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Returns to international R&D activities in European firms

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Abstract

Previous studies indicate that international R&D activities can improve the innovation performance of firms. However, evidence is scarce on the contribution of international R&D activities to firm productivity and R&D returns to productivity. This paper studies whether European firms with international R&D activities obtain higher returns to their R&D investments than firms with domestic R&D. Because international knowledge sourcing is an important driver of international R&D investments, the effect of international R&D activities is likely to depend on the relative technological strengths of home country and R&D host countries. An augmented production function is estimated and the results indicate that the R&D elasticity of output is significantly higher in firms with international R&D activities. In addition, the increase is associated with R&D investments in technologically leading countries, whereas overseas R&D in technologically lagging countries does not significantly boost the returns to R&D. Low-tech firms are shown to gain more from international R&D than high-tech firms, while the host country?s level of technology is more important for high-tech firms.

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JEL codes: O32, D24, F23

Keywords: Productivity, R&D internationalization, R&D returns, knowledge sourcing

1. Introduction

International research and development (R&D) investments have grown considerably in recent decades and now form a significant share of total R&D investments in many firms and countries (European Commission 2012). For example, German pharmaceutical firms now conduct over 60% of their R&D investments overseas, and the share of foreign R&D is even higher in many smaller countries such as Sweden and Switzerland (European Commission 2011; European Commission 2012). The literature indicates that overseas R&D activities are motivated by access to new markets and technological knowledge (Kuemmerle 1999; von Zedtwitz and Gassmann 2002). This is also apparent in global R&D investment flows, which have been moving towards the Far East with an increasing focus on knowledge sourcing in addition to capturing market shares (The Economist 2012). In line with this evidence and prior theoretical literature, recent empirical studies show that internationally distributed R&D activities can improve the innovation performance of firms (Chen et al. 2012; Hsu et al. 2014; Penner-Hahn and Shaver 2005). However, these innovation performance effects are not uniform but depend heavily on a number of firm characteristics such as absorptive capacity or knowledge integration skills (Lahiri 2010; Singh 2008).

Despite the growing R&D internationalization literature, it remains unclear whether international R&D activities increase the returns to R&D investments and thus improve firm productivity at the corporate group level. A study by Todo and Shimizutani (2008) is one of the few to analyze this question. They find that international R&D activities improve domestic productivity growth in Japanese firms but that the effect depends on the type of research activity involved. Recent studies also indicate that multinational firms can obtain higher returns to their R&D investments than domestic firms (Añón Higón and Manjón Antolín 2012; Cincera and Ravet 2014; Kafouros et al. 2008). However, these studies do not measure international R&D operations. Thus, the existing evidence on the returns to international R&D investments is scarce relative to the importance of international R&D investment flows. This paper addresses this shortcoming and analyzes how international R&D activities affect the R&D returns to productivity in European firms.

In addition, this paper contributes to the literature by analyzing how the relative technological strength of a firm's home country and foreign R&D location affect the returns to international R&D. International knowledge sourcing may increase the returns to R&D; however, all firms are not equally likely to benefit from international knowledge sourcing. If a firm's home country is a technological leader in the industry, the firm may have little to learn from its foreign competitors. However, locating overseas R&D activities in technologically more advanced countries enables the firm to access new resources and more advanced technological knowledge (Kuemmerle 1999; Song et al. 2011; Song and Shin 2008).

In this study, we analyze the contribution of international R&D activities to firm productivity by estimating a Cobb-Douglas production function, which is augmented with R&D investments. Analyzing the effect of R&D on productivity captures both cost reductions and price increases resulting from improved product quality and new product developments. Our sample includes firms from Germany, the United Kingdom, France and Italy. Our key variable of interest is the share of international R&D of firm's total R&D activities. As in many previous studies, we rely on the address information of patent inventors to determine the locations of corporate R&D activities. This variable is included in the production function, which is estimated using ordinary least squares and System GMM methods. To analyze how the technological strength of countries affects this relationship, we classify countries as technologically leading and lagging by comparing the number of patent applications at the industry- and country-level.

Our empirical results suggest that the R&D elasticity of output is significantly higher in firms with international R&D activities. In firms that conduct 20% of their R&D abroad, the R&D elasticity of output is approximately 2 percentage points higher than in firms with domestic R&D. Moreover, firms appear to benefit more from international R&D if they locate their R&D activities in countries that are technologically more advanced than their home country. In contrast, overseas R&D in technologically lagging countries does not boost the returns to R&D. Industry-specific differences are also discussed.

The remainder of the paper is organized as follows. In the second section, we discuss previous studies and theories to predict the effect that international R&D has on R&D returns. The research hypotheses are also developed in this section. The third section presents our empirical framework. The fourth section discusses data and variable construction. The fifth section reports and discusses the results and robustness tests. Finally, the sixth section concludes the paper.

2. Background and research hypotheses

The growth of international R&D investments and its drivers are well documented in the academic literature. Prior studies indicate that R&D internationalization is driven by market-seeking objectives as well as knowledge-seeking motives that aim to improve the innovation performance of a firm (Kuemmerle 1999; von Zedtwitz and Gassmann 2002). The importance of knowledge-seeking foreign direct investments (FDI) is particularly emphasized in recent work (Chung and Alcácer 2002; Todo and Shimizutani 2008). Firms increasingly establish overseas R&D units to obtain access to resources, expertise and technologies that are new to the firm or complement its existing technological capabilities. Because knowledge spillovers from other firms or universities are typically national or even local in scope, foreign firms need to establish overseas R&D facilities to access local technological knowledge (Branstetter 2001; Jaffe et al. 1993). International R&D can improve learning and technology sourcing from foreign competitors, customers, universities and other parties, and moreover, it provides better access to local informal knowledge networks (Griffith et al. 2006; von Zedtwitz and Gassmann 2002). Ambos and Ambos (2011) also mention access to a highly qualified work force as an important motive for locating R&D activities abroad. At the same time, international R&D may enable a firm to reduce the costs of R&D by utilizing country-specific cost advantages, exploiting country-specific R&D subsidies or patent boxes.

International R&D investments are also motivated by improved access to foreign markets (Le Bas and Sierra 2002; von Zedtwitz and Gassmann 2002). In this case, international R&D activities may be a by-product of exports and FDI and only secondarily intended to improve innovation performance. Local R&D activity may be needed to improve speed to market and adapt domestically developed products to the tastes and regulations of foreign markets. This view implies no clear relationship between the innovation performance of a firm and the international distribution of its R&D activities. However, improved access to international markets may help the firm to better appropriate the returns to its innovations (Kafouros et al. 2008; Tsang et al. 2008). Firms can exploit returns to scale by spreading the costs of research investments across several markets and thus better cover its investment costs even if the product life cycle is short, which also explains why multinational and exporting firms obtain higher returns to their R&D investments (Añón Higón and Manjón Antolín 2012; Aw et al. 2011). Thus, international R&D may increase the returns to R&D investments by improving both firm innovativeness and appropriation capacity. However, establishing and managing overseas R&D units is also associated with significant fixed costs. Moreover, Argyres and Silverman (2004) argue that coordination and communication costs increase in a dispersed R&D organization. Thus, the overall effect of international R&D activities on firm performance remains an empirical question.

There are a few papers that directly analyze the effect of international R&D on firm productivity. Todo and Shimizutani (2008) analyze Japanese firms and find that overseas innovative R&D has a weak positive effect on a parent firm’s productivity growth but not on the rate of return on R&D. Harhoff and Thoma (2010) and Belderbos et al. (2014) also report that overseas R&D contributes to firm productivity. In contrast, Fors (1997) finds that international R&D has no effect on parent firm productivity growth. International R&D activities are also shown to improve access to foreign knowledge spillovers and thus improve firm productivity (Griffith et al. 2006; Harhoff et al. 2014). However, the latter papers do not analyze the returns to a firm’s in-house R&D investments. Moreover, growing empirical evidence reveals that overseas R&D can improve innovation performance, at least for some firms. These studies indicate that international R&D activities may increase the number of patents (Penner-Hahn and Shaver 2005) and patent citations (Chen et al. 2012; Hsu et al. 2014; Lahiri 2010). While these studies measure performance using patents, they nevertheless imply that the international R&D activities can increase the returns to R&D investments.

Based on previous studies, we form the following hypothesis:

H1: Firms with international R&D activities have a higher R&D elasticity of output than firms with domestic R&D activities.

Prior studies indicate that the relationship between international R&D and firm performance is nonlinear and that all firms are not able to benefit from international R&D investments. Firm characteristics such as capability to integrate knowledge (Lahiri 2010; Singh 2008), previous innovation experience and absorptive capacity (Penner-Hahn and Shaver 2005) and previous international experience (Hsu et al. 2014) affect how a firm can utilize its overseas R&D activities. Absent these capabilities, international R&D may prove useless. A failure to control for these contingencies may also explain why prior studies report somewhat mixed results with respect to international R&D and firm productivity. In addition to firm characteristics, firms differ with respect to their technological operating environment, which is of interest in the present paper. Knowledge sourcing is an important factor underlying international R&D investment decisions, and the relative technological strengths of home and R&D host countries are recognized to be important in determining the location and extent of international knowledge sourcing (Alcácer and Chung 2007; Chung and Alcácer 2002; Shimizutani and Todo 2008; Song and Shin 2008). Thus, we can expect that knowledge-sourcing opportunities also affect how the gains from international R&D activities materialize. This is especially the case if we believe that technology sourcing rather than market access is the key driver of international R&D investments.

Knowledge sourcing and learning opportunities are dependent on the technological level of host countries and local firms. Several studies show that multinational firms are more likely to source knowledge in countries that have a higher level of R&D investments and patents or that are specialized in the firm's industry and technological field (Frost 2001; Song et al. 2011). Moreover, locations with academic innovative activity are known to attract R&D investments, especially from technologically advanced firms (Alcácer and Chung 2007). Thus, technological capabilities affect whether a country is an attractive R&D host, and in addition, they affect which type of R&D activity, innovative or adaptive, is located there. The literature indicates that host country R&D intensity is important in determining the location of overseas innovative R&D, whereas market size is more important for adaptive or existing capabilities exploiting R&D (Kuemmerle 1999; Shimizutani and Todo 2008). Moreover, R&D investments cause significant knowledge spillovers from the firm to other nearby firms. These knowledge spillovers can be important in many less developed countries; however, in technologically advanced countries, knowledge spillovers into foreign multinationals exceed the knowledge outflows (Singh 2007). These arguments support the view that R&D in more advanced countries is used to source technological knowledge and access markets, but R&D in technologically weaker countries is primarily used to access markets. Thus, overseas R&D in technologically advanced countries is expected to improve firm innovativeness and R&D performance to a greater extent than overseas R&D in less advanced countries.

Knowledge sourcing opportunities in the home country are also important for R&D performance. Exporting activities are shown to improve the innovativeness of firms, especially in technologically lagging industries (Salomon and Jin 2008). This implies that when a firm's home country is technologically weak in the firm's industry, the firm has much to learn from its overseas competitors and consequently has much to gain through international R&D. Indeed, Belderbos et al. (2014) find that foreign R&D investments complement domestic R&D but only in industries that are lagging behind the world technology frontier. Somewhat paradoxically, a firm in a technologically lagging country or industry faces large potential gains from international R&D, but it nevertheless needs a certain extent of in-house R&D and technological capabilities to be able to absorb new knowledge (Cohen and Levinthal 1989; Cohen and Levinthal 1990; Salomon and Jin 2010).

In contrast, when a firm's home country is a technological leader in the industry, the firm has abundant knowledge-sourcing opportunities available in domestic operational environment and has less to learn from abroad. Moreover, technological leaders have more to lose, as knowledge spillovers from the firm increase with international R&D (Sanna-Randaccio and Veugelers 2007; Schmiele 2013). Thus, technologically advanced firms may even wish to distance themselves from their competitors (Alcácer and Chung 2007). Therefore, when the home country is technologically advanced, firms have less incentive to engage in international R&D, and overseas R&D may be primarily motivated by access to foreign markets and the exploitation of domestically developed technologies. This type of activity may improve a firm's capacity to appropriate the returns to R&D by creating larger markets for the firm's products. However, when overseas R&D is located in a technologically more advanced country, the returns to R&D may improve due to both improved innovativeness and improved appropriation capacity. This suggests that the potential benefits of international R&D depend on the relative technological strengths of a firm's home and R&D host countries. We can now form our second hypothesis:

> H2: The gains from international R&D activities are larger when the R&D host country is technologically more advanced in firm's industry than the firm's home country.

3. Empirical strategy

To assess how international R&D investments affect the returns to R&D, we use a Cobb-Douglas production function extended to include the R&D stock. This approach is common in empirical studies that examine the returns to R&D investments (Hall et al. 2010). The production function is written as follows:

$$Y_{it} = A_{it} K_{it}^{\beta_K} L_{it}^{\beta_L} C_{it}^{\beta_C} \tag{1}$$

In the above equation, output Y_{it} is real value added, A_{it} is total factor productivity (TFP), K_{it} is physical capital and L_{it} is the number of employees in firm i at time t. C_{it} denotes the knowledge capital stock, which is constructed using R&D expenditure information. β_C reflects the elasticity of output with respect to the R&D stock.

Our key variable of interest is the share of international R&D activities, denoted $\text{int}\,R\&D_{it}$, which we include in the production function. We assume that international R&D can have both a direct effect on TFP and an indirect effect by affecting the returns to R&D. Namely, we assume that the elasticity of value added with respect to R&D stock takes the following linear form:

$$\beta_C = \gamma_0 + \gamma_1 \,\text{int}\,R\&D_{it} \tag{2}$$

In addition, we allow international R&D, the firm-specific term and other observable variables to have an effect on TFP. Empirical evidence suggests that multinational firms are more productive than domestic firms (Tomiura 2007; Yeaple 2009). Therefore, we allow TFP to be affected by a firm's non-R&D FDI and include a variable that measures the number of countries in which the firm has subsidiaries.

$$\ln A_{it} = a_i + \theta_1 \,\text{int}\,R\&D_{it} + \delta' z_{it} + \varepsilon_{it} \tag{3}$$

In equation (3), a_i is a firm-specific productivity term and z_{it} are other observable variables affecting productivity: the number of countries in which the firm is active, time, country and country-time interactions. In the ordinary least squares (OLS) estimation, we also use industry dummies based on NACE codes at the 2-digit level. ε_{it} is an error term.

We take the logarithm of the production function and denote logarithmic variables with lower case letters. Together with the above assumptions, this leads us to the following equation, which we can estimate[1]:

$$y_{it} = \beta_K k_{it} + \beta_L l_{it} + \gamma_0 c_{it} + \theta_1 \,\text{int}\,R\&D_{it} + \gamma_1 \left(\text{int}\,R\&D_{it} \times c_{it}\right) + a_i + \delta' z_{it} + \varepsilon_{it} \tag{4}$$

To estimate this equation, we must address several problems, such as unobserved firm-specific heterogeneity and simultaneity, which may bias the estimation results. Unobservable heterogeneity is likely to occur in this setting because we do not observe all characteristics of the firms. Moreover, simultaneity bias arises if unobserved firm productivity and a firm's input choices are correlated. Nevertheless, our first step is to estimate the equation by pooled OLS. Then, we apply the System

[1] We also considered normalizing the production function with respect to labor, i.e., the output and input variables were denoted in per-employee terms. This did not alter our main findings. A translog production function also produced similar results.

GMM estimation approach, which uses lagged values of input variables, as well as lagged values of the dependent variable, as instruments to address the above-mentioned problems (Blundell and Bond 2000). The System GMM estimates the production function in both levels and differences. The level equation is instrumented with lagged differences, and the differenced equation is instrumented with lagged levels[2]. Endogenous variables can be instrumented with variables lagged two periods or more and predetermined variables with variables lagged once or more. This entails the assumption that the two-period lagged differences in the levels equation and the two-period lagged levels in the differenced equation are uncorrelated with the error term. The validity of this assumption and the validity of instruments needs be tested using the Hansen test. In the levels equation, the instruments are also assumed to be exogenous to firm fixed effects and other constant firm-level variables; thus, we need not include industry or country dummies. In fact, including dummies that take value zero or one for most observations might bias the results of System GMM estimation (Roodman 2009). However, time dummies and country-time interactions are included to control for country-specific trends.

Difference GMM could be used instead of System GMM (Arellano and Bond 1991). Difference GMM estimates only the differenced equation using lagged levels as instruments. However, the advantage of System GMM is that it allows us to estimate the coefficients of time-invariant variables provided that we are willing to assume that they are exogenous. Moreover, the Difference GMM suffers from the weak instruments problem, which makes System GMM preferable provided that the instruments for the levels equation are valid (Blundell and Bond 1998). Other popular approaches to solving the simultaneity problem include, e.g., methods suggested by Olley and Pakes (1996) and Ackerberg et al. (2006). However, for the purposes of this paper, the advantage of System GMM estimation over such alternative methods is that System GMM allows us to include interaction terms in a simple manner. Moreover, this method allows the comparison of our R&D elasticity estimates with those of previous studies.

4. Data

4.1 Data sources

The two main datasets used are drawn from Bureau van Dijk's Orbis database and the EPO PATSTAT patent database. From Orbis, we include manufacturing firms that have consolidated balance sheet data available and report R&D expenditures at least once during time period 2004-2011. We also require information on all variables needed to estimate the production function. Our sample includes firms from Germany, the United Kingdom, France and Italy. These four countries are similar in size, and therefore, the motives for and benefits of R&D internationalization are expected to be similar in these

[2] In the differences equation, we use orthogonal deviations proposed by Arellano and Bover (1995) rather than first differencing, because there are gaps in the data and the orthogonal deviations can preserve sample size in panels with gaps.

countries[3]. Analyzing the internationalization of R&D activities in these European countries appears worthwhile because European firms have exhibited a higher level of R&D internationalization than, for example, their American or Japanese competitors (European Commission 2012). Thus, we can expect that the effects of R&D internationalization may be especially important for European firms.

Obtaining data on the geographic location of firms' R&D activities is not straightforward. Many studies on R&D internationalization rely on patent data because patent information is available for a long period and across nearly all countries. The addresses of patent inventors provide information on where patented inventions are developed, and thus we use this information to track the geographic locations of corporate R&D activities. Patent data have well known weaknesses as a measure of research output. However, in this paper, we do not use patents to measure the output or quality of R&D efforts, but we assume that a firm's patent applications are correlated with firm R&D activities and that the country distribution of inventors is a good proxy for the country distribution of a firm's R&D activities. Inventor location information is employed in many previous studies to explore the effects of internationally or geographically distributed R&D activities (for example Griffith et al. (2006), Singh (2008), and Lahiri (2010)). According to Bergek and Bruzelius (2010), the inventor information contains some mistakes, but it nevertheless provides a fairly reliable picture of the locations of R&D activities.

To obtain as comprehensive a picture of a firm's R&D activities as possible, we count the worldwide priority patent filings of each firm. By using priority filings from every national patent office, we can cover more inventions than by using EPO (European Patent Office) or PCT (Patent Cooperation Treaty) patent counts (de Rassenfosse et al. 2013). Using priority filings is also important for avoiding bias arising from the fact that firms from different countries differ in their probability to rely on, e.g., EPO or PCT patents (de Rassenfosse and de la Potterie 2007; de Rassenfosse et al. 2013). A problem with the priority filing approach is that the PATSTAT has missing inventor information for many national patent offices. However, missing inventor country information can be retrieved by following the steps suggested by de Rassenfosse et al. (2013), which recover the missing information with 97% accuracy. An additional problem is that there may be gaps in the patent data at some smaller national patent offices. However, if a firm later files the same patent at another patent office, these patents are still included in the sample. Moreover, international R&D activities are primarily concentrated in developed countries, which are typically well represented in PATSTAT.

The patents are matched to firms based on applicant names. The OECD HAN database and manual matching are used for name matching. The patent data are aggregated at the corporate group level under the assumption that the parent firm (ownership over 50%) is the ultimate owner of its

[3] Firms in small European countries are more open to international trade and FDI, and the benefits of R&D internationalization may differ in small countries (European Commission, 2012).

subsidiaries' patents. This aggregation is performed using firm ownership information obtained from the Orbis database.

4.2 Variables

To estimate the production function, we need data on a firm's turnover, capital stock, costs of goods sold, number of employees and R&D expenditure. Turnover and costs of goods sold are used to calculate value added, which is the dependent variable in our estimations. Capital stock is measured using tangible fixed assets by their book value. The R&D stock measure is constructed using R&D expenditures and the perpetual inventory method with a depreciation rate of 15%, as is typical in the literature (Hall et al. 2010). The initial value of the R&D stock is formed using the R&D expenditure in the first year and scaling it up using the depreciation rate and assumed steady-state growth rate (5%).

The financial variables are deflated to year 2010 prices using country-level manufacturing producer price index, investment price index and intermediate goods price index obtained from OECD Statistics. Turnover is deflated with the manufacturing PPI, capital with investment PPI, and costs of goods sold and R&D expenditure with the intermediate goods price index. Using common price indices makes an implicit assumption that all firms face a perfectly competitive market environment. If some firms have more market power and obtain higher prices than others, this may bias the estimated production function coefficients. However, Mairesse and Jaumandreu (2005) argue that availability of firm-level output prices does little to change the estimated production function coefficients.

We use value added as the output variable in the production function estimation. This is constructed by subtracting deflated costs of goods sold from deflated firm turnover. Thus, value added is counted using double deflating, because otherwise changes in input prices would be incorrectly interpreted as changes in firm productivity (Eberhardt and Helmers 2010).

Our key variable of interest is the share of international R&D activities. We construct this measure for each firm and year by taking a firm's all priority patent applications within the previous 10 years and counting the share of inventors that are located outside firm's home country. Some patents may be co-applied by several firms. These patents are included in our measure and thus the $\text{int}\,R\&D_{it}$ variable includes not only in-house R&D but also possible international R&D cooperation that results in a patent application. Because a lead inventor is not indicated in all patent applications, we consider all inventors listed in the applications. However, the different number of inventors in patents is considered by weighting the data, such that each patent application has the same weight in the construction of $\text{int}\,R\&D_{it}$ variable.

The gains from international R&D are expected to depend on the relative technological strengths of firm's home and R&D host countries. Because countries can be specialized in certain industries and technologies, we wish to measure technological capabilities at the industry-level. To measure the technological strength of each industry and country, we follow previous studies and use patent data (Alcácer and Chung 2007; Song et al. 2011; Song and Shin 2008). Because patent technology classifications (IPC codes) do not directly translate to industry classifications, we use a concordance table developed by Schmoch et al. (2003). The table links over 600 patent technology codes to corresponding manufacturing sectors[4]. Using this concordance, we count the number of priority patent applications in each industry and country. Patents are assigned to countries based on inventor addresses. We consider all patent applications over the past 10 years and relate their number to the number of inhabitants in a country to obtain a measure of technological strength of the country. Next, we compare the technological strength of each R&D host country to the firm's home country. If an R&D host country has more patents per capita in firm's industry than the firm's home country, we classify the host country as technologically stronger in the firm's industry. If the country has fewer patents, it is considered technologically weaker. We then separately count the share of international R&D in technologically stronger and weaker countries. International R&D conducted in technologically leading countries is expected to be motivated by international knowledge sourcing and to contribute to higher R&D returns. R&D in technologically lagging countries is expected to be primarily motivated by market-seeking motives and have smaller effect on the R&D returns.

Although patents are only one way to measure the technological capabilities of an industry, Schmoch et al. (2003) show that a country's specialization in patenting is generally correlated with specialization in industry value added and exporting. Thus, patents can also convey more general information on industry competitiveness. In the robustness section, we will consider other ways to measure the technological capabilities of countries.

Access to international markets may also affect firm productivity, as discussed above. Therefore, we need to control for firms' non-R&D FDI. For this purpose, we use information contained in Orbis on firms' subsidiaries and their locations. Because not only owning foreign subsidiaries but also the scale of international activities is likely to be related to firm productivity (Yeaple 2009), we construct a control variable to measure the scale of international activities. We count the number of countries in which a firm has subsidiaries and use the logarithm of this figure as a control for a firm's international activities[5]. The information on firm subsidiaries is only available in a single cross-section using the most recent information, and therefore, our control variable for a firm's non-R&D FDI is time invariant.

Table 1 presents the main descriptive statistics of our sample. Our final dataset is an unbalanced panel for the period 2004-2011. We remove outliers from the sample. First, we drop all observations with negative value added or capital. We also drop the 1st and 99th percentiles of the distribution of the ratio of value added per employee, value added per capital and value added per R&D stock, as well as in the growth of employment and value added. After cleaning the data, we are left with 546 firms and

[4] All other manufacturing sectors are covered except for NACE 18: Printing and reproduction of recorded media.

[5] Ideally, we would like to measure firm sales or employment in each country, but unfortunately these figures are missing for many subsidiaries.

2855 observations. Our sample primarily consists of relatively large firms with a median turnover of 332 million euros because many smaller firms do not report R&D or have missing data for other items needed to calculate the production function. Moreover, the required patent data further restricts our sample to larger firms.

Table 1

Our sample mostly consists of multinational firms. Table 1 shows that 91% of the firms own at least one foreign subsidiary. On average, the sample firms have subsidiaries in 18 countries. Most firms also engage in international R&D activities, with an average international R&D intensity, that is, the share of inventors located overseas, of 20.6%. However, the median of the share of international R&D is 9.1%. Thus, even in multinational firms, R&D activities remain mostly concentrated in the home country. Moreover, the overseas R&D activities in our sample are mainly confined to European countries and the US. Turning to the R&D host countries, European firms locate R&D activities both in countries that are technological leaders and in countries that lag behind. This indicates that both knowledge and market-seeking motives may motivate international R&D investments. However, technologically stronger countries appear to attract more R&D investments than technologically weaker countries.

Many firms enter or exit the sample during observation period, primarily because they start or stop reporting their R&D expenditure information. These changes are likely to be endogenous and may therefore cause selection bias. However, previous studies do not report large differences in the rate of return on R&D between firms that report and those that do not report R&D (Hall et al. 2010). Thus, we do not expect the selection to significantly impact the R&D elasticity estimates, which are the primary interest of the present study.

5. Results

5.1 Main results

Now, we can proceed to estimate the Cobb-Douglas production function. We first use pooled OLS estimation and then apply System GMM estimation. Table 2 presents the OLS estimates of the augmented Cobb-Douglas production function. Standard errors clustered at the firm level are presented in parentheses.

Table 2

First, we estimate the production function and include only capital, labor and R&D stock (column 1). The coefficients of labor and capital, 0.647 and 0.306, respectively, are close to the values we can expect based on typical income shares. The output elasticity of R&D in our OLS estimation is 0.073, which also appears reasonable and is in line with elasticities reported in previous studies (Hall et al. 2010). In fact, the estimates indicate constant returns to scale, as the coefficients of the inputs sum close to unity. Note that the production function is estimated using present R&D stock. This can be problematic because the results of R&D activity may reach the market only after a lag. However, we use an R&D stock measure that includes past R&D investments in addition to current investments. Moreover, using lagged R&D stock in the estimation did not affect the main results but cost in sample size, and thus, the present R&D stock is employed in the estimations.

Next, we include the share of international R&D and also control for a firm's non-R&D FDI. These results are presented in column 2. The number of subsidiary countries has a positive coefficient, 0.285, which implies that a higher level of international activities is associated with higher productivity. However, international R&D does not appear to have similar direct effect on TFP. In column 3, we include the interaction term of international R&D and the R&D stock in the regression. When the interaction term is included, the coefficient of international R&D becomes negative. This suggests that there are costs associated with locating R&D activities in foreign countries. However, the interaction term is 0.104 and statistically significant, suggesting that the R&D elasticity of output is significantly higher in firms that have international R&D activities. This finding supports our first hypothesis. The average share of international R&D is 20.6% in our sample, and thus our results imply that in these firms the R&D elasticity of output is approximately 2 percentage points higher than in firms with no international R&D. This increase is substantial because, as we can see, the R&D elasticity estimates are approximately 5-7%.

Next, we divide the international R&D investments based on the relative technological strength of R&D host countries. Columns 4 and 5 show how the returns to R&D change when the R&D is located in technologically stronger countries versus weaker countries. The results indicate that when firms locate their R&D in countries that are technologically more advanced in the firm's industry, the returns to international R&D are higher than average. The coefficient of the interaction term is 0.147. At average international R&D intensity, this would imply a 3% higher R&D elasticity. In contrast, if the R&D investments are located in countries that are relatively weaker (column 5), the effect of international R&D is not statistically significant. These findings support hypothesis 2.

Now, we proceed to estimate the production function using the System GMM approach, which addresses both unobserved heterogeneity and the endogeneity of a firm's input choices. We also tested the Arellano-Bond Difference GMM estimation. However, the Difference GMM estimation performed poorly, and the moment conditions for the levels equation were not rejected in the Difference-in-Hansen tests[6]. Therefore, we rely on System GMM as the preferred estimation method.

[6] The Difference-in-Hansen test p-values for the levels equation instruments were in the range of 0.199-0.497.

System GMM results are reported in Table 3. We estimate a dynamic model that adds lagged levels of the output and input variables to the right-hand side of the estimation equation. We assume that the time-variant firm-level variables are endogenous, including the interaction term of international R&D and R&D stock. However, we assume that the share of international R&D activities and the number of countries in which the firm is active are exogenous variables. Both international R&D and non-R&D FDI are clearly choice variables for the firm and, thus, could be correlated with unobserved productivity shocks. Unfortunately, the firm subsidiary information is not available as a time series. Absent other proper instruments, this does not allow us to treat it as an endogenous variable in the System GMM estimation. Moreover, because we use the average of inventor locations over 10 years to construct the international R&D variable and because each patent application is a result of years of research effort, the current productivity shocks can have only a very limited effect on current $\text{int}\,R\&D_{it}$.

Diagnostic tests are presented at the bottom of Table 3. The Arellano-Bond serial correlation tests find no evidence of second-order serial correlation in the differenced residuals. Thus, we can use 2-3 period lags as instruments for the endogenous variables. Further lags are excluded to avoid instrument proliferation. The Hansen test is a test of instrument validity, but a rejection may also indicate that important input variables are omitted. The p-values of these tests are reported at the bottom of Table 3 and suggest that the instruments are valid. However, a high instrument count weakens the test and may overfit the endogenous variables. The robustness of results and instrument validity is further investigated in section 5.3.

Table 3

We now turn to the System GMM results. As Table 3 shows, the coefficient of R&D stock is now clearly higher than in the OLS results, but the standard errors are also considerably higher, and thus the coefficient is not statistically significant. The coefficient of the capital stock is now lower, while the coefficient of labor is somewhat higher. The results from the model without interactions (column 2) show that neither the coefficient of international R&D variable nor the number of subsidiary countries is statistically significant. However, the number of subsidiary countries is significantly positive in columns 3-5 (the coefficient is approximately 0.15). This suggests that, as in the OLS estimates, multinational firms are more productive according to the System GMM estimation.

When the interaction between international R&D and R&D stock is included (column 3), the results reveal the same picture as the OLS results. Firms with international R&D activities obtain higher returns to their R&D investments, while the coefficient of international R&D is negative. The coefficients of international R&D (-1.282) and the interaction term (0.115) are very close to the OLS estimates. In columns 4 and 5, we divide the international R&D investments based on the relative technological strength of R&D host countries as we did in the OLS estimation. The System GMM results again confirm the findings of the OLS estimates. When the R&D host country is technologically more advanced in a firm's industry, the R&D elasticity of output increases. The coefficient of the interaction term is 0.232, which is significant and even higher than in the OLS estimates. This implies a nearly 5 percentage point higher R&D elasticity of output when one-fifth of R&D activities are located in a technologically stronger country. However, when an R&D host country is technologically weak, the returns to R&D do not change significantly (column 5).

Both OLS and System GMM estimation indicate that there are costs associated with overseas R&D investments, but firms with overseas R&D obtain higher R&D returns, which compensates for these costs. The median log R&D stock is approximately 11 in our sample (the nominal value is in thousands). Thus, the increase in the R&D returns is sufficient to compensate for the additional costs of overseas R&D for firms with above-average R&D investments. This is not the case for firms with below-average R&D stock. This suggests that international R&D can be lucrative if the scale of R&D activities is sufficiently large. This finding is in line with the prior evidence indicating that the firms need a certain level of absorptive capacity, i.e., a certain level of in-house R&D investments, to be able learn from competitors and benefit from international knowledge sourcing (Cohen and Levinthal 1989; Cohen and Levinthal 1990).

For firms with average international R&D intensity, the results imply an approximately 2 percentage point higher R&D elasticity of output. If the host country is technologically strong, the R&D elasticity is 3-5% higher. Locating R&D activities in a country that is technologically weaker than the firm's home country does not have a significant effect on firm R&D productivity. These results imply that the higher returns to R&D stem from access to more advanced technological knowledge and are due to improved technology sourcing rather than improved access to foreign markets. Moreover, when we included an interaction term between R&D stock and the number of countries in which the firm is active, we did not observe a significant effect when we also controlled for international R&D, and thus the interaction was not included in the final estimation. This also suggests that technology sourcing rather than market access is the source of higher R&D returns. Nevertheless, market-seeking motives may drive R&D investments in technologically weaker countries, and these investments may benefit the firm in other ways that are not revealed in the present study. However, because a majority of overseas R&D is located to technologically more advanced countries and because these investments improve R&D productivity, we may speculate that technology sourcing is the key driver of international R&D investments among European firms.

5.2 Industry-specific results

Next, industry-specific results are presented and discussed. The returns to R&D are shown to vary across industries (Czarnitzki and Thorwarth 2012) and thus the returns to international R&D may exhibit similar differences. We find that the results vary somewhat from industry to industry, and a simple low-tech versus high-tech division does not explain the differences. Therefore, estimation is repeated separately for the largest industry categories. The industry categories are the following: chemicals (NACE 19 and 20), pharmaceuticals (NACE 21), computers, electronic and optical products (NACE 26), machinery and electrical equipment (NACE 27 and 28), other high-tech industries and low-tech industries. The category of other high-tech industries includes, e.g., manufacturing of motor vehicles, other transport equipment and medical instruments. The final category includes low-tech and medium-low-tech firms such as manufacturers of food, basic metals, rubber and plastic products, etc.

The number of observations per industry is low in comparison to the number of instruments and thus System GMM estimation cannot be used. Therefore, industry-specific OLS results are presented in Table 4. Specification 1 estimates the model with all international R&D activities, specification 2 considers R&D investments in technologically stronger countries and specification 3 considers R&D investments in technologically lagging countries. The industry-specific means of R&D variables are reported at the bottom of the table.

Table 4

The industry-specific results mirror our main results for most of the industries. Firms with international R&D investments have a higher R&D elasticity of output. The largest gains appear in low-tech industries. Thus, the low-tech firms gain more from international R&D activities than high-tech firms. Two clear outlier industries emerge from the tables, namely manufacturing of computers, electronic and optical products and other high-tech industries. In the former, the relationship between international R&D and R&D elasticity is significantly negative except for leading R&D host countries. However, this category includes, on average, smaller firms that may not be able to cover the fixed costs of R&D internationalization. In the latter category, the relationship between international R&D and firm performance is insignificant overall but highly positive for technologically stronger countries and negative for weaker countries. In addition to the other high-tech category, the host country's technological strength is particularly important for pharmaceutical firms. In general, the level of technology in the host countries appears to affect high-tech firms more than low-tech firms. This result is intuitive, as knowledge sourcing is probably more important for the competitiveness of high-tech firms. It may also explain the result that, on average, low-tech firms benefit more from international R&D.

5.3 Robustness

Above, we measured the technological strength of countries using patent data. We tried also the approach of using the OECD median of patents per capita as a guide in dividing R&D host countries into technological leaders and laggards. This did not materially affect our results. However, using the

OECD median classified approximately 80% of the host countries as technological leaders, and therefore, we employed the above-described criterion, which achieves a more balanced division. Nevertheless, patents are only one way to measure the technological strength of countries, and using them may ignore important aspects of countries' technological capabilities. The propensity to patent also varies across industries, and thus a patent-based measure of technological strength may provide an inaccurate picture of certain industries. Therefore, we test whether our findings are robust to different measures of technological strength. As an alternative, we measure the technological competitiveness of countries using the innovation index contained in the Global Competitiveness Report, which is published annually by the World Economic Forum (WEF). This index analyzes countries by their R&D investments, quality of research institutions, university-industry collaboration and availability of scientists and engineers. Unfortunately, the index is at the country- rather than the industry-level. The composition of the report has changed over time, and the innovation index is unavailable for the earliest years, and thus we have to rely on a more general technology index for the two earliest years. While the innovation index measures technology and innovativeness more broadly than patents, it does not cover all countries. However, most developed countries are included throughout our sample period. In addition, we also measure the technological strength of countries using their R&D intensities (aggregate R&D investments divided by GDP), following, e.g., Kuemmerle (1999) and Shimizutani and Todo (2008). The data on R&D intensities are obtained from the OECD. The data primarily cover developed countries, and thus we assume that excluded countries are technologically weaker.

Table 5 represents summary statistics on overseas R&D locations using these alternative measures of country-level technological strength. First, we rank as leading countries those that rank in the top ten on the WEF ranking. As Table 5 indicates, the top ten countries already attract a clear majority of the overseas R&D investments of our sample firms. This further illustrates how geographically concentrated international R&D investments are. We tried categorizing technological leaders as countries with WEF scores higher than that of the firm's home country; however, this led to a more unbalanced distribution than in Table 5, and thus we dropped it. Second, we categorize technologically leading countries as those with a higher R&D intensity than the firm's home country. The variables in Table 5 are correlated with the patent-based technological strength variables presented in Table 1. Correlation coefficients between the variables measuring international R&D in technologically stronger countries are over 0.8, whereas the correlations are somewhat lower for the variables measuring R&D in technologically weaker countries. Thus, it appears that patent-based measures also relate to the general technology and innovation competitiveness of countries.

Table 5

Table 6 presents results using the alternative measures of host country technological strength. The table reveals that the main results do not change when we use the WEF rankings. The coefficient of the interaction term between international R&D share and R&D stock is 0.214 and significant. The estimate is quite close to results in Table 3. The gains from international R&D are positive when firms locate overseas R&D in technologically leading countries. When using country-level R&D intensities as a measure, we note that the coefficients are no longer statistically significant. However, the sign and magnitude of the coefficient estimates in columns 3 and 4 support our main findings.

Table 6

Next, we test the robustness of System GMM results with respect to the assumptions regarding the instrument lag structure. A large instrument count weakens the Hansen test and it may not be able to detect whether the instruments are valid. Therefore, we estimate our models using only 2-period-lagged values as instruments, which improves the strength of the Hansen and Difference-in-Hansen tests. We also estimate the model using all available lags as instruments. Using longer lags can increase the precision of the estimation; however, the informativeness of instruments may deteriorate at longer lags. The results can be found in Table 7. We again estimate the overall effect (specification 1), the effect of R&D in technologically leading countries (specification 2) and in lagging countries (specification 3).

Table 7

The choice of lag structure has some impact on estimation results. Using only the most recent lags as instruments results in higher coefficient estimates for international R&D and the interaction term. Estimation using a larger instrument set results in lower coefficient estimates for these variables. In the latter case, only international R&D in technologically stronger countries has a statistically significant effect. However, the main finding remains that international R&D activities improve the returns to R&D, at least when knowledge is sourced from a technologically leading country.

Changing the lag structure also changes the Hansen test p-values. Using all available lags as instruments leads to higher p-values. Using fewer lags improves the strength of the Hansen test and yields p-values between 0.12 and 0.21. While not statistically significant, these p-values may already be an indication of a potential problem with instrument validity. However, the Difference-in-Hansen tests do not reject the separate instrument sets for the levels or the differences equation. Thus, excluding the levels equations and estimating the Difference GMM would not improve the situation and the System GMM remains our preferred model.

6. Conclusions

Despite the growth in international R&D investment flows, little attention has been devoted to how these investments affect the returns to R&D investments. This study has analyzed the international R&D activities of European firms and how these activities affect corporate group level productivity through returns to R&D. We have also explored how the relative technological strength of R&D host countries affects the gains from international R&D.

International R&D activities may improve firm productivity and the returns to R&D investments by improving a firm's knowledge sourcing and providing new technological knowledge. International R&D also helps a firm to access foreign markets which, in turn, may help it to better exploit and appropriate the returns to its innovations. In our empirical analysis, we estimate a production function that is augmented with a firm's R&D stock and the share of international R&D investments. The empirical results obtained using both OLS and System GMM estimation show that the R&D elasticity of output is higher in firms that conduct a part of their R&D activities abroad. For firms that conduct 20% of their R&D abroad, this implies an approximately 2 percentage point higher R&D elasticity of output.

Based on the prior literature on the locations and geography of international R&D, we expect that the gains from international R&D activities depend on the relative technological strengths of a firm's home country and foreign R&D locations. When the domestic industry lags behind the world technological frontier, firms can improve their R&D performance by learning from their foreign competitors. The more advanced the R&D host country, the larger the technology sourcing opportunities are. The estimation results confirm these expectations. The gains from international R&D materialize when the firms locate overseas R&D in technologically more advanced countries. In this case, the R&D elasticity is 3-5% higher with average international R&D intensity. In contrast, when the overseas R&D is located in technologically weaker countries, the returns to R&D do not improve significantly. However, this type of R&D activity may be driven by market-seeking motives and may benefit the firm in other ways that are not considered in the present study. In general, the results suggest that technology sourcing rather than market access is the source of higher R&D returns. The industry-specific results also indicate that both high- and low-tech firms benefit from international R&D, while on average, the gains are larger for low-tech firms. However, the level of technology in host countries is more important for the high-tech firms and their technology sourcing.

At the firm-level, our results suggest that firms can improve the returns to their R&D investments by locating some of their R&D activities abroad and by sourcing new technological knowledge internationally. However, the choice of target countries must be carefully considered, because the knowledge-sourcing opportunities are dependent on the technological level of the foreign R&D location. Moreover, our results show that there are significant fixed costs associated with international R&D that smaller or less R&D-intensive firms may not be able to cover. Thus, while large

European firms can significantly benefit from international knowledge sourcing, the results may not apply to smaller firms. Our analysis is also limited to the manufacturing industry. Further research is needed to explore whether the results also apply to other types of firms, industries and countries. Moreover, while the results suggest that the higher R&D returns stem from access to more advanced knowledge, we do not have knowledge of firms' motives for international R&D or the exact nature of their international R&D activities. More detailed data would allow an analysis that would identify the exact cause of higher R&D returns.

From a policy perspective, our results suggest that the increasing relocation of R&D activities abroad does not necessarily weaken the home country's competitiveness and welfare as improved firm productivity can also benefit the home country. Instead, international R&D collaboration and knowledge sourcing by firms should be supported to improve the innovativeness and competitiveness of European firms.

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Table 1. Descriptive statistics

	Mean	SD	Median	Min	Max	Obs
Turnover	4453.149	15593.478	332.319	0.069	275554.200	2855
Value added	1690.321	4715.951	145.728	0.040	48671.050	2855
Capital	1209.181	4918.017	62.594	0.002	106743.300	2855
Employees	16188.519	43734.227	1752.000	4.000	472500	2855
R&D stock	910.812	3464.186	49.865	0.028	33014.500	2855
International R&D intensity	0.206	0.267	0.091	0	1	2855
International R&D in leading countries	0.121	0.226	0.001	0	1	2842
International R&D in lagging countries	0.086	0.162	0.013	0	1	2842
Multinational firm	0.914	0.280	1	0	1	2855
Subsidiary countries	17.935	20.672	10	0	114	2855

Notes. 546 firms in 2004-2011. Monetary values are in millions in 2010 prices.

Table 2. OLS results

Dependent variable ln(Value added)	1.	2.	3.	4. Leading host countries	5. Lagging host countries
ln(L)	0.647***	0.520***	0.509***	0.510***	0.521***
	(0.048)	(0.050)	(0.050)	(0.050)	(0.050)
ln(K)	0.306***	0.317***	0.322***	0.324***	0.316***
	(0.035)	(0.033)	(0.033)	(0.033)	(0.033)
ln(C)	0.073***	0.062***	0.046*	0.049**	0.060***
	(0.024)	(0.023)	(0.024)	(0.023)	(0.023)
intR&D		-0.082	-1.216**	-1.780***	-0.032
		(0.092)	(0.500)	(0.666)	(0.795)
intR&D*ln(C)			0.104**	0.147**	0.010
			(0.044)	(0.057)	(0.071)
ln(Subsidiary countries)		0.285***	0.285***	0.290***	0.278***
		(0.044)	(0.044)	(0.044)	(0.044)
Constant	2.944***	3.198***	3.389***	3.321***	3.225***
	(0.171)	(0.163)	(0.178)	(0.171)	(0.168)
Adj. R-squared	0.940	0.945	0.945	0.946	0.945
Obs	2855	2855	2855	2842	2842

Notes. * p<0.10, ** p<0.05, *** p<0.01. All regressions include country, industry and year dummies as well as country-year interactions. Firm-clustered standard errors are presented in parenthesis.

Table 3. System GMM results

Dependent variable ln(Value added)	1.	2.	3.	4. Leading host countries	5. Lagging host countries
L.ln(Y)	0.717***	0.686***	0.677***	0.664***	0.664***
	(0.087)	(0.085)	(0.080)	(0.080)	
ln(L)	0.707***	0.596**	0.589**	0.695***	0.553**
	(0.268)	(0.282)	(0.251)	(0.260)	(0.246)
L.ln(L)	-0.531**	-0.400	-0.403*	-0.526**	-0.326
	(0.246)	(0.261)	(0.233)	(0.236)	(0.230)
ln(K)	0.211*	0.227*	0.231**	0.159	0.199**
	(0.115)	(0.117)	(0.109)	(0.115)	(0.099)
L.ln(K)	-0.171	-0.200*	-0.200*	-0.106	-0.178*
	(0.114)	(0.120)	(0.117)	(0.123)	(0.108)
ln(C)	0.204	0.195	0.156	0.068	0.200
	(0.183)	(0.178)	(0.175)	(0.164)	(0.173)
L.ln(C)	-0.140	-0.160	-0.140	-0.056	-0.175
	(0.172)	(0.167)	(0.166)	(0.153)	(0.167)
IntR&D		0.002	-1.282*	-2.632***	0.801
		(0.039)	(0.654)	(0.723)	(0.965)
IntR&D*ln(C)			0.115**	0.232***	-0.065
			(0.058)	(0.062)	(0.084)
ln(Subsidiary countries)		0.127	0.151**	0.167**	0.150**
		(0.080)	(0.070)	(0.071)	(0.072)
Constant	0.882***	1.278***	1.562***	1.612***	1.439***
	(0.260)	(0.401)	(0.417)	(0.385)	(0.372)
Observations	2252	2252	2252	2243	2243
Firms	481	481	481	478	478
Instruments	93	95	112	112	112
AR1, p-value	0.000	0.000	0.000	0.000	0.000
AR2, p-value	0.496	0.498	0.493	0.535	0.518
Hansen test, p-value	0.485	0.506	0.494	0.605	0.551
Hansen test, df	61	61	77	77	77

Notes. * p<0.10, ** p<0.05, *** p<0.01. All regressions include year dummies and country-year interactions. Foreign R&D is assumed exogenous; interaction term and all other time-varying firm-level variables are assumed endogenous. Other variables are assumed exogenous. Endogenous variables are instrumented with 2 and 3 period lags. Two-step robust standard errors are presented in parenthesis.

Table 4. Industry specific results

Dependent variable	Chemicals			Pharmaceuticals			Computers		
ln(Value added)	1.	2.	3.	1.	2.	3.	1.	2.	3.
ln(L)	0.739***	0.739***	0.705***	0.488***	0.506***	0.490***	0.499***	0.496***	0.483***
	(0.095)	(0.099)	(0.089)	(0.115)	(0.113)	(0.116)	(0.040)	(0.040)	(0.039)
ln(K)	0.181***	0.184***	0.203***	0.305***	0.294***	0.303***	0.207***	0.212***	0.217***
	(0.051)	(0.053)	(0.047)	(0.067)	(0.067)	(0.069)	(0.037)	(0.037)	(0.037)
ln(C)	-0.048	-0.044	-0.031	0.057	0.057*	0.090***	0.197***	0.188***	0.191***
	(0.041)	(0.041)	(0.046)	(0.037)	(0.033)	(0.034)	(0.030)	(0.030)	(0.029)
IntR&D	-0.812	-1.332	-0.087	-1.150	-2.582**	0.172	1.080*	0.802	5.045***
	(0.580)	(0.987)	(1.908)	(0.745)	(1.118)	(0.891)	(0.649)	(0.732)	(1.027)
IntR&D*ln(C)	0.098*	0.148	0.038	0.117*	0.259***	-0.015	-0.107*	-0.089	-0.434***
	(0.053)	(0.095)	(0.139)	(0.060)	(0.083)	(0.073)	(0.057)	(0.066)	(0.090)
ln(Subsidiary countries)	0.326***	0.324***	0.344***	0.522***	0.527***	0.531***	0.308***	0.312***	0.311***
	(0.079)	(0.079)	(0.082)	(0.089)	(0.088)	(0.088)	(0.043)	(0.043)	(0.042)
Constant	4.312***	4.279***	4.054***	3.173***	3.186***	2.822***	3.017***	3.059***	3.063***
	(0.274)	(0.270)	(0.319)	(0.361)	(0.324)	(0.324)	(0.224)	(0.217)	(0.211)
Adj. R-squared	0.969	0.969	0.969	0.946	0.947	0.945	0.902	0.902	0.903
Obs	294	294	294	332	332	332	618	618	618
R&D stock		595.886			2358.158			270.141	
International R&D intensity		0.190			0.234			0.202	
International R&D in leading countries		0.122			0.089			0.153	
International R&D in lagging countries		0.068			0.145			0.049	

Notes. * p<0.10, ** p<0.05, *** p<0.01. All regressions include country and year dummies as well as country-year interactions. Robust standard errors are presented in parenthesis.

Table 4. Continued

Dependent variable	Machines and equipment			Other high-tech			Low-tech		
ln(Value added)	1.	2.	3.	1.	2.	3.	1.	2.	3.
ln(L)	0.448***	0.462***	0.476***	0.559***	0.487***	0.563***	0.440***	0.453***	0.453***
	(0.082)	(0.080)	(0.079)	(0.079)	(0.073)	(0.081)	(0.046)	(0.047)	(0.049)
ln(K)	0.302***	0.297***	0.281***	0.360***	0.389***	0.354***	0.418***	0.413***	0.414***
	(0.047)	(0.046)	(0.044)	(0.058)	(0.053)	(0.058)	(0.035)	(0.036)	(0.037)
ln(C)	0.013	0.032	0.028	0.078*	0.089**	0.101**	-0.008	0.007	0.025
	(0.030)	(0.030)	(0.031)	(0.041)	(0.040)	(0.041)	(0.021)	(0.020)	(0.019)
IntR&D	-1.906**	-1.743**	-0.865	-1.111	-5.871***	6.941***	-2.120***	-2.689***	-1.022**
	(0.788)	(0.825)	(1.631)	(1.263)	(1.482)	(1.675)	(0.371)	(0.513)	(0.481)
IntR&D*ln(C)	0.188***	0.155**	0.127	0.083	0.449***	-0.613***	0.202***	0.246***	0.099**
	(0.068)	(0.070)	(0.128)	(0.097)	(0.113)	(0.143)	(0.034)	(0.044)	(0.043)
ln(Subsidiary countries)	0.323***	0.328***	0.318***	-0.070	-0.058	-0.019	0.232***	0.242***	0.227***
	(0.057)	(0.057)	(0.056)	(0.058)	(0.055)	(0.055)	(0.039)	(0.039)	(0.038)
Constant	4.277***	4.030***	4.117***	2.941***	3.042***	2.611***	3.385***	3.208***	3.018***
	(0.187)	(0.172)	(0.206)	(0.250)	(0.213)	(0.264)	(0.197)	(0.193)	(0.190)
Adj. R-squared	0.931	0.931	0.931	0.961	0.963	0.962	0.946	0.946	0.944
Obs	534	534	534	349	349	349	641	628	628
R&D stock		601.248			2823.431			255.124	
International R&D intensity		0.136			0.173			0.281	
International R&D in leading countries		0.074			0.113			0.155	
International R&D in lagging countries		0.062			0.060			0.131	

Notes. * p<0.10, ** p<0.05, *** p<0.01. All regressions include country and year dummies as well as country-year interactions. Robust standard errors are presented in parenthesis.

Table 5. Overseas R&D location using alternative measures of technological strength

	Mean	SD	Median	Min	Max	Obs
International R&D in leading countries (WEF)	0.128	0.214	0.025	0	1	2855
International R&D in lagging countries (WEF)	0.078	0.151	0.011	0	1	2855
International R&D in leading countries (R&D)	0.143	0.232	0.031	0	1	2855
International R&D in lagging countries (R&D)	0.063	0.135	0.002	0	1	2855

Notes. 546 firms in 2004-2011.

Table 6. System GMM results using alternative measures of technological strength

Dependent variable	WEF rankings		R&D intensity	
ln(Value added)	Leading host countries	Lagging host countries	Leading host countries	Lagging host countries
L.ln(Y)	0.644***	0.717***	0.650***	0.671***
	(0.090)	(0.076)	(0.084)	(0.075)
ln(L)	0.797***	0.501*	0.727***	0.511**
	(0.300)	(0.264)	(0.269)	(0.238)
L.ln(L)	-0.554**	-0.287	-0.505**	-0.278
	(0.258)	(0.240)	(0.241)	(0.221)
ln(K)	0.117	0.225**	0.178*	0.235**
	(0.114)	(0.114)	(0.106)	(0.100)
L.ln(K)	-0.090	-0.209*	-0.147	-0.212**
	(0.120)	(0.110)	(0.114)	(0.106)
ln(C)	0.142	0.268	0.129	0.262*
	(0.161)	(0.166)	(0.168)	(0.154)
L.ln(C)	-0.146	-0.235	-0.113	-0.238
	(0.152)	(0.157)	(0.161)	(0.145)
IntR&D	-2.382**	2.169	-1.454	0.587
	(0.961)	(1.426)	(1.177)	(1.241)
IntR&D*ln(C)	0.214**	-0.191	0.129	-0.052
	(0.086)	(0.124)	(0.104)	(0.110)
ln(Subsidiary countries)	0.143*	0.087	0.148*	0.123
	(0.075)	(0.066)	(0.081)	(0.079)
Constant	1.797***	1.025***	1.626***	1.363***
	(0.454)	(0.315)	(0.442)	(0.393)
Observations	2252	2252	2252	2252
Firms	481	481	481	481
Instruments	112	112	112	112
AR1, p-value	0.000	0.000	0.000	0.000
AR2, p-value	0.517	0.532	0.515	0.503
Hansen test, p-value	0.678	0.332	0.598	0.541
Hansen test, df	77	77	77	77

Notes. * p<0.10, ** p<0.05, *** p<0.01. All regressions include year dummies and country-year interactions. Foreign R&D is assumed exogenous; interaction term and all other time-varying firm-level variables are assumed endogenous. Other variables are assumed exogenous. Endogenous variables are instrumented with 2 and 3 period lags. Two-step robust standard errors are presented in parenthesis.

Table 7. System GMM results using different instrument lag structures

Dependent variable	Instrumented with 2 period lags			Instrumented with all lags		
ln(Value added)	1.	2.	3.	1.	2.	3.
L.ln(Y)	0.718***	0.704***	0.720***	0.663***	0.686***	0.667***
	(0.095)	(0.088)	(0.090)	(0.070)	(0.066)	(0.068)
ln(L)	0.693**	0.761**	0.541	0.468**	0.566***	0.380**
	(0.331)	(0.344)	(0.351)	(0.227)	(0.192)	(0.193)
L.ln(L)	-0.539*	-0.615**	-0.367	-0.250	-0.399**	-0.156
	(0.297)	(0.300)	(0.318)	(0.213)	(0.168)	(0.188)
ln(K)	0.196	0.103	0.231	0.205**	0.169*	0.227**
	(0.147)	(0.146)	(0.150)	(0.101)	(0.089)	(0.099)
L.ln(K)	-0.165	-0.050	-0.214	-0.200*	-0.143	-0.215**
	(0.143)	(0.143)	(0.143)	(0.110)	(0.095)	(0.100)
ln(C)	0.091	0.048	0.148	0.222	0.120	0.267*
	(0.190)	(0.170)	(0.196)	(0.175)	(0.173)	(0.159)
L.ln(C)	-0.087	-0.046	-0.118	-0.198	-0.090	-0.228
	(0.175)	(0.156)	(0.182)	(0.165)	(0.161)	(0.150)
IntR&D	-1.611**	-2.850***	0.393	-0.460	-1.810**	1.361
	(0.769)	(0.902)	(1.133)	(0.684)	(0.803)	(1.196)
IntR&D*ln(C)	0.144**	0.250***	-0.032	0.040	0.156**	-0.113
	(0.069)	(0.078)	(0.099)	(0.060)	(0.069)	(0.106)
ln(Subsidiary countries)	0.139*	0.146*	0.131	0.176**	0.160***	0.146**
	(0.078)	(0.080)	(0.081)	(0.073)	(0.060)	(0.066)
Constant	1.462***	1.468***	1.207***	1.640***	1.485***	1.386***
	(0.427)	(0.384)	(0.380)	(0.381)	(0.334)	(0.350)
Observations	2252	2243	2243	2252	2243	2243
Firms	481	478	478	481	478	478
Instruments	87	87	87	162	162	162
AR1, p-value	0.000	0.000	0.000	0.000	0.000	0.000
AR2, p-value	0.460	0.493	0.506	0.520	0.530	0.535
Hansen test, p-value	0.119	0.159	0.192	0.343	0.492	0.693
Hansen test, df	52	52	52	127	127	127

Notes. * p<0.10, ** p<0.05, *** p<0.01. All regressions include year dummies and country-year interactions. Foreign R&D is assumed exogenous; interaction term and all other time-varying firm-level variables are assumed endogenous. Other variables are assumed exogenous. Two-step robust standard errors are presented in parenthesis.