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The returns to foreign R&D

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ABSTRACT

Extant research on R&D internationalization has not examined how effective foreign R&D investments are in generating positive returns for the investing firms, in particular in comparison and conjunction with the effects of domestic R&D investments. We examine the effectiveness of international knowledge sourcing through foreign R&D in an empirical analysis of the productivity effects of foreign and domestic R&D investments in a large panel of firms based in the Netherlands. We argue that foreign and domestic R&D will exhibit complementarity in their effects on productivity, but that the roles of domestic and foreign R&D depend on the relative position of the home country with respect to the global technology frontier and the related relative opportunities for knowledge sourcing abroad. We estimate a dynamic panel data model derived from a knowledge stock augmented production function framework allowing for productivity convergence and declining returns to R&D. We confirm that for firms active in industries in which the home country is behind the global technology frontier, foreign R&D provides positive returns and has a complementary relationship with domestic R&D. For industries at the global technology frontier, in contrast, domestic R&D is the primary source of productivity growth.

Keywords: Foreign R&D, multinational enterprises, innovation, productivity
JEL Classification: O32, O33, D24

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INTRODUCTION

The geographic dispersion of R&D activities by multinational firms has drawn considerable interest among both policy makers (UNCTAD, 2005; OECD, 2007) and IB scholars (e.g. Dunning, 1994; Di Minin and Bianchi, 2011; Nieto and Rodriguez, 2010; Song and Shin, 2008; Singh, 2008; Contractor et al., 2010; Castellani, Jimenez, and Antonello, 2013). Whereas, traditionally, overseas R&D has been motivated by the need to adapt domestic technologies, products and processes to foreign markets and manufacturing circumstances (Kuemmerle, 1997), extant research has emphasized that foreign R&D activities may also serve as an instrument of knowledge sourcing and 'reverse' knowledge transfer, increasing multinational firms' innovation and productivity at home (e.g. Alcacer and Chung, 2007; Belderbos, Lykogianni, & Veugelers, 2008; Cricuolo, 2009; Chung & Alcacer, 2002; Chung & Yeaple, 2008; Driffield, Love, & Menghinello, 2010; Song, Asakawa & Chu, 2011).

Studies indicate that knowledge sourcing and reverse knowledge transfer through foreign R&D is not a common phenomenon (Govindaranjan and Gupta, 2000) and that the effects on innovative performance are subject to a number of contingencies, such as effective cross-border collaboration and knowledge integration (Singh, 2008; Lahiri, 2010), embeddedness of affiliates in local technology and R&D clusters (Griffith, Harrison, & Van Reenen, 2006; Odagiri & Iwasa, 2004), top management team characteristics (Mihalache et al., 2012), organizational slack (Chen et al., 2012) and the absorptive capacity at home to assimilate and integrate technological knowledge coming from abroad (Penner-Hahn and Shaver, 2005).

Although the effects of the presence of foreign R&D activities on firm performance have been empirically examined, a lack of suitable data on R&D expenditures has led most studies to substitute patent indicators on the location of inventors for indicators of foreign

R&D in their analysis. As a result, extant research has not been able to investigate the effectiveness of foreign R&D in terms of generating positive returns, in particular in comparison to, and in conjunction with, the effects of domestic R&D investments.[1] In other words, the relative performance effects of R&D internationalization compared to domestic R&D investments have been underexposed. This is not a trivial issue since conclusions on the effectiveness of R&D internationalization and the implications for management can only be derived if the costs of such foreign R&D investments are considered as well.

The performance effects of foreign and domestic R&D are likely to be interrelated since knowledge sourced from abroad may be complementary to domestic R&D efforts. Foreign R&D can broaden technology search, build up specialized expertise, and facilitate knowledge recombination and cross-fertilization with domestic R&D (e.g. Nieto & Rodrigues, 2011, Leiponen & Helfat, 2011). Incoming technological knowledge and cross fertilization feed domestic process and product innovation efforts and allow the firm to create more value from the use of capital and inputs, hence improving productivity (e.g. Todo & Shimizutani, 2008; Griffith, Harrison & van Reenen, 2006). Effective knowledge sourcing and complementarities between foreign and domestic R&D rely on the presence of absorptive capacity in the firm's domestic operations (Cohen & Levinthal, 1989; 1990; Penner Hahn & Shaver, 2005) to evaluate, absorb and integrate relevant knowledge transferred from overseas R&D units. International knowledge sourcing is, however, not expected to be equally important across industry and home country contexts. The importance and effectiveness of overseas knowledge sourcing and reverse knowledge transfer will depend on the presence of rich sourcing opportunities in the industry environment abroad, in comparison to the home country environment (e.g. Song et al., 2011; Song & Shin, 2008; Winston Smith, 2014). If the

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[1] On the other hand, advantages of exploiting patent data are related to the detail they can provide on technologies, locations of inventors, and knowledge flows (as proxied by citations).

home industry is operating at the global technology frontier and is characterized by intensive local knowledge spillovers, firms' foreign R&D investments will have relatively little to contribute to home country performance but may instead focus on adaptation of technologies, developed at home, to the local host country environment.

This research note addresses the above issues by examining the returns to foreign and domestic R&D investments through an analysis of productivity growth in a large panel of firms based in the Netherlands (1995-2003) and operating across a wide variety of industries. We draw on comprehensive yearly official surveys on R&D expenditures and value added creation at the firm level conducted by the Central Bureau of Statistics in the Netherlands. Our study's inferences are drawn from a dynamic panel data model estimated with system-GMM and derived from a knowledge stock augmented production function framework, which allows us to control for endogeneity and for persistent firm-level differences in productivity levels. We specifically examine the potential complementarity between foreign and domestic R&D in enhancing productivity, while allowing for declining marginal returns to R&D in both locations. We find that the returns to R&D and its complementarity with domestic R&D depend crucially on the relative presence of knowledge-sourcing opportunities abroad, as indicated by the relative position of the local industry with respect to the global technology frontier.

Before we proceed, we note an important limitation of our study. While the arguments for complementarity between foreign and domestic R&D suggest a number of mechanisms at work related to knowledge recombination and augmentation, and suggest differential mandates and motivations for foreign R&D in leading and lagging countries, we do not observe such mechanisms, mandates, and locations in our data. Our results should be interpreted as average effects of foreign and domestic R&D on productivity growth, with as crucial differentiator the status of the home industry in terms of distance to the global technology frontier. We do provide additional evidence that the pattern of foreign R&D by firms based in the Netherlands (as derived from patent data) is generally consistent with our arguments.

The remainder of this note is organized as follows. In the next section, we provide a synopsis of the theoretical background concerning international R&D and firm performance, and develop our hypotheses. We then discuss the empirical base for our analysis and present the augmented productivity model in condensed form, from which we derive the equation to be estimated. After presenting the empirical results, we discuss our findings and their implications. We conclude with a discussion of the limitations of our study and possible avenues for future research.

BACKGROUND AND HYPOTHESES

The extant literature has produced substantial evidence of knowledge-sourcing objectives connected to foreign R&D units (e.g. Driffield et al., 2010; Florida, 1997; Frost, 2001; Kuemmerle, 1999), as affiliates obtain broader R&D mandates and global product development responsibilities (e.g. Belderbos, 2003; Cantwell & Mudambi, 2005; 2011; Feinberg & Gupta, 2004). Technology sourcing through foreign R&D affiliates allows multinational firms to tap into leading-edge knowledge by locating affiliates in close proximity to clusters of excellence in the search for new ideas on novel technologies, products and processes. Overseas knowledge sourcing and 'reverse' knowledge transfer enhances the knowledge base of the firm at home, feeding process and product innovation processes, and enhancing the parent firm's ability to create value (e.g. Todo and Shimizutani, 2008; Griffith et al. 2006; Driffield et al., 2007; Criscuolo, 2009; Belderbos, van Roy & Duvivier, 2013). At the same time, effective reverse knowledge transfer involving integration and implementation at home requires a sufficient level of absorptive capacity built up through domestic R&D investments (Cohen & Levinthal, 1989; 1990; Penner-Hahn & Shaver, 2005). This is likely to create a complementarity between foreign and domestic R&D: the effectiveness of foreign R&D in enhancing domestic efficiency is likely to increase with the presence of domestic R&D capabilities (e.g. Todo & Shimizutani, 2008).

While recent studies have suggested that the dispersion of international R&D activities can improve firms' financial and innovative performance (e.g. Lahiri, 2010; Griffith et al., 2006; Penner-Hahn & Shaver, 2005), prior studies have generally not examined the joint impact of domestic and foreign R&D investments. The two studies that did take foreign R&D expenditures into account – Fors (1997) and Todo & Shimizutani (2008) – obtained mixed findings. Fors (1997) found that parent R&D investment increases value-added growth in the affiliates of Swedish firms, whilst affiliate R&D had no significant influence on parent firm growth. Todo & Shimizutani (2008) examined R&D expenditure data in a panel of Japanese firms and found weakly positive effects of foreign research activities on parent productivity, but no complementarity between foreign and domestic R&D. A related study by Penner-Hahn & Shaver (2005) also focused on complementarity between foreign and domestic R&D but had to rely on patent data. Their findings indicated that Japanese pharmaceutical firms with overseas R&D units saw an increase in the number of patent applications, once parent firms had some prior patenting activity in the domain of the foreign R&D activities. Although this finding is suggestive of complementarity conditional on a sufficient absorptive capacity in domestic operations, clear evidence on the intertwined performance effects of domestic and foreign R&D is lacking.

In this study, we develop arguments for the joint effects of foreign and domestic R&D on parent firm productivity. The focus on productivity follows a number of earlier studies (Todo & Shimizutani, 2008; Griffith et al. 2006; Driffield et al., 2007; Winston Smith, 2014).[2] Productivity is a measure of the value created through the efficient use of capital and labor inputs, which is regarded as being a function of the firm's knowledge base - which in turn is a function of cumulative R&D investments (e.g. Hall, Mairesse & Mohnen, 2012). In this sense, productivity as a performance measure has a direct relationship with firms' R&D investments and firms' efforts to augment the knowledge base through particular (international) configurations of their R&D activities. Productivity captures both the cost-reducing effects of R&D (e.g. through process innovations and their implementation) and the effects of new product development and introductions (which may allow for an increase in price-cost margins).

Hypotheses

The inconclusive results on the role of foreign R&D and its complementarity with domestic R&D may be related to the failure to take into account an important contingency: the relative 'richness' of opportunities for knowledge sourcing abroad compared to the home country. Firms will in particular be looking for expertise and frontier technological knowledge abroad if this expertise is lacking at home. Incoming technological knowledge augments the domestic technological knowledge from which new product development efforts and process improvements are derived, improving productivity firm (e.g. Todo & Shimizutani, 2008; Griffith, Harrison & van Reenen, 2006). There is ample evidence that home-based augmenting R&D laboratories with a clear knowledge-sourcing objective are most likely to be located in countries with competitive and technological advantages (Ambos and Ambos, 2005; Alcacer and Chung, 2002; Belderbos et al., 2008; Kuemmerle, 1999).

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[2] Productivity has also been the dependent variable of choice in the international business literature focusing on knowledge spillovers due to Foreign Direct Investment (e.g. Altomonte & Pennings, 2009; Driffield and Love, 2007).

Studies have also suggested that local knowledge sourcing by foreign affiliates is positively associated with the abundance of R&D and the strength of technological capabilities in the host country (Song et al., 2011; Song & Shin, 2008). In locations where there is a critical mass of R&D activity and a large stock of relevant technological knowledge, multinational firms have greater opportunities to source valuable knowledge, benefit from spillovers from local R&D clusters, potentially find valuable partner firms or organizations with which to conduct joint R&D activities, and to hire talented and experienced scientists and engineers for their R&D laboratories (Iwasa & Odagiri, 2004; Griffith et al. 2006; Lewin et al., 2009). In contrast, if the home country itself provides such a rich environment for knowledge sourcing at the technology frontier, with abundant R&D resources and potential knowledge spillovers, overseas R&D may have relatively little to contribute to the knowledge base of the firm and hence little effect on productivity is expected. If R&D activities do take place abroad, these activities are more likely to focus on ‘home base exploiting’ tasks. R&D, in this case, draws primarily on parent firm knowledge in order to adapt technologies to local manufacturing and market conditions in host countries that do not specifically provide a leading environment in terms of technological capabilities.

The above arguments suggest that the opportunities for foreign knowledge sourcing, the potential for reverse knowledge transfer and, hence, the effectiveness of foreign R&D in strengthening firm productivity at home depends on the relative strength of technological capabilities related to the R&D environment in the home country. If the home country provides a leading environment and operates at the technology frontier, foreign R&D is less likely to improve parent firm productivity. If the home country is lagging behind the technology frontier and if there are strong technology environments abroad, foreign R&D investment is likely to be associated with overseas knowledge sourcing and improved parent productivity performance. Thus, we formulate:

Hypothesis 1. Foreign R&D improves parent firm productivity if the home country is lagging behind the global technology frontier, but not if the home country is close to, or at the global technology frontier.

There are several ways in which simultaneous investments in foreign and domestic R&D may generate complementarity effects (mutually reinforcing effects on parent firm productivity), provided that foreign R&D is motivated by knowledge sourcing in countries providing a rich technology sourcing environment. In these circumstances, knowledge flows from affiliates to parent firms are likely to be aimed at augmenting the domestic knowledge base by utilizing foreign R&D to monitor and draw on technological efforts in existing or emerging fields of technology that are complementary to domestic R&D (e.g. Dunning & Narula, 1995; Kuemmerle, 1997). Creating linkages to multiple locations with rich technological resources increases the breadth of search and provides greater opportunities for knowledge recombination and cross fertilization (Criscuolo et al., 2009; Leiponen &Helfat, 2011; Nieto & Rodriquez, 2011). Pursuing different but related R&D projects at home and abroad can in this way lead to economies of scope and complementarities in R&D (Henderson & Cockburn, 1996). Knowledge generated by foreign R&D can be leveraged to improve project selection and provide new ideas for domestic R&D activities, with the potential to increase the returns to domestic R&D (c.f. Cassiman & Veugelers, 2006; Lokshin et al., 2008). Expanding the scope and variety of R&D projects through internationalization may be particularly important as the returns to R&D investment are likely to decline in larger firms (Cohen & Klepper, 1996; Harhoff; 2005; Zenger, 1994). At the same time, know-how and absorptive capacity built up through domestic R&D will increase the returns to foreign

R&D by providing more fertile ground to assimilate and integrate knowledge sourced abroad (Cohen and Levinthal, 1989; 1990).

These arguments suggest the presence of complementarity between foreign and domestic R&D - in the circumstance where the host countries provide a leading environments for R&D. Reverse knowledge transfer generated by foreign R&D is likely to provide important inputs to domestic R&D operations, enhancing the returns to domestic R&D, while investments in domestic R&D are required to absorb and integrate knowledge derived from foreign R&D operations, such that the returns to foreign R&D positively depend on domestic R&D investments. In contrast, if the home industry is operating at the technology frontier, the relative scarcity of effective knowledge-sourcing opportunities abroad and the limited potential for reverse knowledge transfer from foreign R&D laboratories will also imply a lack of potential for complementarity between domestic and foreign R&D. On the one hand, domestic R&D is not likely to strengthen the effectiveness of knowledge sourcing through foreign R&D in the absence of important knowledge flows from abroad and the absence of a strong need to assimilate and integrate this knowledge. Similarly, if foreign R&D is unlikely to produce knowledge flows relevant to parent firm operations, it is, by implication, also unlikely to increase the effectiveness of domestic R&D. Hence, a mutually reinforcing effect of foreign and domestic R&D is expected to be absent. This suggests the following hypothesis:

Hypothesis 2. There is complementarity between foreign and domestic R&D (foreign and domestic R&D strengthen each other’s effects on parent firm productivity) if the home country is lagging behind the global technology frontier, but not if the home country is close to, or at the global technology frontier.

DATA AND METHODS

The empirical analysis makes use of the annual R&D surveys from the Dutch Central Bureau of Statistics (CBS), in combination with production statistics on Dutch firms. The R&D surveys are our source of information on firms' R&D expenditures and their breakdown. They are conducted yearly among enterprises with more than 10 employees. CBS draws a stratified sample from among all firms listed in the General Business Register each year, while it surveys a set of approximately 500 known R&D-active firms every year. Given that CBS has to provide official numbers on R&D expenditures in the Netherlands to Eurostat and the OECD, the bureau ensures that the R&D reported is reliable and representative of total R&D expenditures in the Netherlands.[3] While the sampling method does imply a certain over-representation of R&D-intensive sectors, there is a good coverage of less R&D-intensive sectors as well. The CBS production statistics survey provides the information to construct the dependent variable in our analysis, productivity. The survey contains information on output, employment, and the output deflators of Dutch enterprises. Finally, we used a link, provided by CBS, to a variable drawing on consolidated financial statistics in order to determine which firms have multinational operations. Firms are considered to be multinationals if they own assets in foreign affiliates.[4] All datasets are anonymized by CBS before they are made available to researchers, and we use a unique firm identifier to merge data from the different sources. For our research purpose, we focus solely on Dutch firms that are not foreign owned, since foreign-owned affiliates have broader sourcing opportunities at their disposal through their foreign parents, on which we lack suitable data. An important

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[3] CBS does not report the precise response rates, but the mandatory nature of the survey and follow-up by CBS ensures that responses are representative among R&D-conducting firms.

[4] Given that the information is derived from consolidated financial statistics, the ownership of assets will generally imply management control of the foreign affiliate and a majority equity stake.

advantage of merged sets of micro data is the diversity of firms included in the data: both large R&D-intensive firms as well as small and medium-sized enterprises are included, and the data cover all industries.

Our sample covers the years 1995-2003 but, given the partially random sampling in each year for smaller firms, we are unable to observe each firm for the entire period, and so the panel is unbalanced in nature. Although we observe firms on average for approximately four consecutive years, the dynamic specification and lagged instruments needed for GMM estimation requires that we use two lags of firm observations. This reduces the effective average number of years a firm enters the empirical model to approximately two. Hence, we have 4038 unique firms and approximately twice the number of observations: 8658. Among these firms, 48 percent (1938 firms) are identified as multinational firms with headquarters in the Netherlands.

We use parent firm productivity as the indicator of firm performance. This choice of dependent variable derives from a knowledge-augmented production function framework, which we adopt to model the effects of R&D investments (see below). The dependent variable, labor productivity, is constructed as net value added – calculated as the value of gross output less the value of intermediate inputs – per employee at constant prices. Productivity, arguably, is a more comprehensive performance measure than profitability. Productivity measures indicate the value created by the firm through the effective use of capital and labor inputs. The value created is subsequently distributed over shareholders (profits) and managers and employees (wages). While such distributional issues are important, it is clear that a primary question is to what extent the use of technology creates value in the first place. This value created depends on the competitiveness of the firm’s products and its process technology. An additional advantage of using a productivity measures is that we can draw on a rich prior literature on R&D and productivity that provides a clear modeling framework with explicit assumptions and a precise interpretation of the estimated coefficients. The 'return to R&D' in the context of the knowledge-augmented production function framework is the increase (in euros) in value added as a result of an extra euro spent on R&D.[5]

Firms' R&D expenditures are differentiated as R&D conducted by the firm in the Netherlands (domestic R&D) and R&D conducted by the firms' foreign subsidiaries (foreign R&D). The production function framework suggests inclusion of the ratio of R&D to value added. Other variables to be included in the dynamic productivity model suggested by a production function framework are (the growth in) employment, measured as the number of employees expressed in full-time equivalents, and the growth in the capital stock, approximated by the growth in fixed capital investments. Value added, fixed capital investment, and R&D are deflated using industry-specific deflators. The models include a dummy variable for multinational firms, taking the value of 1 if the firm owns assets in foreign affiliates, a control for firm size (employment), 9 year dummies and 27 industry dummies.

In order to examine differential effects of foreign and domestic R&D based on the distance to the global technology frontier, we utilize variation in the domestic and foreign environments faced by firms across industries and time. We identify domestic industries that are at the technology frontier by comparing the R&D intensity of the domestic industry with the R&D intensity in the top performing OECD countries in that industry. This approach follows Griffith et al., (2006) and Salomon & Jin (2008) and derives from the notion that

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[5] We note that this definition of 'return' differs, in part, from the notion of return on invested capital (ROIC), since the latter focuses on accounting profits rather than value creation, examines all capital invested rather than R&D investments, and expresses the average ratio of profits to capital rather than a marginal gain.

spillover and knowledge sourcing benefits from domestic or foreign R&D are a function of the strength of local R&D pools that can provide such knowledge spillovers and sourcing benefits. We use OECD statistics on industry-level R&D intensity (R&D divided by value added at constant prices) and define a leading industry, on a yearly basis, as an industry for which the R&D intensity in the Netherlands is higher than the R&D intensity in the top quartile of OECD countries.

Table 1 reports the descriptive statistics of the variables for each subsample as well as correlations among the variables used in the estimation. The (natural logarithm of) productivity and the ratio of domestic R&D over value added are slightly larger in the leading industry subsample. Investment growth is a more salient characteristic of lagging industries. The correlations in the subsamples do not indicate multicollinearity concerns.

Empirical model

We derive our empirical specification from a knowledge stock augmented Cobb Douglas model (e.g. Hall et al., 2012; Lokshin et al., 2008), in which value added is a function of capital stock, labor, and foreign and domestic R&D stocks for firm *i* at time *t*:

$$Y_{it} = \alpha_i L_{it}^{\beta} C_{it}^{\delta} K_{it}^{\gamma} e^{\sigma_{it}} \qquad (1)$$

where Y is output, L is labor input, C is the physical capital stock and K is the knowledge (R&D) stock. The parameters β, δ, and γ are elasticities with respect to labor, physical capital, and the knowledge stock, which in turn is a function of investments in domestic and foreign R&D. The multiplicative constants α_i represent fixed firm-specific (organizational and managerial) capabilities allowing for higher productivity, while the parameter σ_{it} is a time-variant firm-specific efficiency parameter. In further steps to derive the model for estimation (relegated to an appendix), we divide both sides by labor, take logarithms and difference the equation (through which the firm fixed effects α_i drop out). Because an important feature of firm-level productivity patterns is persistent productivity heterogeneity across firms and industries (e.g. Klette, 1996), we use a more general dynamic specification by allowing firm-specific productivity advantages σ_{it} to depend on past productivity. This leads to a dynamic specification in which productivity growth is a function of the past productivity level and the growth in labor and capital. In the absence of longer time series on R&D to calculate R&D stocks, we can express productivity as a function of the ratio of R&D investments over value added, while assuming that the depreciation of R&D is small. For estimation purposes, we rewrite the final equation in levels:

$$\begin{aligned} q_{it} = {} & (1+\theta)q_{it-1} + (\beta-1)\Delta l_{it} + \delta\Delta i_{it} + \\ & \varphi[\eta_1 r^{dom}_{it-1} + \eta_2 r^{for}_{it-1} + \eta_3 (r^{dom}_{it-1})^2 + \eta_4 (r^{for}_{it-1})^2 + \eta_5 r^{dom}_{it-1} r^{for}_{it-1}] + \lambda_t + v_{it} \end{aligned} \tag{2}$$

where small letters denote natural logarithms, q_{it} denotes labor productivity, Δc_{it} the growth in fixed capital investment, Δl_{it} is growth in labor input, and r^{dom}_{it-1} and r^{for}_{it-1} the ratios of domestic and foreign R&D to value added, respectively. The parameters $\varphi\eta$ capture the marginal effects of R&D investments on value added. The parameter θ [-1,0] is the convergence parameter and indicates what share of productivity lead disappears through convergence in a year. The equation includes year-specific intercepts λ_t in addition to a normally distributed error term v_{it}.

Equation (2) implies a more general, nonlinear, specification for the augmentation of the knowledge stock that allows for (dis)economies of scale and scope in pursuing domestic and foreign R&D, indicated by the square terms and the interaction term. Previous studies have suggested that the process of augmentation of the knowledge capital stock is, indeed, characterized by declining returns to scale (Acs & Isberg, 1991; Cohen & Klepper, 1996).

Since we are interested in testing complementarities between foreign and domestic R&D, it is important to separate the complementarity effect from the potentially declining marginal impact of domestic and foreign R&D.

At the same time, equation (2) still has its limitations as it does not extend to a full polynomial. Prior studies have adopted a more general specification in which moderator variables are allowed to interact with both the linear term and the quadratic term of the focal variable (e.g. Vasudeva & Anand, 2011; Lahiri, 2010; see Aiken & West, 1991). The moderator variable may not only increase or decrease the slope of the linear part of the (inverted-U shaped) relationship between the dependent variable and the focal variable and the location of the inflexion point, but may also affect the slope of the declining part of the curve. In the context of our empirical model, there is an added level of complexity because our analysis includes two 'focal variables': foreign and domestic R&D, which are hypothesized to reinforce each other's effect in specific circumstances. Hence, equation (2) can be augmented by two additional interaction effects: $\eta_6 r_{it-1}^{for}(r_{it-1}^{dom})^2, \eta_7 r_{it-1}^{dom}(r_{it-1}^{for})^2$. In addition, expansion of the model to a full polynomial implies the inclusion of the interaction between the squared terms of foreign and domestic R&D: $\eta_8 (r_{it-1}^{dom})^2 (r_{it-1}^{for})^2$. We report the results of these augmented specifications in the supplementary analysis section.

We estimate the equation with the System General Method of Moments (GMM-SYS) instrumental variables approach due to Blundell and Bond (2000). GMM-SYS provides consistent and efficient estimates when panel data have a large cross-section dimension but a relatively short time dimension, as is the case for our data. The instrumental variable approach corrects for the potential endogenous nature of the R&D variables and has been found to perform well in production function and investment models (e.g. Almeida, Camello and Galvao, 2010). System GMM implies the estimation of a system of equations: a level equation as well as an equation in first differences. The level equations also include a set of industry dummies, year dummies, a multinational firm dummy and a firm size measure (employees) to control for a potential effect of firm size on productivity. As instruments for the equations in levels we use differenced values of the right-hand-side variables, i.e. twice lagged differences in productivity and R&D, and lagged differences in employment and investment and employment growth. Equations in differences use twice-lagged values of productivity and R&D, and lagged growth in labor and capital.

In order to examine differential effects of foreign and domestic R&D depending on the status of the industry, we perform subsample analysis, distinguishing between leading and lagging industries. Subsample analysis is the more general test for structural differences since it does not assume that other coefficients (e.g. those of labor and capital) have to be equal across leading and lagging industries. Several prior studies have used the approach to investigate structural differences in effects due to a key moderator variable (e.g. Belderbos & Zou, 2009; Salomon & Jin, 2008).

EMPIRICAL RESULTS

Table 2 reports the results of the estimation of equation (2). Model 1 is estimated on a subsample of lagging industries and Model 2 on the corresponding subsample of leading industries at the technology frontier. In general, the models perform well and are highly statistically significant. The Hansen test statistic for over-identification is insignificant, suggesting that instrument exogeneity cannot be rejected and that the instruments used are valid. The estimated coefficients on past labor productivity are in the range of 0.43 - 0.48, indicating a comparatively mild persistence in productivity: approximately half of the productivity lead disappears through convergence. The models suggest an elasticity of output with respect to labor of about 0.55 (1 - 0.45) and an elasticity of capital ranging between 0.14 and 0.21. These estimates are in line with other studies using a similar production function framework (e.g., Fors, 1997; Belderbos, van Roy & Duvivier, 2013). The positive and significant coefficients on the multinational firm dummy indicates that Dutch multinational firms exhibit higher productivity – also in the absence of foreign R&D – than their purely domestic counterparts. This is consistent with findings in prior studies (e.g. Criscuolo & Marin, 2009; Temouri et al., 2008).

Turning to the R&D variables, the estimates for the lagging industries (Model 1) suggest an inverted U-shaped relationships between productivity and domestic as well as foreign R&D, with positive linear terms and negative quadratic terms. For leading industries, in contrast, only the linear domestic R&D coefficient is significant with no evidence of declining returns to R&D, while foreign R&D has no significant effect on productivity.[6] These results provide support for Hypothesis 1, which suggested that foreign R&D enhances parent firm performance in lagging industries but not in leading industries. Furthermore, the interaction effect of foreign and domestic R&D is significant in the subsample of lagging industries but insignificant (with a negative sign) in the subsample of leading industries, in support of Hypothesis 2.

The estimates on R&D for lagging industries indicate positive and, at some point, declining returns to R&D. However, the inflexion points, beyond which marginal returns to R&D start to decline, are not generally within the (sample) range for the variables: The estimates imply an inflexion point of 0.35 for foreign R&D intensity and of 2.6 for domestic R&D intensity. This difference indicates that the marginal effects of foreign R&D are reduced more quickly while, for domestic R&D, the flattening out of the curve is much less pronounced. This is consistent with the notion that domestic R&D incorporates relatively more basic research, characterized by stronger scale economies, while foreign R&D is more likely to involve applied research (e.g. Chacar & Lieberman, 2003; Arora et al., 2011). At

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[6] We note that the linear term remains insignificant when leaving out the square term of foreign R&D.

small initial levels of R&D, the estimated coefficients indicate a return on domestic R&D for lagging industries of 0.51 (0.45 for leading industries), suggesting that a euro spent on domestic R&D raises net value added by 51 euro cents. This estimated marginal effect falls within the range of R&D estimates in prior studies (Hall et al., 2012). For foreign R&D, the rate of return is significantly higher at 0.97. The higher marginal effect of foreign R&D substantiates the idea that geographic diversity of R&D enhances firm performance in industries where the domestic industry is behind the global technology frontier.

In order to examine the full effects of domestic and foreign R&D, the interaction term has to be taken into account since it plays an important role in enhancing the returns to geographically distributed R&D. To illustrate the impact of foreign and domestic R&D on productivity, based on all estimated coefficients, Figure 1 plots the logarithm of value added per employee as a function of foreign and domestic R&D intensity; it is drawn based on the estimated coefficients and sample means in Model 1. The figure illustrates that an allocation that sets one type of R&D to zero and maximizes the other is not optimal. Conditional on a sufficient level of domestic R&D, firms can achieve higher productivity gains by switching from a purely domestic R&D strategy to a distributed configuration involving both domestic and foreign R&D.

Supplementary analysis

We performed a number of tests with alternative specifications of the empirical model. First, as discussed in the methods section above, we estimated a more general specification with two additional interaction terms of foreign and domestic R&D: $\eta_6 r_{it-1}^{for}(r_{it-1}^{dom})^2, \eta_7 r_{it-1}^{dom}(r_{it-1}^{for})^2$. The results did not show any significant effects of these additional terms. In addition, specifications with the interaction between the squared terms similarly produced insignificant coefficients. These results suggest that the ‘linear’ complementarity effect is dominant and that the complementarity effect is restricted to the range of R&D values where the marginal returns to R&D are still increasing. On the one hand, this is consistent with the estimates reported in Table 2, which indicated only mildly declining returns to scale in the productivity-R&D relationships. Given that negative returns to R&D do not occur within the sample, there is obviously little scope for positive moderation in this part of the curve. Figure 1 illustrates this pattern and shows moderation effects throughout the actual range of R&D. On the other hand, we note that the additional interaction terms are not easily identified given the implied greater complexity and associated correlations in the models. GMM models moreover require instrumenting each variable with past values or differences of the right hand side variables; this becomes increasingly difficult with a larger set of (correlated) variables to instrument.

Recognizing that returns to R&D may differ between industries, we also re-estimated our split sample models for the groups of high-tech and low-tech industries -effectively partitioning the data into four subsamples. We define high-tech industries in accordance with the official OECD classification (OECD, 2011). Results from the high-tech sample were similar to the results for the full sample, while results from the low-tech subsample revealed no significant coefficients for the foreign R&D variables. While these results are partially due to the generally thinner spread of R&D investments in low-tech industries and, in particular, R&D investments abroad – necessary to establish a complex relationship between R&D and productivity – they indicate that our findings may also be contingent on the general importance of R&D investments in industries. Finally, estimating our models on a subsample of only the multinational firms generated results that were closely in line with results in Table 2. Similar findings were also obtained when replacing value added as the denominator of R&D investment by sales. The results of these supplementary analyses are available in the (online) appendix to this research note.

Our arguments on technology sourcing suggest that the location of foreign R&D differs depending on the status of the home country industry. We sought to provide evidence on the location of foreign R&D activities in an auxiliary analysis exploiting patent data. We collected patent data applied for at the European Patent Office by firms (patent assignees) incorporated in the Netherlands and use inventor location information as the indicator of where foreign R&D activities of these firms are taking place. We assigned patents to industries based on the IPC-NACE industry concordance table developed by Smoch et al. (2003). We can subsequently look at the distribution of foreign invented patents and compare this distribution with the lagging vs. leading status of the Dutch industry and the position of the countries compared to the technology frontier. For the ten years covered in the empirical analysis we identified over 20000 foreign invented patents by firms based in the Netherlands. Overall, 98% of foreign patents were invented in one of the 24 OECD countries. In cases where the Dutch industry was lagging, on average 71% of foreign ‘R&D’ (patent applications) was in countries that ranked above the Netherlands in terms of distance to the technology frontier (defined in terms of industries’ comparative R&D intensity) , whereas for leading industries this was only 14%. Similarly, if we examine the percentage of overseas R&D taking place in the top-5 countries (excluding the Netherlands) this was almost twice as high for lagging industries (36%) compared with leading industries (19%). These numbers suggest, consistent with our arguments, that firms in lagging industries are more likely to concentrate their foreign R&D in leading countries, with foreign R&D locations providing substantial knowledge sourcing opportunities, while this is much less the case for leading industries.

DISCUSSION AND CONCLUSION

The present study has shown evidence that the returns to foreign R&D can be substantial and greater than the returns to domestic R&D. Such returns, however, depend on two key contingencies. First, firms should have ample opportunity to source knowledge abroad that is not – or not to the same extent – available at home. Hence, the effects of foreign R&D are only noticeable for firms operating in industries in which the home country is lagging behind the global technology frontier, with limited potential R&D spillovers in the home country. Second, under these circumstances, the returns to foreign R&D are significantly enhanced if firms maintain investments in domestic R&D, while foreign R&D, in turn, enhances the return to domestic R&D. The broader search scope and potential for cross-fertilization and recombination due to combining foreign and domestic R&D produces a complementarity that generates productivity gains of R&D internationalization, which would not have been achieved from a sole focus on domestic R&D activities.

Our findings suggest that foreign knowledge sourcing by multinational firms and the effective combination of this knowledge with the fruits of domestic R&D enhances firms' technology development efforts to bring productivity gains at home. An important qualification is that this only occurs if firms conducting foreign R&D can benefit from foreign knowledge spillovers by exposure to a more advanced technology-intensive industry environment abroad. In industries where R&D and technology development plays a lesser role, these effects are muted or absent. We note that our results should not be taken to suggest that investing in R&D abroad by leading home country industries – in contrast to lagging industries – would always be an inappropriate strategy. While foreign R&D is, in this case, unlikely to provide domestic productivity benefits, R&D abroad is more likely to be directed at adaptation and development of existing technologies to increase the effectiveness of foreign affiliate operations – hence, increasing foreign affiliate productivity rather than productivity at home. In our analysis, we confined attention to the effects of foreign R&D on domestic productivity.

Our study informs the literature on R&D internationalization by providing systematic evidence on the returns to foreign R&D, by demonstrating that these can surpass returns to domestic R&D, and by providing evidence on the contingent presence of complementarity between foreign and domestic R&D. Of crucial importance is the relative strength of the home country environment, which has, until now, been examined only in the specific context of (learning from) exports and imports (Salomon & Jin, 2008; Winston Smith, 2014). It corroborates the notion in Winston Smith (2014) that the effects of internationalization strategies are highly contingent on the role of industries' global leadership status. The key implication for extant research on R&D internationalization by multinational firms is that the industry and home and host country contexts should be taken into account for a proper understanding of the nature of R&D investment and its performance consequences. Prior ambiguous findings on the performance effects of foreign and domestic R&D (Fors, 1997; Todo & Shimizutani, 2008) may be related to the failure to take such contingencies into account. Performance effects arise from the interplay between firm-specific capabilities, industry and country environments driving location advantages, and the different objectives pursued by foreign R&D activities – of which knowledge sourcing is gaining in importance.

In terms of managerial implications, our results suggest the need for careful analysis of the relative strength of the R&D environment abroad and domestically, and the allocation of R&D accordingly. Awareness that foreign R&D may strengthen the returns to domestic R&D and that a search for complementarities may pay off is particularly important. For policy makers, the results suggest that providing targeted incentives to firms in order to keep R&D investment at home may not always be the best policy option. Domestic welfare may instead be enhanced by firms locating R&D abroad, allowing for effective knowledge sourcing, reverse knowledge transfer, and complementary effects on domestic productivity. The implication is that international R&D can provide important benefits to home economies and can contribute to convergence in global productivity growth.

Our study has a number of limitations, which qualify the results and suggest avenues for future research. First, as noted in the introduction, although we could include key moderators of the effects of foreign R&D on firm productivity at home – domestic R&D and the lagging or leading nature of the home industry – data limitations did not allow us to examine other relevant factors and mechanisms such as the nature and scope of knowledge generated domestically and abroad, the nature of international R&D management and coordination practices, and the precise location of foreign R&D. In this sense, our study examines average effects, which could be disentangled further if such fine-grained data were available in the present context. A clear opportunity for research would be created if information on firms from R&D and innovation surveys could in the future be matched with firm-level patent indicators on inventor locations, technology profiles at home and abroad, and cross-border integration as evidenced by citations and co-inventor teams.

Second, while our empirical model had the important advantage of exploiting rich panel data on R&D expenditures at home and abroad and allowed a rich setup including the lagged dependent variable in a growth specification, data limitations did not allow us to control for other potential features of firms' time-variant technology strategies (such as R&D alliances). Third, we relied on an imperfect proxy of the global technology frontier: the position of the industry and country in OECD R&D intensity rankings. This measure has the advantage that it is well available across countries, years and industries (including services industries), but will not capture the full richness of, and variation in, knowledge sourcing environments at home and abroad. Future research could examine other indicators of distance to the technology frontier such as total factor productivity (which currently is not available for all countries, years and industries) and indicators based on patent applications and their citations. Fourth, our results apply to firms based in a small and open economy with a strong presence of multinationals; future research should explore whether similar patterns hold for firms in large countries with greater domestic R&D spillover pools. Fifth, foreign and domestic R&D are important for technology development and productivity in domestic operations as well as in overseas affiliates. While the current study focused on home country productivity effects, future work should endeavor to examine the contingent effects of geographically dispersed R&D investments on firms' global activities and performance.

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Table 1. Descriptive statistics and correlations: Lagging and Leading industries

Lagging industries (N = 5126)

	Variable	Mean	S. D.	Correlations						
				1	2	3	4	5	6	7
1	Productivity	3.89	0.48							
2	Productivity$_{t-1}$	3.87	0.46	0.81						
3	Δ Labor	0.01	0.21	-0.08	0.13					
4	Δ Investment	0.05	0.43	0.06	-0.06	0.22				
5	Domestic R&D	0.09	0.13	-0.03	-0.07	0.03	0.04			
6	Foreign R&D	0.01	0.01	-0.01	-0.01	0.03	-0.00	0.23		
7	Multinational firm	0.46	0.50	0.15	0.16	0.01	-0.01	-0.02	0.19	
8	Firm size	4.52	1.11	0.14	0.13	-0.06	0.03	-0.12	-0.06	0.29

Leading industries (N = 3532)

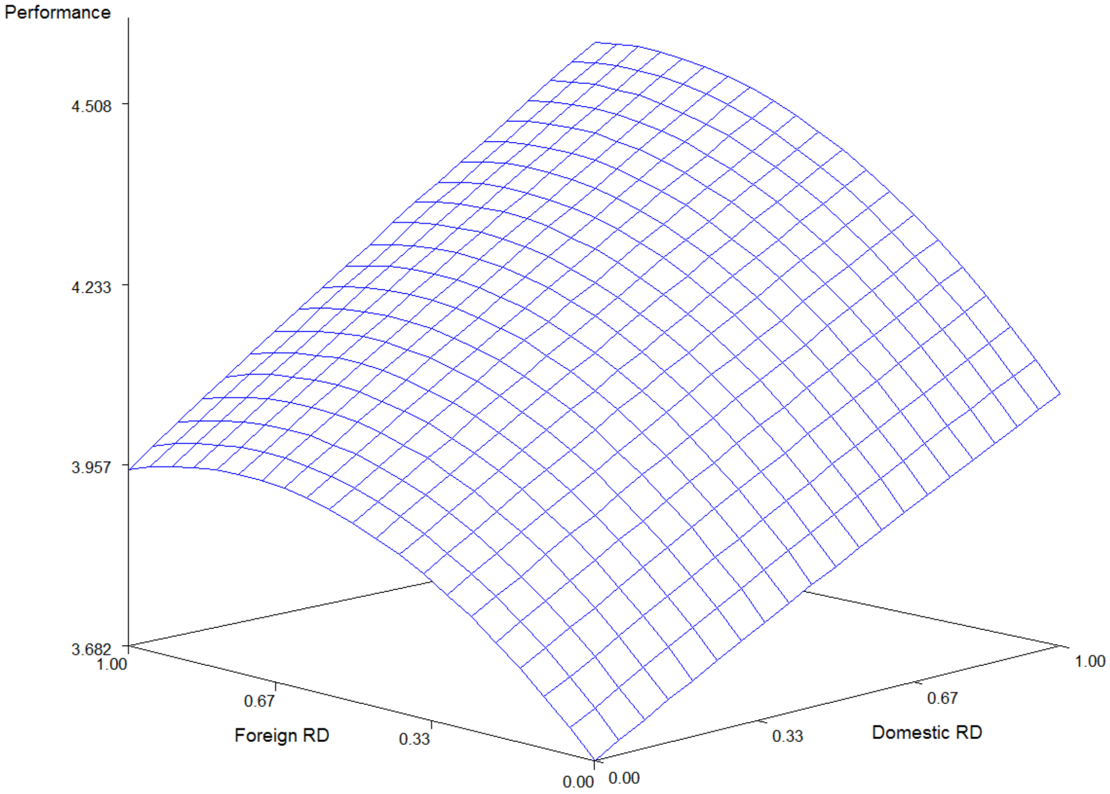
	Variable	Mean	S. D.	Correlations						
				1	2	3	4	5	6	7
1	Productivity	3.97	0.52							
2	Productivity$_{t-1}$	3.90	0.48	0.84						
3	Δ Labor	-0.00	0.23	-0.07	0.09					
4	Δ Investment	0.02	0.38	0.10	-0.04	0.33				
5	Domestic R&D	0.08	0.13	-0.03	-0.07	0.03	0.05			
6	Foreign R&D	0.01	0.01	0.01	0.01	-0.01	-0.02	0.21		
7	Multinational firm	0.50	0.50	0.12	0.12	0.01	-0.01	0.00	0.18	
8	Firm size	4.75	1.15	0.09	0.08	-0.08	-0.07	-0.10	0.02	0.35

Table 2: The Effects of Foreign and Domestic R&D on Productivity: Results of System GMM Dynamic Panel Analysis, 1995-2003

	Model 1: Lagging industries	Model 2: Leading industries
Productivity$_{t-1}$	0.48***	0.43***
	(0.06)	(0.07)
Δ Labor	-0.45***	-0.44***
	(0.06)	(0.16)
Δ Capital stock	0.14***	0.21***
	(0.03)	(0.05)
Domestic R&D	0.51***	0.45**
	(0.11)	(0.16)
Domestic R&D squared	-0.10***	-0.02
	(0.11)	(0.03)
Foreign R&D	0.97**	2.06
	(0.44)	(1.28)
Foreign R&D squared	-0.69**	0.26
	(0.28)	(9.68)
R&D domestic * R&D foreign	0.33**	-1.77
	(0.12)	(3.51)
Firm size	0.03	0.01
	(0.03)	(0.01)
Multinational firm (dummy)	0.04*	0.08***
	(0.03)	(0.02)
Time and industry dummies	included	included
Observations	5126	3532
Firms	2659	2149
Hansen test	100.11	146.50
(p-value)	(0.26)	(0.14)
Wald Chi-squared	1544.58	1183.06

Notes: One-step GMM robust standard errors in parentheses. *,**,*** indicate 10, 5 and 1 percent levels.

Figure 1. Predicted Effects of Foreign and Domestic R&D (divided by value added) on (the natural logarithm of) Productivity – Lagging industries



The Returns to Foreign R&D: Appendix

Derivation of the Empirical Model

The model from which we estimate the returns to foreign and domestic R&D builds on Lokshin, Belderbos and Carree (2008). This modeling framework allows estimating labor productivity as a function of foreign and domestic R&D from an augmented Cobb-Douglas production function for firm *i* at time *t*:

$$Y_{it} = \alpha_i L_{it}^{\beta} C_{it}^{\delta} K_{it}^{\gamma} e^{\sigma_{it}} \tag{1}$$

where Y is output, L is labor input, C is the physical capital stock and K is the knowledge (R&D) stock. The parameters β, δ, and γ are elasticities with respect to labor, physical capital, and the knowledge stock. The parameter σ_{it} is a time-variant firm-specific efficiency parameter. Dividing both sides by labor, taking logarithms and differencing the resulting equation in two consecutive periods, we obtain the equation in the growth form:

$$\Delta q_{it} = (\beta - 1)\Delta l_{it} + \delta \Delta c_{it} + \gamma \Delta k_{it} + \Delta \sigma_{it} \tag{2}$$

where $q_{it} = log(Y_{it}) - log(L_{it})$ denotes labor productivity, $\Delta q_{it} = q_{it} - q_{it-1}$ is the proportional growth in labor productivity, and with lower-case letters denoting variables in logarithms. We assume that the change in firm-specific efficiency levels is a function of past productivity, in order to allow for a gradual convergence in efficiency levels between firms. Klette (1996), for instance, shows that the empirically observed persistent productivity differences between firms require a model specification that allows for gradual convergence.

$$\Delta \sigma_{it} = \theta q_{it-1} + \varepsilon_{it} \tag{3}$$

Firms that are behind the productivity frontier are more likely to be able to record strong productivity growth through technology spillovers from frontier firms. We expect θ to fall within the interval [-1,0]. If θ is zero, there is no gradual convergence between leading firms and lagging firms; if θ is –1, complete convergence materializes in one period. To allow unobserved firm-level heterogeneity in efficiency growth and an impact of common macro-economic efficiency shocks, the error term ε_{it} in equation (3) includes year-specific intercepts λ_t in addition to serially uncorrelated measurement errors v_{it}:

$$\varepsilon_{it} = \lambda_t + v_{it} \qquad \text{for} \quad i = 1, \dots, N;\ t = 1, \dots, T \tag{4}$$

We can transform the knowledge stock portion of the specification (cf. Griffith et al., 2004, p.7; Jones, 2002, p. 233) as follows:

$$\gamma \Delta k_{it} \approx \frac{\partial Y}{\partial K} \frac{K_{i,t-1}}{Y_{i,t-1}} \frac{\Delta K_{it}}{K_{i,t-1}} \approx \varphi \frac{\Delta K_{it}}{Y_{i,t-1}} \qquad with\ \varphi = \frac{\partial Y}{\partial K} \tag{5}$$

With φ the marginal return to R&D knowledge. The change in the R&D stock is a function of investments in both domestic and foreign R&D:

$$\Delta K_{it} / Y_{i,t-1} = f(R_{it-1}^{dom} / Y_{i,t-1}, R_{it-1}^{for} / Y_{i,t-1}) = f(r_{i,t-1}^{dom}, r_{i,t-1}^{for}) \tag{6}$$

We approximate the unknown function (6) with a reduced second-order polynomial in R&D investment.[7] If the depreciation rate of the knowledge stock is small[8], we can write:

---

[7] We note that a full polynomial would add interactions between the linear term of foreign (domestic) R&D and the square term of domestic (foreign) R&D, as well as the product between the squared terms. Given the high correlations between these higher order terms, this renders identification highly problematic. We report on the results of specifications with higher order terms in the paper.

[8] Higher depreciation rates lead to an upward bias of the estimate on the rate of return (Mairesse and Sassenou, 1991). We could expand the approximation of changes in the knowledge stock by including more lags of R&D. However, findings in previous studies, e.g. Pakes and Schankerman (1984), Hall et al. (1986) and Klette and Johanson (1998), suggest that the most significant effect of R&D on productivity occurs with a one-year lag.

$$\gamma\Delta k_{it} = \varphi[\eta_1 r_{it-1}^{dom} + \eta_2 r_{it-1}^{for} + \eta_3 (r_{it-1}^{dom})^2 + \eta_4 (r_{it-1}^{for})^2 + \eta_5 r_{it-1}^{dom} r_{it-1}^{for}]$$

(7)

Sufficiently long series of capital investments are not available to us in order to construct the capital stock variable with the perpetual inventory method. Instead, we approximate the log-growth in the capital stock Δc_{it} with the log-growth in fixed capital investment. In steady state, the proportional change in the capital stock can be approximated by the proportional change in fixed capital investments (Jones, 2002).

Combining equations (2), (3), and (7) and bringing the lagged productivity term to the right-hand side, we arrive at the dynamic panel equation:

$$\begin{aligned} q_{it} &= (1+\theta)q_{it-1} + (\beta - 1)\Delta l_{it} + \delta\Delta c_{it} + \\ &\varphi[\eta_1 r_{it-1}^{dom} + \eta_2 r_{it-1}^{for} + \eta_3 (r_{it-1}^{dom})^2 + \eta_4 (r_{it-1}^{for})^2 + \eta_5 r_{it-1}^{dom} r_{it-1}^{for}] + \lambda_t + v_{it} \end{aligned} \tag{8}$$

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