathematically:

1. The two-sided test checks the hypothesis of equality of the two distributions, and the null can be expressed as:

$$H_0: F(z) - G(z) = 0 \ \forall \ z \in \Re \ \textit{vs.} \ H_1: F(z) - G(z) \neq 0 \text{ for some } z \in \Re \qquad (5)$$

2. The one-sided test checks the sign of the difference between the two distributions, and can be expressed as:

$$H_0: F(z) - G(z) \leq 0 \ \forall \ z \in \Re \ \textit{vs.} \ H_1: F(z) - G(z) > 0 \text{ for some } z \in \Re \qquad (6)$$

The stochastic dominance methodology has also a graphical interpretation. So let us assume that we want to compare R&D elasticity distributions between firms belonging to group F, *F(z)*, and firms belonging to group G, *G(z)*. We say that *F(z)* dominates *G(z)* if *F(z)* is located to the right of *G(z)* in a graph where we represent the R&D elasticity in the horizontal axis and the cumulated probability in the vertical axis. The distribution functions represented in the graphs are estimated non-parametrically using *kernel* densities.

4. Data

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 of 292 manufacturing firms observed at least three consecutive years over the period 2002 to 2006. The panel is unbalanced due to the existence of missing observations in critical variables (see the appendix

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panel data requires independence of observations both between the samples under comparison and among the observations of a given sample (see e.g. Mañez *et al.*, 2010).

for definitions and data sources). 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 here]

In Table 1 we provide the main descriptive statistics of the sample. Nine out of ten of the firms in the sample have more than a hundred employees, about three quarters are more than ten years old and nearly 90% can be considered multinationals (39% domestic-owned and 48% foreign-owned). Moreover, these firms spend on average around £32 million per year on R&D. Therefore, our sample consists mostly of large, mature and internationalized firms that dedicate a substantial amount of resources to R&D. It is also interesting to note that there are practically no differences between domestic-owned MNEs and foreign-owned MNEs (except for the fact that domestic-owned MNEs are older). In contrast, domestic-based firms are on average smaller, younger, and spend less in R&D than the MNEs in the sample.

5. Results

Table 2 provides estimates of the production function (1) using alternative estimation methods: OLS, fixed effects, and GMM (with and without R&D in the Markov process that defines productivity, i.e. using the Wooldridge (2009) estimator with an Exogenous Markov Process and the simplified version of the Controlled Markov Process of Doraszelski and Jaumandreu (2009), respectively). Results are similar to those obtained in previous studies —see Hall *et al.* (2009). 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. Still, a positive albeit small coefficient emerges in the Controlled Markov Process.

In any case, our main goal here is not to analyze the coefficients of the production function but the elasticities with respect to R&D. As discussed in the previous section, these are obtained by a numerical approximation method applied to the estimated productivity. However, it is worth noting that since the instruments employed to estimate productivity are two-period lags of some variables, we are able to compute the R&D elasticity distributions only for the last three years of the sample (2004-2006).

[Table 2 here]

In order to isolate the effects of multinationality and foreignness on the R&D returns we compare the R&D elasticity distribution functions of domestic-based firms, domestic-owned MNEs and foreign-owned MNEs. That is, the pairwise comparison of the R&D elasticity distributions of domestic-owned MNEs and domestic-based firms allows isolating the multinationality effect, since both groups of firms share their domestic character. Analogously, as both domestic-owned MNEs and foreign-owned MNEs share the multinational status, we isolate the foreignness effect by pairwise comparing the R&D distribution functions of these two groups of firms. Finally, it should be noted that the pairwise comparison of the foreign-owned MNEs and domestic-based firms depends both on the multinationality and foreignness effects, as firms belonging to these two groups of firms differ both in their multinationality and foreignness attributes.

[Figure 1 here]

Prior to formally testing for stochastic dominance we show in the nine panels of Figure 1 the year-by-year pairwise comparisons of the R&D elasticity distributions described in the former paragraph. In particular, the first three panels (a, b and c) map the kernel estimations of the cumulative distribution functions of domestic-owned MNEs and domestic-based firms. These panels show that, regardless of the year considered, the distribution of domestic-owned MNEs lies to the right of the distribution of domestic-based firms. This suggests first order stochastic dominance of domestic-owned MNEs over domestic firms, i.e. the R&D returns are higher for domestic-owned MNEs than for domestic-based firms. Similarly, panels d, e and f of Figure 1 allow comparing the estimates of the R&D elasticity distributions of domestic-owned MNEs and foreign-owned MNEs. It is possible to observe that for each year the distribution of domestic-owned MNEs lies to the right of that of foreign-owned MNEs, thus suggesting that R&D returns of domestic-owned MNEs outperform those of their foreign counterparts. Finally, panels g, h and i of Figure 1 plot the estimates of the R&D elasticity distribution of foreign-owned MNEs and domestic-based firms. Regardless of the year, the estimate of the R&D elasticity distribution of foreign-owned MNEs is at the right of that of domestic-based firms, thus suggesting that R&D returns are higher for foreign-owned MNEs than for domestic-based firms.

On the basis of the observed differences in Figure 1, the next step is to formally test: (i) whether the R&D elasticity distribution of domestic-owned MNEs stochastically dominates that of domestic-based firms; (ii) whether the R&D elasticity distribution of domestic-owned MNEs stochastically dominates that of foreign-owned MNEs; and, (iii) whether the R&D elasticity distribution of foreign-owned MNEs dominates that of domestic-based firms. To this end, we use one and two sided KS tests. In particular, given the requisite of independence of observations both between the groups under comparison and among the observations of a given group of the KS tests, we carry out the comparisons year-by-year.

[Table 3 here]

Table 3 reports results for the KS tests of R&D elasticity differentials.[6] First, for each year we reject the null hypothesis of equality of the R&D elasticity distributions (at a 5% level of significance for all years) when comparing domestic-owned MNEs and domestic-based firms. Second, we can never reject the null that the R&D elasticity of domestic-owned MNEs in *t* is higher than that of the domestic-based

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[6] We also report the yearly number of firms in each group, in addition to the empirical differences in the q25, q50 and q75 of the R&D elasticity distribution.

firms. Therefore, we can infer that the R&D elasticity distribution of domestic-owned MNEs stochastically dominates that of domestic-based firms. This result suggests a positive sign for the multinationality effect.

As for the comparison between domestic-owned MNEs and foreign-owned MNEs, the one and two-sided KS tests indicate that the R&D elasticity distribution of domestic-owned MNEs stochastically dominates that of foreign-owned MNEs (we reject the null of equality of the distributions for each year, although we cannot reject the null of favorable differences for domestic-owned MNEs). This evidence suggests, in line with the "liability of foreignness" argument claimed by Hymer (1976), that foreignness influences negatively R&D returns. Therefore, there seems to be a negative foreignness effect.

Finally, KS tests do not confirm for any year that the distribution of R&D elasticity of foreign-owned MNEs dominates that of domestic-based firms, as we cannot reject the null of equality of the distributions. This result arises from the interaction of the multinationality and foreignness effects, which suggests that the positive multinationality effect is counterbalanced by the negative foreignness effect, as a result of unfavorable attitudes by local stakeholders towards foreign firms.

6. Concluding remarks

The past decade has seen a notable increase in the internationalization of corporate R&D. This process has been especially intense in the UK, in which both the share of R&D funded and performed by foreign firms as well as the share of UK-owned firms with R&D departments abroad has increased considerably. Therefore, there is a need of research analyzing the impact of internationalization on R&D activities. This study tries to fill this gap by analyzing the effects of multinationality (domestic-based firms *vs.* MNEs) and foreignness (foreign *vs.* domestic-owned firms) on the returns of R&D to productivity for a sample of UK manufacturing firms.

Our empirical strategy has two steps. First, we consistently estimate firm's productivity under the assumption that firm's expectations on future productivity depend on both current productivity and current R&D expenditures. We then use numerical approximation methods to obtain the sample distribution of the returns of R&D to productivity. Second, we analyze the impact of multinationality and foreignness effects on the distribution of the R&D returns using stochastic dominance techniques. This two-step strategy allows us to overcome some of the major shortcomings that characterize previous studies.

Our results suggest that the impact of multinationality on R&D returns is the result of the interaction of both the multinationality and the foreignness effects. On the one hand, we detect the existence of a positive multinationality effect, as domestic-owned MNEs obtain higher R&D returns than domestic-based firms. From the policy perspective these results call for coordination between internationalization and innovation policies, and particularly for instruments that allow innovative domestic firms to engage globally. On the other hand, the foreignness effect seems to be negative, as R&D by domestic-owned MNEs renders higher returns than foreign affiliates R&D. As a result of the interaction of these two effects, the R&D returns of foreign-owned MNEs do not significantly differ from those obtained by domestic-based firms.

Appendix: Variable Definitions and Statistical Sources

Value Added (y): This is obtained from the FAME (*Financial Analysis Made Easy*) dataset and it is measured as the difference between the value of firm's turnover and the cost of sales. To obtain the value added at constant prices we deflate the nominal data by the UK Producer Price Index at the three-digit SIC level sourced by EUKLEMS.[7]

Labor (l): This is measured as number of employees and is drawn from FAME.

*Capita*l (k): This is measured as the value of tangible assets. The adjustment in constant prices is made using the Investment Price Index sourced by EUKLEMS at the three-digit SIC level.

Intermediate Inputs (*m*): This is measured as the cost of sales and is drawn from FAME. The adjustment in constant prices is made using the Intermediate Inputs Price Index sourced by EUKLEMS at the 3 digit SIC level.

Firm's Age (a): Years since foundation, obtained from FAME.

R&D expenditures (r): Data 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.

Domestic, *Foreign MNE* and *UK MNE:* We distinguish between domestic MNEs and UK-based firms depending on whether the firm reports to have subsidiaries abroad or not in 2006. If a UK-owned firm reports to have subsidiaries abroad then it is regarded as a UK MNE. 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.

[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.

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Table 1: Descriptive Statistics

	Means by group of firms			Full sample			
	Foreign MNEs	Domestic MNEs	Domestic-based Firms	Mean	Std. Dev.	Min.	Max
Value Added*	10.27	10.84	8.62	10.31	1.95	-0.12	16.61
Age	33.62	40.73	23.26	35.26	32.92	1	123
Capital*	10.17	10.56	8.94	10.19	2.09	2.93	17.74
Labor*	6.59	7.16	5.50	6.69	1.72	1.79	12.46
Intermediate Inputs*	11.33	11.34	9.44	11.12	2.13	-0.13	18.42
R&D*	8.07	8.71	7.41	8.25	1.56	3.43	14.91

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

Table 2: Production Function Estimates

	OLS	Fixed Effect	GMM (Exogenous Markov Process)	GMM (Controlled Markov Process)
	(1)	(2)	(3)	(4)
Age	-0.0009 (0.0008)	0.0604*** (0.0094)	-0.3662 (0.5214)	0.0517*** (0.0196)
Capital	0.1330*** (0.0271)	0.0982*** (0.0420)	0.2390*** (0.0579)	0.2340*** (0.0633)
Labor	0.8573*** (0.0333)	0.7122*** (0.0687)	0.5770*** (0.0267)	0.4713*** (0.0304)

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

Table 3: Yearly differences in R&D elasticity between different groups of firms classified according to multinational/ownership status

Group A/Group B		Number of firms		Differences in R&D elasticity			Equality of the distributions		Differences favorable to group A	
		Group A	*Group B*	*q25*	*q50*	*q75*	*Statistic*	*p-value*	*Statistic*	*p-value*
Domestic-owned MNEs/ Domestic-based firms	2004	93	24	0.012	0.019	0.052	1.391	0.024	0.141	0.961
	2005	92	26	0.022	0.026	0.055	1.630	0.005	0.000	1.000
	2006	89	26	0.024	0.022	0.050	1.607	0.006	0.000	1.000
Domestic-owned MNE/ Foreign-owned MNE	2004	93	117	0.009	0.016	0.039	1.350	0.037	0.232	0.898
	2005	92	123	0.013	0.013	0.039	1.683	0.004	0.059	0.993
	2006	89	107	0.009	0.007	0.030	1.232	0.071	0.235	0.895
Foreign-owned MNE/ Domestic-based firms	2004	117	24	0.004	0.002	0.013	0.815	0.424	0.191	0.930
	2005	123	26	0.009	0.013	0.016	1.033	0.170	0.065	0.992
	2006	107	26	0.015	0.014	0.019	1.123	0.110	0.048	0.995

Figure 1: Comparing the R&D elasticity distributions of different groups of firms according to multinational/ownership status