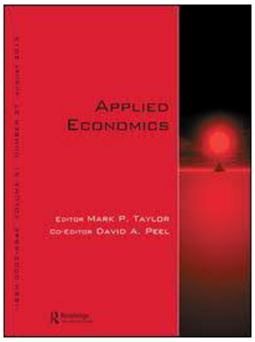

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R&D internationalization and firm productivity. Does the host country matter?

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ABSTRACT
The prior literature has established that the internationalization of corporate R&D is motivated by access to new markets and technological knowledge. However, the empirical literature has overlooked whether the market and technological characteristics of R&D host countries influence the firm-level productivity gains from international R&D. This study empirically examines whether international R&D activities affect the productivity of European multinational firms. Estimating an R&D augmented production function shows that the output elasticity of R&D depends positively on the share of international R&D activities. The analysis further shows that the improvements are associated only with offshore R&D in host countries that have experienced fast economic growth or that are technologically stronger than firms' home country.

KEYWORDS
R&D internationalization; productivity; knowledge sourcing; market-seeking

JEL CLASSIFICATION
D24; F23; O32

I. Introduction

International research and development (R&D) investments have grown in recent decades and now form a significant share of total R&D investments in many firms and countries (European Commission 2012; de Rassenfosse and Thomson 2019; Alkemade et al. 2015). The literature has established that these overseas R&D activities are to large extent motivated by access to new markets and advanced technological knowledge (for early contributions see Kuemmerle (1999) and von Zedtwitz and Gassmann (2002), for a recent survey see Papanastassiou, Pearce, and Zanfei (2020)). In line with this literature, recent studies show that internationally or geographically distributed R&D activities can improve firms' inventive output, although the effects are found to be nonlinear and heavily dependent on a number of firm characteristics (Chen, Huang, and Lin 2012; Penner-Hahn and Shaver 2005; Hsu, Lien, and Chen 2014; Lahiri 2010; Hurtado-Torres, Aragón-Correa, and Ortiz-de-Mandojana 2018). Contrary evidence has also been presented (Singh 2008). However, the relationship between international R&D investments and firm productivity has received less attention in this literature, even though productivity is the key driver of long-term economic growth. Productivity is also a more comprehensive measure of firm performance because it captures whether internationalization changes R&D costs or firms' sales.

Prior studies show that R&D returns to productivity vary significantly among firms. Añón Higón and Manjón Antolín (2012) and Cincera and Ravet (2014) show that multinational firms obtain higher returns to their R&D investments than domestic firms. Prior studies also indicate that internationally distributed R&D investments may improve parent firm productivity, although not for all firms (Todo and Shimizutani 2008; Fors 1997). Furthermore, Tabrizy (2017) shows that offshore R&D and engineering activities are correlated with a higher total factor productivity among multinational firms. Finally, Belderbos, Lokshin, and Sadowski (2014) show that the productivity gains from foreign R&D activities are dependent on the technological position of firms' home country. In contrast, many previous studies have highlighted the importance of R&D host country characteristics, such as technological capabilities and market potential, as key motivators of overseas R&D investments (Papanastassiou, Pearce, and Zanfei 2020). Thus, it is probable that these host country characteristics also influence the investing firm's R&D returns to productivity. This question has,

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nevertheless, remained unexplored in the literature. Therefore, as the main contribution to the literature, this paper analyzes how the characteristics of R&D host countries affect the R&D returns to productivity by studying the international R&D activities of large European manufacturing firms. Analysing the internationalization of R&D activities in European countries appears worthwhile because European firms have exhibited a higher level of R&D internationalization than, e.g., their American or Japanese competitors (European Commission 2012; Alkemade et al. 2015).

As established in the literature, we assume that the relative technological strength and market potential of the R&D host countries are the central drivers of international R&D investments. We further hypothesize that these same characteristics are also key determinants of how international R&D activities affect R&D-productivity relationship, and we test these hypotheses in our empirical setting. In doing so, this paper extends the focus of existing literature on firm performance effects of international R&D by considering market potential along with knowledge and technological factors, which have received the main attention thus far (e.g. Belderbos, Lokshin, and Sadowski (2014)).

We analyse the contribution of international R&D to productivity at the firm level by estimating a Cobb-Douglas production function, which is augmented with R&D investments (Hall, Mairesse, and Mohnen 2010). We test whether R&D returns to productivity, i.e. R&D elasticity of output, varies with the share of international R&D activities and especially depends on the characteristics of R&D host countries. We rely on the address information of patent inventors to determine the location of corporate R&D. Thus, we examine innovative offshore R&D. Our empirical results show that R&D elasticity of output is significantly higher in firms with international R&D activities. Specifically, we show that international R&D activities improve R&D returns to productivity only if these activities are located in countries that are technologically more advanced in firm's industry than firm's home country or in countries that have experienced rapid economic growth.

The remainder of this paper is organized as follows. The second section discusses the prior literature and develops the research hypotheses. The third section presents the empirical framework. The fourth section presents the data and descriptive statistics. The fifth section covers the results and robustness tests. Finally, the sixth section concludes the paper.

II. Background and research hypotheses

International R&D activities have drawn increasing interest in the academic literature. Studies have cited several drivers and possible gains that firms seek through these activities but also potential costs. Similar to globalization of manufacturing activities, overseas R&D may also be pursued because of cost savings. Internationalization may reduce R&D costs because firms benefit from country-specific cost advantages, R&D subsidies and patent boxes or from locating R&D close to their offshore manufacturing activities (von Zedtwitz and Gassmann 2002). However, cost savings are typically not reported as the most important determinant of international R&D (Moncada-Paternò-Castello, Vivarelli, and Voigt 2011; Thursby and Thursby 2006) and co-location with manufacturing activities is more typical for firms that rely less on intangible assets (Castellani and Lavoratori 2020). Instead, the literature highlights the importance of knowledge-seeking and market-seeking strategies for foreign R&D (Kuemmerle 1999; Chung and Juan 2002; Papanastassiou, Pearce, and Zanfei 2020), which can affect productivity by increasing sales or price-cost margins.

Knowledge spillovers and technology sourcing from collaborators and competitors are typically national or local in scope (Jaffe, Trajtenberg, and Henderson 1993; Griffith, Harrison, and Van Reenen 2006). According to the knowledge-seeking view of international R&D, this is what motivates firms to offshore a part of their R&D and invest in research units close to centres of excellence around the world. Access to a qualified workforce is also recognized as a central motive for establishing offshore R&D units (Thursby and Thursby 2006; Lewin, Massini, and Peeters 2009). Thus, overseas R&D units can provide firms with completely new or easier access to foreign knowledge spillovers, resources and technologies than that which domestic R&D units could provide. By obtaining a more varied knowledge base, better-qualified workforce or other more productive R&D inputs, offshore R&D can improve firms' capability to develop more valuable and a larger number of innovations. These innovations are likely to lead to more cost-effective processes and new products that allow for an increase in demand and price-cost margins, thus improving the revenue productivity of firms (Dai and Cheng 2018). More varied knowledge base can also bring economies of scope in R&D (Henderson and Cockburn 1996). Empirical studies support these arguments, revealing that internationally or geographically distributed R&D activities can increase the number of patent applications and citations in firms, although some studies reveal a curvilinear relationship (Penner-Hahn and Shaver 2005; Lahiri 2010; Chen, Huang, and Lin 2012; Hsu, Lien, and Chen 2014). While higher inventive output is likely to be associated with higher R&D productivity, these studies do not directly reveal whether this improvement in inventiveness also leads to higher sales or changes in R&D costs.

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 investments may be a by-product of exports and foreign direct investments (FDI). Local R&D activity may be needed to improve speed to market and adapt domestically developed products to the tastes, regulations and other needs of foreign customers and markets (Florida 1997; Kuemmerle 1999). This view implies no clear improvement in the innovation performance of firms; however, productivity can improve for other reasons. Investing in offshore R&D can help firms to adapt to foreign market needs, which can increase offshore demand for firms' innovations and products. Higher demand is likely to increase sales and the prices the firm can charge for its products and can thus outweigh the costs of foreign R&D units. Moreover, productivity will also improve if the firm is in a better position to appropriate the returns to its R&D (Teece 1986). International R&D investments may provide just that by giving the firm lead-time in international markets and by better integrating R&D activities with overseas marketing activities (Le Bas and Sierra 2002). These factors can increase firm's market power in overseas markets, which allows the firm to increase its revenue productivity by setting higher prices and capturing a larger share of the value of its innovations.

While the literature has highlighted the benefits of international R&D, such activities may also be associated with cost increases. First, establishing overseas R&D facilities involves entry costs, thus restraining many smaller or less productive firms from entering (Rahko 2016). Second, Argyres and Silverman (2004) argue that a dispersed R&D organization can create additional coordination and communication costs within the organization. These and other management costs may also increase when firms internationalize their R&D activities. These costs can hinder firms from reaching economies of scale and scope in R&D. Third, R&D activities and knowledge-sourcing benefit from being strongly embedded in the local innovation system, something that foreign firms may find costly or time consuming to establish (Belderbos, Leten, and Suzuki 2013; Añón Higón and Manjón Antolín 2012). Finally, firms may wish to avoid international R&D because the knowledge outflows and risk of imitation increase with international R&D activities (Sanna-Randaccio and Veugelers 2007; Schmiele 2013). This can be the case even in developed countries (Ben Hassine, Boudier, and Mathieu 2017). These additional costs can partially offset or exceed the benefits of foreign R&D.

To summarize the theoretical arguments, we find that firms can obtain significant productivity gains from international R&D but also face additional costs and risks. Prior empirical literature suggest that international R&D can improve firm innovativeness although not for all firms (Lahiri 2010; Chen, Huang, and Lin 2012). These studies together with the continuing international R&D investments imply that after initial fixed costs multinational firms expect benefits from international R&D, which should be observable in firm productivity. Thus, we propose a following hypothesis to be tested:

H1: International R&D activities increase firms' R&D returns to productivity.

The prior empirical studies show that the innovation performance effects of geographically distributed R&D activities depend on several firm characteristics (see e.g. Lahiri (2010) and Singh (2008)). In addition to firm characteristics, firms have differing technological and market environments in their home and R&D host countries. As important drivers of international R&D investments, these country characteristics are likely contributing factors to the productivity gains or losses from offshore R&D.

Literature indicates that multinational firms utilize location-specific advantages and conduct overseas R&D and source knowledge in countries that have strong technological capabilities in those firms' industries (Shimizutani and Todo 2008; Song, Asakawa, and Chu 2011; Song and Shin 2008). These studies imply that the gains from international R&D depend on the richness of knowledge-sourcing opportunities in the industry environment of host country. However, firms need to analyse knowledge-sourcing opportunities in the host countries in comparison to those in their home country. If a firm's home country and industry are technologically weaker than the R&D host country, the firm has much to learn from foreign competitors and collaborators in terms of catching up and knowledge diversification (Awate, Larsen, and Mudambi 2015; Belderbos, Lokshin, and Sadowski 2014). Instead, a firm from a technologically stronger country has abundant knowledge-sourcing opportunities domestically and more limited potential for learning in the host country, although knowledge diversification can still be valuable (Chung and Juan 2002; Phene, Fladmoe-Lindquist, and Marsh 2006).[1]

The relative technological characteristics of host countries may also matter for the disadvantages of offshore R&D. Firms from technologically advanced countries may have more to lose through possible knowledge leakages. Singh (2007) shows that in technologically weaker host countries the knowledge outflows from multinational firms often exceed the knowledge inflows. Thus, multinational firms need to employ costly intellectual property protection tools or adopt internal mechanisms to protect themselves from knowledge outflows (de Faria and Sofka 2010; Zhao 2006). Especially, firms may restrain from forming close linkages to host country firms to avoid knowledge outflows; however, this also limits their potential to source knowledge from local firms (Perri and Andersson 2014; Perri et al. 2013). The risk of knowledge leakages may thus limit the gains of overseas R&D for firms from technologically advanced countries especially when they operate in technologically weaker countries.

Overall, when the firm's industry in the R&D host country is technologically more advanced than in the home country, knowledge sourcing gains are expected to be larger and the costs related to knowledge outflows are expected to be lower than when the host country is technologically weaker. In line with these arguments, Singh (2007) shows that the knowledge inflows to foreign firms exceed the knowledge outflows to local firms in technologically advanced countries but not in technologically weak countries. Knowledge flows from foreign subsidiaries to headquarters are also shown to be larger the higher the economic and technological level of the host country is relative to the parent firm's home country (Gupta and Govindarajan 2000; Song and Shin 2008). Higher knowledge inflows are expected to lead to higher innovativeness and thus to improved productivity. This suggests that the productivity gains from international R&D are higher and the additional costs lower when offshore R&D is located in technologically more advanced countries. This leads us to propose the following hypothesis:

H2: When the R&D host country is technologically stronger in a firm's industry than a firm's home country, international R&D activities lead to a larger improvement in R&D returns to productivity, than when the R&D host country is technologically weaker.

Although technologically less advanced countries appear to be less desirable locations for knowledge sourcing, these countries may provide access to growing markets or other important country-specific advantages and thereby affect

[1]A strong domestic technology base may provide firms with absorptive capacity, although firm-level absorptive capacity through, e.g., R&D investments, is seen as more important (Penner-Hahn and Shaver 2005; Salomon and Jin 2010).

R&D-productivity relationship. E.g., Thursby and Thursby (2006) found that market growth is the single most important motive for overseas R&D investments in emerging markets. As argued above, market-seeking overseas R&D can increase international demand for a firm's products and thus improve R&D returns. The size of increase in returns is likely to be dependent on the magnitude of demand increase. Moreover, the literature suggests that access to larger markets improves productivity by enabling the firm to spread its R&D costs out using increased sales and allowing it to more quickly recoup its R&D investments (Hitt, Hoskisson, and Kim 1997; Cohen and Klepper 1996). A competitive global environment can require large investments in R&D, the results of which are often quickly imitated. Thus, access to larger markets helps the firm to generate more sales and capture more value from its innovations before they are imitated. Overall, the above-presented gains from market-seeking R&D investments appear to be positively associated with the host country's market potential, as measured by the size or growth of the market (Athukorala and Kohpaiboon 2010; Shimizutani and Todo 2008). Formally, we hypothesize:

H3: When the R&D host country's market potential is large, international R&D activities lead to a larger improvement in R&D returns to productivity, than when the R&D host country's market potential is small.

III. Empirical strategy

To assess how international R&D investments affect productivity, we use a Cobb–Douglas production function extended to include the R&D stock. This approach is common in empirical studies examining the returns to R&D investments (Hall, Mairesse, and Mohnen 2010). This approach captures the notion that R&D returns can increase due to both reductions in R&D costs and sales and price increases resulting from innovations or increased market power. The Cobb-Douglas 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, 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 expenditures. β_C reflects the elasticity of output with respect to the R&D stock, i.e., the returns to R&D. A_{it} is a productivity shifter that captures other factors affecting the value added.

Our key variable of interest is the share of overseas R&D activities, denoted $intR\&D_{it}$. In the later stage, we also divide the international R&D measure into parts according to host country characteristics. We assume that the share of international R&D activities can have both a direct effect on the productivity shifter and an indirect effect by affecting the returns to R&D; thus, our approach resembles that of Griffith, Harrison, and Van Reenen. (2006) and Cincera and Ravet (2014). The elasticity of value added with respect to R&D stock is assumed to have the following form:

$$\beta_C = \gamma_0 + \gamma_1 intR\&D_{it} \tag{2}$$

The theoretical and empirical evidence suggests that multinational firms are more productive than domestic firms (Tomiura 2007; Antras and Helpman 2004). Therefore, we allow the productivity shifter A_{it} to be affected by both share of international R&D and firm's FDI. We model the productivity shifter A_{it} as follows:

$$\ln A_{it} = a_i + \theta_1 intR\&D_{it} + \delta' z_{it} + \varepsilon_{it} \tag{3}$$

If there is a self-selection effect into foreign R&D or foreign R&D has a direct effect on productivity that is not mediated by R&D investments, coefficient θ_1 in equation 3 captures this. Furthermore, 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.

Next, 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 estimate the following equation[2]

$$\begin{aligned} y_{it} = {} & \beta_K k_{it} + \beta_L l_{it} + \gamma_0 c_{it} + \theta_1 intR\&D_{it} \\ & + \gamma_1 (intR\&D_{it} \times c_{it}) + a_i + \delta' z_{it} + \varepsilon_{it} \end{aligned} \tag{4}$$

To estimate this equation, we must address several problems, such as unobserved firm-specific heterogeneity and simultaneity. Unobservable heterogeneity can occur 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.[3] We then apply the System GMM approach, which uses lagged values of input variables as instruments to address the abovementioned problems (Blundell and Bond 2000). The System GMM estimates the production function in both levels and differences. Endogenous variables can be instrumented with variables lagged by two periods or more. The level equation is instrumented with lagged differences, and the differenced equation is instrumented with lagged levels.[4] This entails the assumption that the two-period-lagged differences in the level equation and the two-period-lagged levels in the differenced equation are uncorrelated with the error term. The validity of this assumption and the instruments are tested using the Hansen test. In the level equation, the instruments are assumed to be exogenous to firm-fixed effects and other constant firm-level variables.

Difference GMM could be used instead of System GMM (Arellano and Bond 1991). However, System GMM allows us to estimate the coefficients of time-invariant variables provided that we are willing to assume them to be exogenous. Moreover, the Difference GMM suffers from the weak instruments problem (Blundell and Bond 1998). Other popular approaches to solving the simultaneity problem include newer methods suggested, e.g., by Olley and Pakes (1996), Levinsohn and Petrin (2003) and Ackerberg, Caves, and Frazer (2015). However, including the necessary R&D and interaction terms, which then affect the evolution of productivity, is nontrivial in these approaches. Doraszelski and Jaumandreu (2013) present an approach that includes R&D investments in these methods; however, their approach has not gained popularity in international R&D literature. Instead, prior studies with similar aims as the present study such as Griffith, Harrison, and Van Reenen. (2006), Belderbos, Lokshin, and Sadowski (2014) and Aldieri, Sena, and Vinci (2018) apply System GMM estimation. Finally, it should be noted that the causal interpretation of System GMM results depends on the validity of lagged variables as instruments, which is a weaker identification strategy than if we would observe some exogenous variation in firms' international R&D activities.

IV. Data

Data sources

The empirical analysis combines firm-level financial data from Bureau van Dijk's Orbis database and patent data from the EPO PATSTAT patent database. From Orbis,[5] we include manufacturing firms that have consolidated balance sheet data available, report R&D expenditures and have information on other variables needed to estimate the production function in time period 2004–2011. Our sample includes firms from Germany, the United Kingdom, France and Italy. Country distribution is presented in Appendix A. It should be noted that the practices for reporting R&D expenditures vary over countries. This means that UK firms are overrepresented in the dataset.

The PATSTAT database covers patent data from over 180 patent offices over a long time period. Patent inventor location information has been employed in many previous studies to measure the geographical distribution of R&D activities (e.g., Singh (2008) and Laurens et al. (2015)). Patent assignee may be a local unit or corporate headquarters, thus assignee address may not reveal the location where the patent was developed. In contrast, according to Bergek and Bruzelius (2010), patent inventor information provides

[2] We also considered normalizing the production function with respect to labour. This did not alter our main findings.

[3] Fixed effect estimation is not used, because the variables of interest change quite slowly over time. Furthermore, the largest changes over time happen in firms that file few patents and that also have more measurement error in the variables of interest. This measurement error is aggravated in the fixed effect estimation, which implies that the fixed effect estimates are likely to be more biased towards zero than OLS or System GMM estimates.

[4] We use orthogonal deviations rather than first differencing because the orthogonal deviations can preserve sample size in panels with gaps.

[5] Orbis database is the largest cross-country firm-level database and it is frequently used in the economic research. However, it is worth noting that the representativeness of the database varies over countries (Bajgar et al. 2020; Kalemli-Ozcan et al. 2015). Especially smaller firms are often under-represented in Orbis; however, as Bajgar et al. (2020) argue Orbis is better suited to analyse multinational firms as is the case in this study.

a fairly accurate picture of the locations of R&D activities. Thus, we follow previous literature using firm-level patent data and use this information to track the locations of corporate R&D activities (e.g. Harhoff, Mueller, and Van Reenen. (2014) and Noailly and Ryfisch (2015)). Patent data have well-known weaknesses as a measure of research output. However, in this paper patents do not measure R&D output, but we assume that the location of inventors proxies the location of a firm's R&D activities. A weakness is that we are not able to track R&D activities that do not result in patents and, thus, overseas development activities may not be well covered.

To obtain a comprehensive picture of a firm's R&D activities, we count firms' worldwide priority patent filings. Using priority filings covers more inventions than national patent office data and avoids the bias arising from the fact that firms from different countries differ in their probability of relying on, e.g. US or European patent office patents (de Rassenfosse et al. 2013). A problem with the priority filings 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). A further 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 our analysis.

The patents are matched to firms based on applicant names. The OECD HAN database, which corrects names from punctuation, accents, abbreviations and legal information, is used for name matching.[6] Additional manual checks are conducted to correct variations in applicants' names. The patent data are aggregated at the corporate group level under the assumption that the parent firm is the ultimate owner of its subsidiaries' patents. This aggregation is performed using firm ownership information obtained from the Orbis database and manually checking the year of merger or acquisition in cases when subsidiaries are observed to file patents.

Variables

Our aim is to estimate a production function; thus, we use 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.[7] 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, Mairesse, and Mohnen 2010). Following the prior literature, we form the initial value of the R&D stock by using the R&D expenditures 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 (PPI), investment price index and intermediate goods price index obtained from OECD Statistics. Turnover is deflated with the manufacturing PPI, capital with investment price index, and costs of goods sold and R&D expenditure with the intermediate goods price index. Value added is constructed by subtracting deflated costs of goods sold from deflated firm turnover. Thus, value added is counted using double deflating, which avoids incorrectly interpreting changes in input prices as changes in firm productivity (Eberhardt and Helmers 2010).

A key variable of interest is the share of international R&D activities.[8] The variable is measured for each firm and year by taking a firm's priority patent applications within the previous 10 years and counting the share of inventors that are located outside a firm's home country.[9] We consider all inventors listed in the patent applications and consider the varying number of inventors by weighting

[6]Thoma et al. (2010) describe the methodology.

[7]Using the book value of capital can be subject to measurement error. Another commonly used approach would be to calculate the capital stock using perpetual inventory method. However, this would require information on investments which is often missing in our data. Moreover, there is potential measurement error even with the perpetual inventory method.

[8]We measure the share of international R&D instead of the number of R&D host countries or a geographical diversity index, because unlike the alternatives the share of international R&D is uncorrelated with the number of patents a firm applies.

so that each application has the same weight. Some patents in our data are co-applied by several firms. Thus, the int R&D variable includes not only in-house R&D but also international R&D cooperation that results in a patent filing.

Next, we need to measure the relative technological strength and market potential of R&D host countries. Because countries can specialize in certain industries and technologies, we wish to measure technological capabilities at the industry level. We follow prior studies and use patent data to do this (Song and Shin 2008; Furman, Porter, and Stern 2002). Patent technology codes can be translated to industry classifications using a concordance table developed by Schmoch et al. (2003), which links over 600 technology codes to corresponding manufacturing sectors.[10] Using this concordance and the inventor addresses, we count the number of priority patent applications in each industry and country. We consider all priority patent applications over the past 10 years and relate their number to the number of inhabitants in a country to obtain a measure of the technological strength of the country[11][12] If an R&D host country has more patents per capita in a firm's industry than the firm's home country, we classify this host country as technologically stronger. 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 host countries. In section 5.3, we test alternative measures for technological strength.

The gains from international R&D are also hypothesized to depend on the market potential of host countries. According to Thursby and Thursby (2006), market growth is the single most important factor for locating R&D in an emerging market and an important factor for investments in developed markets as well. Thus, we measure market potential with the country's GDP growth rate in the same 10-year time window and compare the growth to the median GDP growth rate among the host countries.[13] Accordingly, we separately count the share of international R&D in countries with above-median growth and slower growth countries. The GDP data are obtained from the World Bank database. Instead of growth also market size could be used as a market potential indicator. This is tested in section 5.3.

We also control for firms' non-R&D FDI. We use information contained in Orbis on firms' subsidiaries and their locations. We count the number of countries in which a firm has subsidiaries and use the logarithm of this figure as a control variable. Ideally, we would like to measure firm sales or employment in each country, but these figures are missing for many subsidiaries. The subsidiary information is also only available in a single cross-section using the most recent data; therefore, the control variable is time invariant.

Descriptive statistics

Table 1 presents descriptive statistics. To obtain the final sample we removed some outliers. First, we dropped all observations with negative value-added or capital. We also dropped 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. Thus, we are left with an unbalanced sample of 546 firms and 2855 observations for the period 2004–2011. Some firms start or stop reporting R&D or start patenting during the sample period. These changes may be endogenous and 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, Mairesse, and Mohnen 2010).

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, file patents or they have missing data for other items. Our sample also mostly consists of multinational firms. Table 1 shows that 91% of the firms own at

[9]Shorter time windows of 5 and 3 years were also tested, which confirmed our findings. However, shorter windows lead to more imprecise measurement of R&D locations in firms that file few patents and more gaps in the data for firms that do not file patents every year.
[10]All manufacturing sectors are covered except for NACE 18: Printing and reproduction of recorded media.
[11]The propensity to patent and patentability requirements vary across countries, which could bias our measure based on priority filings. However, we measured technological strength also with triadic patent families, which did not change our results..
[12]Patents per population type of measure is used, e.g., by Furman, Porter, and Stern (2002). Some prior studies use an index of revealed technological advantage (RTA). However, the RTA better describes the technological specialization of countries rather than their overall technological strength. RTA often gives high values to small countries, although they may not overall have a high level of technological capabilities (Cantwell and Janne 1999).
[13]Industry-level data are patchy even for the OECD countries and hence we use country level data.

Table 1. Descriptive statistics.

	Mean	SD	Median	Min	Max	Obs
Turnover	4453.149	15,593.478	332.319	0.069	27,5554.200	2855
Value added	1690.321	4715.951	145.728	0.040	48,671.050	2855
Capital	1209.181	4918.017	62.594	0.002	106,743.300	2855
Employees	16,188.519	43,734.227	1752.000	4.000	472,500	2855
R&D stock	910.812	3464.186	49.865	0.028	33,014.500	2855
IntR&D	0.206	0.267	0.091	0.000	1	2855
IntR&D, tech. stronger host countries	0.121	0.226	0.001	0.000	1	2842
IntR&D, tech. weaker host countries	0.086	0.162	0.013	0.000	1	2842
IntR&D, high growth host countries	0.024	0.082	0.000	0	1	2855
IntR&D, low growth host countries	0.182	0.247	0.071	0	1	2855
IntR&D, tech. stronger & high growth host countries	0.006	0.039	0	0	1	2842
IntR&D, tech. stronger & low growth host countries	0.115	0.219	0	0	1	2842
IntR&D, tech. weaker & high growth host countries	0.017	0.073	0	0	1	2842
IntR&D, tech. weaker & low growth host countries	0.069	0.138	0	0	1	2842
Multinational firm dummy	0.914	0.280	1	0	1	2855
Number of subsidiary countries	17.935	20.672	10	0	114	2855

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

least one foreign subsidiary. About 70% of firms also engage in international R&D activities with an average international R&D intensity of 20.6%, that is, the share of inventors located overseas. However, the median of the share of international R&D is 9.1%. These shares have remained roughly similar throughout the observation period.[14] Thus, even in multinational firms, R&D activities remain mostly concentrated in the home country. According to Table 1, European firms locate R&D activities both in countries that are technologically stronger and in countries that lag behind. However, technologically stronger countries appear to attract more R&D investments than technologically weaker countries. Moreover, the countries with above-median economic growth rates, i.e., mostly emerging markets, attract only a small share of international R&D investments. Thus, knowledge sourcing aims for offshore R&D appear more pronounced than market-seeking objectives among the sample firms. Overall, other European countries constitute the most common foreign R&D locations.

V. Empirical analysis

OLS results

We now proceed to estimate the augmented Cobb-Douglas production function. Table 2 presents the OLS estimation results. Standard errors clustered at the firm level are presented in parentheses. First, we estimate the production function and include only labour, capital and R&D stock (specification 1). The coefficients of labour 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 is in line with elasticities reported in previous studies (Hall, Mairesse, and Mohnen 2010). In fact, the estimates indicate constant returns to scale, as the coefficients sum close to unity.

Next, we include the share of international R&D and control for a firm's non-R&D FDI (specification 2). The number of subsidiary countries has a positive coefficient, which implies that a higher level of international activities is associated with higher total factor productivity. However, overseas R&D does not appear to have an additional direct effect on productivity. In specification 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, suggesting that there are additional costs associated with overseas R&D activities. However, the coefficient of the interaction term is 0.104 and statistically significant, suggesting that the R&D elasticity of output, i.e. R&D returns, is significantly higher in firms that have foreign R&D activities.[15] This result supports our hypothesis H1.

[14]There are some differences across countries. E.g. German firms have on average somewhat lower share of international R&D than firms from other three countries. Alkemade et al. (2015) study these differences in more detail.

[15]Coordination and communication costs may increase with the degree of R&D internationalization, implying an inverted U-shape relationship between internationalization and performance. However, we tested and did not find evidence of that. Therefore, only the linear interaction term is included. We also tested the robustness of results by including an interaction term between R&D stock and the number of subsidiary countries. We did not find significant effects, and thus, the interaction was not included in the final estimations.

Table 2. OLS estimation of the production function.

Dependent variable ln(Value added)	1.		2.		3.		4.		5.		6.	
ln(L)	0.647***	(0.048)	0.520***	(0.050)	0.509***	(0.050)	0.509***	(0.050)	0.511***	(0.050)	0.512***	(0.049)
ln(K)	0.306***	(0.035)	0.317***	(0.033)	0.322***	(0.033)	0.324***	(0.033)	0.322***	(0.033)	0.325***	(0.033)
ln(C)	0.073***	(0.024)	0.062***	(0.023)	0.046*	(0.024)	0.047*	(0.024)	0.047*	(0.024)	0.048**	(0.024)
IntR&D			-0.082	(0.092)	-1.216**	(0.500)						
ln(C)×IntR&D					0.104**	(0.044)						
IntR&D, tech. stronger							-1.801***	(0.667)				
ln(C)×IntR&D, tech. stronger							0.149***	(0.058)				
IntR&D, tech. weaker							-0.135	(0.796)				
ln(C)×IntR&D, tech. weaker							0.020	(0.071)				
IntR&D, high growth									-3.479***	(0.546)		
ln(C)×IntR&D, high growth									0.299***	(0.057)		
IntR&D, low growth									-0.841	(0.545)		
ln(C)×IntR&D, low growth									0.072	(0.048)		
IntR&D, stronger & high growth											-5.176***	(0.991)
ln(C)×IntR&D, stronger & high growth											0.512***	(0.099)
IntR&D, stronger & low growth											-1.496**	(0.695)
ln(C)×IntR&D, stronger & low growth											0.118**	(0.060)
IntR&D, weaker & high growth											-2.714***	(0.763)
ln(C)×IntR&D, weaker & high growth											0.213***	(0.074)
IntR&D, weaker & low growth											0.887	(0.875)
ln(C)×IntR&D, weaker & low growth											-0.055	(0.080)
ln(Subsidiary countries)			0.285***	(0.044)	0.285***	(0.044)	0.287***	(0.044)	0.283***	(0.044)	0.288***	(0.043)
Constant	2.944***	(0.171)	3.198***	(0.163)	3.389***	(0.178)	3.339***	(0.179)	3.380***	(0.177)	3.297***	(0.178)
Adj. R-squared	0.940		0.945		0.945		0.945		0.945		0.946	
Obs	2855		2855		2855		2842		2855		2842	

Notes. * p<0.10, ** p<0.05, *** p<0.01. Regressions include country, industry and year dummies and country-year interactions. Firm-clustered standard errors are presented in parentheses.

The average share of international R&D is 20.6% in our sample, and thus, the interaction term implies 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 is a substantial increase in the R&D returns because, as we can see, the R&D elasticity estimates are approximately 5–7%. Thus, international R&D investments appear to create more value-added for the firm than only domestic R&D.

Next, we divide the overseas R&D investments based on the relative technological strength of R&D host countries (specification 4). The results indicate that when firms locate their R&D in countries that are technologically more advanced than the home country in their industry, the R&D returns increase significantly. The coefficient of the interaction term is 0.149. At average international R&D intensity, this implies a 3 percentage points higher R&D elasticity. In contrast, if R&D investments are located in relatively weaker countries, the change in R&D returns is not significant. These findings support our second hypothesis. In specifications 5 and 6, we test our third hypothesis. We observe that the R&D elasticity is significantly higher when foreign R&D is located in countries experiencing above-median GDP growth, which supports hypothesis H3. In specification 6, we consider technological and growth characteristics simultaneously. The largest improvement in R&D returns occurs when the host country's economy is both technologically stronger and growing rapidly. The coefficient would imply over 10 percentage points higher R&D elasticity with average international R&D intensity; however, only a very small group of host countries falls within this category (see Table 1). Host countries that are neither technologically stronger nor growing rapidly have statistically insignificant effect on R&D returns, and the estimate is negative. However, even in this case, offshore R&D does not seem to significantly worsen the R&D productivity.

System GMM results

The results from the System GMM approach are reported in Table 3. We start with a static model and include lags of dependent and endogenous variables in Table 4, where we test different model specifications. Diagnostic tests are presented at the bottom of the tables. The Arellano-Bond serial correlation tests show no evidence of second-order

Table 3. System GMM estimation of the production function.

Dependent variable ln(Value added)	1.		2.		3.		4.	
ln(L)	0.367***	(0.134)	0.299**	(0.117)	0.364***	(0.119)	0.298***	(0.096)
ln(K)	0.297***	(0.067)	0.367***	(0.066)	0.315***	(0.063)	0.369***	(0.061)
ln(C)	-0.011	(0.060)	-0.000	(0.061)	0.014	(0.059)	0.020	(0.046)
IntR&D	-3.462**	(1.616)						
ln(C)×IntR&D	0.304**	(0.135)						
IntR&D, tech. stronger			-3.627***	(1.287)				
ln(C)×IntR&D, tech. stronger			0.318***	(0.106)				
IntR&D, tech. weaker			-1.717	(1.079)				
ln(C)×IntR&D, tech. weaker			0.159	(0.099)				
IntR&D, high growth					-4.925***	(1.668)		
ln(C)×IntR&D, high growth					0.411***	(0.150)		
IntR&D, low growth					-3.406**	(1.472)		
ln(C)×IntR&D, low growth					0.281**	(0.126)		
IntR&D, stronger & high growth							-7.385***	(1.286)
ln(C)×IntR&D, stronger & high growth							0.584***	(0.119)
IntR&D, stronger & low growth							-3.909***	(1.386)
ln(C)×IntR&D, stronger & low growth							0.344***	(0.119)
IntR&D, weaker & high growth							-4.638***	(1.370)
ln(C)×IntR&D, weaker & high growth							0.376***	(0.121)
IntR&D, weaker & low growth							-1.422	(1.533)
ln(C)×IntR&D, weaker & low growth							0.125	(0.130)
ln(Subsidiary countries)	0.563***	(0.140)	0.551***	(0.124)	0.523***	(0.137)	0.517***	(0.107)
Constant	4.738***	(0.539)	4.355***	(0.559)	4.402***	(0.567)	4.221***	(0.484)
Observations	2645		2634		2645		2634	
Firms	410		408		410		408	
Instruments	93		117		117		165	
AR1, p-value	0.002		0.002		0.003		0.003	
AR2, p-value	0.157		0.155		0.147		0.266	
Hansen test, p-value	0.238		0.565		0.320		0.214	
Hansen test, df	55		77		77		121	

Notes. * p<0.10, ** p<0.05, *** p<0.01. All regressions include year and country dummies and country-year interactions. All time-varying firm level variables are assumed endogenous. Other variables are assumed exogenous. Endogenous variables are instrumented with two period lags. Two-step robust standard errors are presented in parenthesis.

Table 4. System GMM estimation with alternative model specifications.

Dependent variable ln(Value added)	1.		2.		3.		4.		5.	
ln(C)	0.035	(0.054)	0.032	(0.050)	0.072*	(0.039)	0.154	(0.115)	0.226**	(0.112)
L.ln(C)							-0.124	(0.111)	-0.193*	(0.105)
IntR&D, stronger & high growth	-7.693***	(1.102)	-6.406***	(0.879)	-6.913***	(0.984)	-4.564***	(0.675)	-4.668***	(0.553)
ln(C)×IntR&D, stronger & high growth	0.610***	(0.104)	0.518***	(0.083)	0.570***	(0.083)	0.378***	(0.061)	0.388***	(0.055)
IntR&D, stronger & low growth	-3.598***	(1.176)	-2.945***	(1.076)	-2.295**	(1.040)	-0.957*	(0.572)	-0.379	(0.475)
ln(C)×IntR&D, stronger & low growth	0.324***	(0.103)	0.271***	(0.089)	0.225***	(0.087)	0.089*	(0.052)	0.048	(0.042)
IntR&D, weaker & high growth	-4.370***	(1.249)	-2.522***	(0.794)	-3.636***	(0.858)	-1.391**	(0.569)	-1.128**	(0.474)
ln(C)×IntR&D, weaker & high growth	0.364***	(0.114)	0.208***	(0.071)	0.309***	(0.080)	0.119**	(0.055)	0.096**	(0.045)
IntR&D, weaker & low growth	-2.725*	(1.411)	-0.858	(1.363)	-1.145	(1.172)	-0.587	(0.781)	-0.708	(0.605)
ln(C)×IntR&D, weaker & low growth	0.231*	(0.120)	0.071	(0.117)	0.100	(0.099)	0.055	(0.063)	0.062	(0.050)
ln(Subsidiary countries)	0.481***	(0.118)	0.373***	(0.096)	0.334***	(0.097)	0.168***	(0.048)	0.184***	(0.046)
Observations	2634		2634		2634		2171		2171	
Firms	408		408		408		408		408	
Instruments	330		183		402		223		353	
AR1, p-value	0.003		0.002		0.002		0.000		0.000	
AR2, p-value	0.221		0.240		0.222		0.508		0.502	
Hansen test, p-value	0.218		0.254		0.407		0.345		0.267	
Hansen test, df	287		139		358		189		309	

Notes. * p<0.10, ** p<0.05, *** p<0.01. All regressions include year and country dummies and country-year interactions. Two-step robust standard errors are presented in parenthesis. Specification 1 is a static model with two period and all longer lags as instruments. Specification 2 is a static model, where R&D variables are assumed predetermined and instrumented with one period lagged values. Specification 3 is a static model, where R&D variables are assumed predetermined and instrumented with one period and all longer lags. Specification 4 is a dynamic model that includes lagged value added, labor and capital as regressors and 2-3 period lagged values as instruments. Specification 5 is a dynamic model that includes lagged value added, labor and capital as regressors and two period and all longer lags as instruments.

serial correlation in the differenced residuals. Thus, we use two period lags as instruments. Longer lags are included in Table 4.[16] The p-values of the Hansen tests at the bottom of Table 3 suggest that the instruments are valid.[17]

In Table 3, the coefficients of R&D stock, i.e. the R&D elasticity of output, are lower than in the OLS results and statistically insignificant. However, the estimate in specification 4 is similar to Harhoff, Mueller, and Van Reenen (2014). The R&D elasticity estimates in Table 4 are somewhat higher. In specification 1 of Table 3, the coefficient of international R&D intensity and the interaction term are almost three times larger than in the OLS estimates and statistically significant, which supports hypothesis H1. The interaction term of 0.304 implies about 6 percentage points higher R&D elasticity with average international R&D intensity. In specifications 2–4, we again divide the international R&D investments based on the relative characteristics of the R&D host countries. The System GMM results confirm the OLS findings and provide further support for hypotheses H2 and H3. When the R&D host country is technologically more advanced than the home country in the firm's industry, the R&D returns are statistically significantly higher. In specification 3, we find that offshore R&D in high growth host countries leads to higher R&D elasticity, although the coefficient for offshore R&D in low-growth host countries is also significant. In specification 4, the coefficients for R&D in technologically stronger but low GDP growth countries and R&D in technologically weaker but high growth countries are both significant and of similar size (0.344 and 0.376), whereas in OLS the latter is two times higher. Overall, the static System GMM shows a higher increase in the R&D returns than the OLS estimation.

In Table 4, we focus on the results of the full model specification to save space. For the same reason, we only report the coefficients for the variables related to international R&D. We first re-estimate specification 4 of Table 3 with all available lags as instruments. In column 2, we estimate the model assuming that the R&D variables are predetermined rather than endogenous, which implies that already one period lags can be used as instruments for the R&D variables. The Difference-in-Hansen test did not reject the exogeneity of one period lagged instruments. In column 3, we estimate the same model with all available lags as instruments. In columns 4, we estimate a dynamic production function where we include lagged value-added, labour, capital and R&D stock as regressors and in column 5 we include all available lags as instruments.

Overall, we find that these specification choices have an impact on the magnitude of the coefficients and that dynamic System GMM models lead to lower coefficient estimates for offshore R&D than the static models. The coefficient estimates in the dynamic models are also lower than in the OLS estimations. However, with respect to the role of host country characteristics the main implications do not change. The R&D elasticity increases the most when international R&D is located in technologically stronger and fast-growing host countries. The interaction coefficient is significant in all specifications and varies between 0.388 and 0.610, whereas the OLS estimate was 0.510. In contrast, international R&D in technologically weaker and slow-growing host countries has a statistically significant effect only in one specification (column 1). With respect to offshore R&D in technologically stronger but slow-growing host countries and offshore R&D in technologically weaker but fast-growing host countries, we notice that the magnitude and order of size of the coefficients varies depending on the assumptions of estimation. The lower estimates in the dynamic model specifications imply an increase in the R&D elasticity of around 2 percentage points with average R&D intensity, which is in line with the OLS results, whereas the estimates in the static models are two to three times higher.

The robustness of our results was also tested by excluding all firms that do not conduct international R&D.[18] The results are in line with Table 2–4. Thus, our findings cannot be explained just by

[16]Increasing the instrument count may overfit the endogenous variables. Moreover, it weakens the power of the Hansen test.

[17]In specification 4 of Table 3 the moment conditions for the levels equation were rejected by the Difference-in-Hansen test at 5% level. However, this was not the case in the other specifications in Tables 3 and 4. Moreover, Arellano-Bond Difference GMM estimation was tested and it performed poorly. Thus, we report System GMM estimation results for all specifications.

[18]The results are available upon request.

firms with more productive R&D self-selecting into offshore R&D.

To summarize our findings, we conclude that foreign R&D activities can improve the productivity of corporate R&D investments. However, if these activities do not bring access either to more advanced technological knowledge or to high growth foreign markets, the knowledge leakages, coordination costs and other costs appear to erode other potential benefits of international R&D. However, our results do not allow us to make final conclusions of the relative importance of these two channels. Moreover, the coefficient of the $intR\&D_{it}$ variable is found to be systematically negative. This indicates that there are costs associated with overseas R&D investments, which do not relate to the productivity of R&D investments but have a negative effect on firm productivity. However, the increase in R&D returns can compensate these costs. The median log R&D stock is approximately 11 in our sample (the nominal value is in thousands). Therefore, the increase in R&D returns appears high enough to exceed the additional costs of overseas R&D for firms with above-median R&D investments, but not for firms below the median. Thus, small firms with low R&D investments may lack the necessary scale to reap the benefits of overseas R&D.

Estimations with alternative measures of host country characteristics

Above, we measure the technological strength of countries using patent data. Schmoch et al. (2003) showed that a country's specialization in patenting is also correlated with industrial specialization and exporting. Nevertheless, patents may ignore some aspects of countries' technological capabilities. As an alternative, we measure the technological strength of countries using their R&D intensities (aggregate R&D investments divided by GDP), following, e.g. Shimizutani and Todo (2008). However, this data is more imprecise as it is at the country rather than industry level. The data on R&D intensities are obtained from the OECD Statistics. The data primarily cover developed countries, and thus, we assume that excluded countries are technologically weaker. We categorize technologically leading countries as those with a higher R&D intensity than the firm's home country. As the second alternative, we measure the technological competitiveness of countries using the innovation index in the Global Competitiveness Report 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. For the two earliest years of our sample the innovation index is unavailable and we rely on a more general technology index. We rank as technologically strong countries those that rank in the top ten on the WEF ranking, because these countries attract a clear majority of the offshore R&D in our sample as shown in Table 5.

Furthermore, we test alternative measures for host country market potential. First, we classify as high market potential countries those countries with higher GDP growth rates than the firm's home country in the previous 10 years. Some prior studies have used host country's GDP to measure the size of potential market. Thus, we test whether the largest countries by GDP entail larger improvement in R&D returns than smaller host countries. We classify China, India and G7 countries (the US, Japan, Germany, the UK, Italy, France and Canada) as countries with large domestic markets and other countries as small market potential countries. Other size classifications were also tested.

Table 5. Overseas R&D using alternative measures of technological strength and market potential.

	Mean	SD	Median	Min	Max	Obs
IntR&D, tech. stronger host countries (R&D)	0.150	0.235	0.038	0	1	2645
IntR&D, tech. weaker host countries (R&D)	0.065	0.133	0.006	0	1	2645
IntR&D, tech. strong host countries (WEF)	0.134	0.215	0.032	0	1	2645
IntR&D, tech. weak host countries (WEF)	0.081	0.151	0.016	0	1	2645
IntR&D, high market potential host countries (relative growth)	0.105	0.184	0.023	0	1	2645
IntR&D, low market potential host countries (relative growth)	0.110	0.206	0.003	0	1	2645
IntR&D, high market potential host countries (size)	0.150	0.228	0.043	0	1	2645
IntR&D, low market potential host countries (size)	0.064	0.134	0.010	0	1	2645

Table 5 represents summary statistics on overseas R&D locations using these alternative measures of country characteristics. The table shows that irrespective of the measure for technological strength, the technologically strong countries attract the majority of overseas R&D investments. Approximately half of R&D is also conducted in countries that have experienced higher economic growth than the firm's home country. Finally, Table 5 shows that the large countries attract the overall majority of R&D investments.

Table 6 presents estimation results from the static System GMM estimation. Here we analyse the technological and market potential characteristics separately. The table reveals that when we use R&D intensities as our measure, the coefficients of interaction terms are both statistically significant, but the coefficient for technologically stronger countries is higher than for technologically weaker countries. When we use the WEF rankings, there are only minor differences in the coefficient estimates. With respect to the host country market potential, the results with relative GDP growth are in line with Table 3. With respect to market size, we find that larger market size does not increase the returns to R&D. In contrast, the coefficient is lower than for international R&D in small countries and statistically insignificant. Thus, the improvement in R&D returns appears to be linked to the host country market growth rather than absolute size of the market.

VI. Conclusions

The present study analyzes whether overseas R&D activities improve firm productivity and especially contributes to the literature by analysing how the effects depend on the relative characteristics of R&D host countries. The analysis reveals that international R&D activities improve the R&D returns to productivity. Our empirical results indicate that the output elasticity of R&D increases when firms locate overseas R&D in countries that are technologically more advanced in their industry than their home country, and that can therefore provide a rich knowledge sourcing environment and access to knowledge spillovers. We also find that research activities in high GDP growth countries are associated with significantly higher R&D returns to productivity. In contrast, we find that the host country's market size does not affect R&D-productivity relationship. Instead, market-seeking foreign R&D appears to improve revenue productivity by enhancing international demand in high growth markets. While we find that overseas research activities in technologically relatively weaker and low-growth host countries do not enhance R&D returns to productivity, we also do not find evidence that such activities would significantly worsen productivity.

Our findings hold important implications for both research and practice. Extant studies have shown that multinational firms are more productive and enjoy higher returns to their R&D than domestic firms.

Table 6. System GMM estimation using the alternative measures of technological strength and market potential.

Dependent variable ln(Value added)	1. R&D intensity		2. WEF		3. Relative GDP growth		4. Market size	
ln(C)	-0.004	(0.064)	0.010	(0.062)	0.029	(0.061)	-0.014	(0.053)
IntR&D, tech. stronger	-3.638**	(1.783)	-4.072***	(1.329)				
ln(C)×IntR&D, tech. stronger	0.325**	(0.148)	0.361***	(0.111)				
IntR&D, tech. weaker	-2.648**	(1.339)	-3.922***	(1.390)				
ln(C)×IntR&D, tech. weaker	0.239**	(0.114)	0.344***	(0.118)				
IntR&D, high market potential					-3.952***	(1.236)	-2.808*	(1.623)
ln(C)×IntR&D, high market potential					0.355***	(0.109)	0.244	(0.148)
IntR&D, low market potential					-3.128***	(1.091)	-4.207***	(1.413)
ln(C)×IntR&D, low market potential					0.284***	(0.100)	0.347***	(0.118)
ln(Subsidiary countries)	0.565***	(0.126)	0.566***	(0.118)	0.488***	(0.120)	0.609***	(0.131)
Observations	2645		2645		2645		2645	
Firms	410		410		410		410	
Instruments	117		117		117		117	
AR1, p-value	0.002		0.002		0.002		0.003	
AR2, p-value	0.151		0.161		0.160		0.143	
Hansen test, p-value	0.347		0.495		0.565		0.638	
Hansen test, df	77		77		77		77	

Notes. * $p<0.10$, ** $p<0.05$, *** $p<0.01$. All regressions include variables for labor, capital, year and country dummies and country-year interactions. All time-varying firm level variables are assumed endogenous. Other variables are assumed exogenous. Endogenous variables are instrumented with two period lags. Two-step robust standard errors are presented in parenthesis.

This finding is confirmed by our empirical results, which further indicate that the advantage is in significant part due to the internationalization of research activities. Moreover, while previous literature has provided somewhat ambiguous evidence on the relationship between R&D internationalization and firm productivity, we show that this may be because the literature overlooks the importance of host country characteristics. The key implication is that the host country's relative technological strength and market growth are crucial to determining the gains from R&D internationalization and, hence, also to corporate R&D location decisions. Another difference to some prior studies is that by using a patent-based measure for foreign R&D, we especially focus on innovative offshore R&D, which may imply stronger productivity gains than other offshore R&D activities. Also of high practical relevance is the finding that there are significant costs associated with international R&D that smaller or less R&D-intensive firms may not be able to cover. Thus, while large firms significantly benefit from international knowledge sourcing and market access in terms of productivity, these results may not apply to smaller firms. This finding also aligns with previous evidence suggesting that firms need to have a certain level of absorptive capacity, for example in the form of prior R&D experience, to benefit from R&D internationalization (Penner-Hahn and Shaver 2005).

From a policy perspective, our results suggest that the increasing relocation of R&D activities abroad does not necessarily weaken the home country's welfare because improved firm productivity can also benefit the home country. In contrast, international R&D collaboration and knowledge sourcing by firms should be recommended to improve the innovativeness and productivity of firms. Moreover, the results indicate that the increasing globalization of innovative activities can boost economy-level productivity growth through R&D.

This study is subject to several limitations, which also suggest avenues for future research. Our analysis is limited to the market potential and relative technological strength characteristics of host countries. Although these are cited as the most important drivers of foreign R&D investments and thus appear as the most central determinants of productivity improvements, other country characteristics such as labour costs, institutions or distance may also matter and merit future study. Moreover, offshore R&D may have different implications for corporate research activities and development activities. E.g., the host country's relative technological and market characteristics may matter for one type of activity but not the other. Unfortunately, the data used in this study do not allow us to study this distinction. A different dataset would be needed to investigate these activities separately.

Furthermore, due to the availability of data, we have analysed a highly selective sample of large innovative firms. This implies that the offshore R&D activities and related performance effects can be more pronounced in our sample of firms than on average. Moreover, our analysis is limited to manufacturing firms in four European countries. On the one hand, European firms have been shown to have higher levels of R&D internationalization than, e.g., American or Japanese firms. Hence, it is possible that European firms are more likely to benefit from R&D internationalization than other multinationals, and thus, our results may provide an overly positive view of the overall effect. On the other hand, it has been argued that international R&D is even more important for firms from small countries that are not covered in this study. Future work should study firms from different industries and countries to determine the generalizability of the results.

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Appendix A

Table A1. Sample by country.

France	536
Germany	993
Italy	142
UK	1148
Total	2855