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International Technology Sourcing and Knowledge Spillovers:
Evidence from OECD Countries

by Sophia Chen and Estelle Dauchy

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I N T E R N A T I O N A L M O N E T A R Y F U N D

IMF Working Paper

Research Department

International Technology Sourcing and Knowledge Spillovers; Evidence from OECD Countries

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Abstract

How much do firms benefit from foreign R&D and through what channel? We construct a global network of corporate innovation using more than 1.5 million patents granted to firms in OECD countries. We test the “international technology sourcing” hypothesis that foreign innovation activities tap into foreign R&D and improve home productivity through knowledge spillovers. We find that firms with stronger inventor presence in technology frontier countries benefit disproportionately more from their R&D. The strength of knowledge spillovers depends on the direction of technology sourcing. Knowledge externality is larger for firms in technology frontier countries than for firms in non-frontier countries.

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"knowledge flows...are invisible; they leave no paper trail by which they may be measured and tracked"

Paul Krugman (1991)

"knowledge flows do sometimes leave a paper trail, in the form of citations in patent"

Adam Jaffe et al. (1993)

I. INTRODUCTION

Many countries acknowledge that innovation is key to sustainable long-term growth. Prior studies provide evidence supporting the view that the social return of private research and development (R&D) is high due to knowledge spillovers to other parts of the economy. Despite this literature, our understanding of the mechanisms underlying knowledge spillovers is limited. Microeconomic evidence remains thin, especially in the international context.² Important unanswered questions include which countries are the main players in global innovations, how firms gain access to foreign knowledge, and how much firms benefit from foreign knowledge. This paper provides quantitative evidence on these and related questions.

We exploit a comprehensive micro data covering more than 1.5 million patents matched to firms in 34 OECD countries during 1978-2013.³ The main data sources are Worldwide Patent Statistical Database (PATSTAT) maintained by the European Patent Office (EPO) and the Orbis database by Bureau van Dijk. The patent-firm matched data provides information on the source and destination countries of the patents. The source country is the country of residence of patent inventors and the destination country is the headquarter country of the firm that owns the patent. Using this information, we construct measures of the intensity (patenting) and location (inventor country) of corporate innovation, as well as international knowledge linkages (source-destination country linkages).

We show that corporate innovation has formed a steadily strengthened global network over the past four decades (Figure 1). Three important patterns emerge. First, an increasing number of corporate innovations are carried out abroad. Second, the network has become increasingly multilateral: firms have inventor presence in an increasing number of countries over time. Third, there are dominant hubs in the network—countries where a dominant share of patents are invented. For example, 71 percent of all patents invented in 2013 are sourced from three countries: Japan, United States, and Germany (Figure 2). Patents invented in these three countries accounts for 49 percent of all foreign invented patents (Figure 3).⁴ Perhaps not coincidentally, these countries also represent the largest aggregate R&D among OECD countries (Figure 4).

² See Wieser (2005) and Swensson (2008) for a review of the literature on return to R&D. See Keller (2004) for a review of the literature on knowledge spillovers. Most existing studies on spillovers use aggregate (country- or industry- level) data or focus on firm-level data of a single source or recipient country.

³ Latvia became the 35th OECD member country in 2016 and is not included in this study.

⁴ We refer to a patent as “foreign patent” if the source country is different from the destination country.

(continued...)

The observation that close to half of foreign patents are invented in countries with the largest aggregate R&D—a common proxy for the global technology frontier—is consistent with "technology sourcing" as a means to gain access to foreign knowledge. Despite the global reach of information technology, many economists believe that knowledge spillovers are largely localized.⁵ Under this view, being geographically close to other inventors is important to learn and build from their knowledge. By setting up R&D labs abroad—especially in technology frontier countries—firms can source technology from foreign countries more effectively and improve their productivity.

We use firm-level data to test the "international technology sourcing" hypothesis that foreign innovation activities tap into foreign R&D and improve home productivity through knowledge spillovers. Following the literature, we use the presence of a firm's patent inventors in a foreign country as a proxy for the firm's foreign innovation activities. We examine whether foreign R&D has a stronger impact on the productivity of firms who has more inventor presence in foreign countries. Relative to a more aggregate approach, the firm-level approach present a number of advantages. First, knowledge linkages between countries and industries vary significantly. Firm-level data allows us to control for all home country and industry trends in innovation with fixed effects. Second, we can flexibly control for other factors that affect productivity and are correlated with the a firm's foreign research. For example, firms with more foreign innovation activities may have higher productivity simply because they also have more knowledge. These firms may also be better at using foreign knowledge in general because they have higher "absorptive capacity".

We report three main results. First, we find strong evidence of knowledge spillovers consistent with international technology sourcing. We find that firms with stronger inventor presence in technology frontier countries benefit disproportionately more from the frontiers' R&D. Second, the strength of knowledge spillovers depends on the direction of technology sourcing. Knowledge spillovers are in general stronger when technology is sourced by non-frontier countries from technology frontier countries than the other way around. Third, knowledge externality are in general larger for firms in technology frontier countries than in non-frontier countries.

Our research relates to several strands in the literature. First, it is linked to the empirical analysis of innovation location and knowledge spillovers. Pioneered by Jaffe et al. (1993), several studies have used the location of patent inventors to trace the geography of knowledge spillovers. The literature suggests that international spillovers are relatively smaller and knowledge externality occur mostly domestically (Almeida and Kogut, 1999; Audretsch and Feldman, 1996). Similar to this literature, we use patents to trace knowledge linkages. The difference is that instead of using patents as an outcome variable, we focus on firm productivity. Second, while a large literature studies the effect of foreign direct investment (FDI) on recipient countries, much less work has been done on the effect of FDI

⁵ See, for example, Audretsch and Feldman (1996), Jaffe et al. (1993), and Keller (2002).

(continued...)

on the source country.⁶ One exception is Branstetter (2006) who studies the effect of FDI on the knowledge flow of the investing firm using Japanese data. He finds that FDI increases knowledge flows both from and to the investing firms. Closest in the spirit to our analysis is Griffith et al. (2006) who show that UK firms benefit from innovative FDI to the US. The main difference between our paper and these prior contributions is that we consider global innovative FDI from a large set of countries rather than a single bilateral FDI relationship. Our results thus complement prior literature with broad-based and multilateral evidence on the mechanism driving knowledge spillovers across countries.⁷ Third, we provide new evidence on the direction of international knowledge spillovers. Except for some aggregate studies, prior studies mostly focus on knowledge diffusion from frontier countries to non-frontier countries, there is little evidence on knowledge diffusion from non-frontier countries to frontier countries. Finally, our paper is also related to a recent empirical literature on patent network using the PATSTAT data, although this literature has focused on very different questions such as environmental policies (Aghion et al., 2016), or trade (Coelli et al., 2016). The novelty of our paper compared to these prior papers is that we link patent network to the output and inputs of firms. Such comprehensive data has not been applied in the context of firm productivity so far.

Our findings support the view that innovations conducted abroad may be seen as a complement rather than substitute for innovations conducted domestically. Thus optimal policy design aimed to stimulate innovations should take into account the internationalization of innovations for at least two reasons. First, firms need to invest in innovations abroad—especially in technology frontier countries—in order to reap the full benefit of foreign knowledge. So policies that incentivize the repatriation of foreign-based innovations may compromise domestic productivity growth.⁸ Second, when evaluating the effectiveness of R&D tax policy, one should take into account the social return from global knowledge spillovers. If the domestic social return of R&D is large as prior studies suggest, its total social return is much larger when global spillovers are taken into account, in which case, the recent increase in public support to private R&D may be well justified.

Our analysis also sheds light on the long-standing question of income convergence. We find that knowledge externality for firms in non-frontier countries is smaller than for firms in technology frontier countries. This finding suggest that international knowledge spillovers may have contributed to technology and income divergence. A fruitful topic for future research is to investigate whether the economic and institutional environment can explain such differences, and why.

The remainder of the paper is organized as follows. Section II describes stylized facts on patents and innovation network. Section III presents the model and explains our econometric

⁶ See Keller (2004) for a review.

⁷ We also differ from Griffith et al. (2006) in the measurement of innovation location. Whereas Griffith et al. (2006) only considers the location of a patent's lead inventor, we use the location all inventors.

⁸ The literature also shows the positive effect of foreign direct investment (FDI) on domestic employee compensation and investment (Desai et al., 2009).

approach. Section IV describes the data and measurement. Section V presents the results. Section VI concludes.

II. PATENTS AND CORPORATE INNOVATION NETWORK: STYLIZED FACTS

Our primary data for patents is the Worldwide Patent Statistical Database (PATSTAT) maintained by the European Patent Office (EPO). PATSTAT contains bibliographic data of patents from 90 patent issuing authorities, covering close to the population of all patents worldwide. The PATSTAT data allows us to follow the geography of a firm's innovations over time. The patent documents provided by PATSTAT provide information on the address for all patent inventors, which we use to assign the source country of the innovation. In our analysis, a patent corresponds to a unique invention in the sense that filings of the same patent in multiple locations do not inflate our patent count. We date a patent based on the date of application.⁹ We also restrict our analysis to patents that firms own directly and have been granted as of 2015. Finally, we link the patent data to firms' balance sheet data using patent-firm match through the Orbis database by Bureau van Dijk.¹⁰ These steps yield a total of 1,560,694 patents matched to 14,132 publicly listed firms in OECD countries. We focus on publicly listed firms because private firms are not required to report R&D expenditure, thus information on firm-level R&D is very limited.

The global network of corporate innovation shows three important patterns. First, an increasing number of corporate innovations are carried out abroad. The increase occurs in both the extensive margin and intensive margin. For example, 8,001 firms in our sample had patents invented abroad in 2013, compared to 801 in 1978 (Figure 5). In total, these firms had 138,048 foreign patents in 2013, compared to 1,217 in 1978 (Figure 6).

Second, the network has become increasingly multilateral. The number of bilateral knowledge linkages between OECD countries increased from 132 in 1978 to 684 in 2013 (Figure 7).¹¹ Firms also have innovation presence in an increasing number of countries over time. In our sample, firms in 18 OECD countries did not have innovation presence in any foreign countries in 1978. This number has decreased to only 5 OECD countries by 2013. Countries on average sourced from 14.7 (out of 33) foreign OECD countries in 2013, compared to only 2.5 in 1978 (Figure 8). In 2013, most countries sourced from multiple foreign countries. For example, the United States and Japan sourced from all other OECD countries. Germany, Sweden, Finland, Netherlands, the United Kingdom, France, and Switzerland sourced from over 25 foreign OECD countries. 21 countries in total sourced from more than 10 foreign OECD countries (Figure 9).

⁹ Under the Paris convention, anyone who files a patent can file an identical application in another country within 12 months of the first application. Multiple filings of the same invention are identified as a "patent family" in PATSTAT. We use the application time of the first application to date a patent family.

¹⁰ We do not include patents of a firm's subsidiaries. We use the patent-firm match information as of 2015.

¹¹ We consider a bilateral knowledge linkage exists between country i and country j if firms in country i have patents invented in country j , and vice versa.

(continued...)

Third, there are dominant hubs in the network—countries where a dominant share of patents are invented. In 2013, 548,796 (35 percent) of all patents in our sample are invented in Japan, followed by 456,385 (29 percent) the United States, 227,894 (14 percent) in Korea, and 109,828 (7 percent) in Germany (Figure 10). Japan, the United States, and Germany were also three of the top source countries for foreign invented patents. In total, they account for 49 percent of all foreign invented patents in 2013 (Figure 11).¹²

III. MODEL AND METHODOLOGY

Our main interest is to estimate the effect of foreign R&D on firm productivity. Following Griliches (1979) and Griffith et al. (2006), we use a firm-level production function augmented with knowledge. The production function has a conventional Cobb-Douglas form with firm-specific and aggregate domestic and foreign R&D:

$$Y_{ijct} = Z_{it} L_{it}^{\alpha_l} K_{it}^{\alpha_k} A_{it}^{\alpha_r} DOM_{jct}^{\gamma_{i1}} FOR_{jct}^{\gamma_{i2}} \quad (1)$$

where i, j, c, t are the indexes for firm, industry, country, and year respectively; Y_{ijct} is output; Z_{it} is a productivity shifter; L_{it} is labor; K_{it} is physical capital; A_{it} is the firm's own R&D stock; DOM_{jct} and FOR_{jct} are, respectively, domestic and foreign R&D stock in the firm's industry. We use “domestic” and “foreign” to loosely refer to a single country or the aggregate of multiple countries, which we will specify later.

We are interested in how the geography of a firm's innovation affects the elasticity of output with respect to domestic and foreign R&D stocks captured by γ_{i1} and γ_{i2} respectively. We assume that γ_{i1} and γ_{i2} depend on a firm's innovation location in a linear way,

$$\begin{aligned} \gamma_{i1} &= \theta_1 + \theta_2 W_i^d, \\ \gamma_{i2} &= \varphi_1 + \varphi_2 \sum_{f \neq d} W_i^f, \end{aligned} \quad (2)$$

where W_i^d and W_i^f are the share of firm i 's domestic and foreign innovation activities respectively. We interpret a positive estimate of θ_2 as evidence of domestic knowledge spillovers and a positive estimate of φ_2 as evidence of foreign knowledge spillovers associated with technology sourcing.

We assume the productivity shifter takes the following parametric form

¹² The United Kingdom was the other top source countries for foreign patents in 2013, accounting for 13 percent of all foreign invented patents. Korea is one of the top four countries for all patents, but the majority of patents invented in Korea are by domestic firms.

$$\ln Z_{it} = \eta_1 W_i^d + \eta_1 \sum_{f \neq d} W_i^f + \delta' V_{it} + \varepsilon_{it}, \quad (3)$$

where W_i^d and W_i^f capture the direct effect of locating innovation activities abroad. V_{it} is a vector of controls such as demand shifters and ε_{it} is a stochastic error term.

We obtain our empirical model by taking natural logarithms of the production function (1). Denoting the natural logarithms of a variable X by the lower-case letter x , we have

$$y_{ijct} = z_{it} + \alpha_l l_{it} + \alpha_k k_{it} + \alpha_r a_{it} + \theta_1 dom_{jct} + \varphi_1 for_{jct} + \theta_2 W_i^d dom_{jct} + \varphi_2 \sum_{f \neq d} W_i^f for_{jct} + \eta_1 W_i^d + \eta_2 \sum_{f \neq d} W_i^f + \delta' v_{it} + \varepsilon_{it}. \quad (4)$$

We estimate (4) using a pooled ordinary least squares (OLS) method. A main concern is that the coefficients on our knowledge spillovers may reflect shocks unrelated to firm inputs and aggregate R&D. We control for such biases by including time fixed effects, industry fixed effects, country fixed effects and country-level macro variables in the z vector. Another concern is that W_i^d and W_i^f may be correlated with firm- or industry-level shocks, thus may be correlated with firm inputs. To mitigate this problem, we use presample information to construct W_i^d and W_i^f . As a result, a firm's location of innovation activity is not affected by shocks that affect firm-level input and output in the same period. The only threat to this strategy is that firms locate innovation activity in foreign countries in anticipation of positive shocks to productivity. Such biases are likely small considering that our measures are based on presample patents that are the results of R&D decisions taken many years prior to the sample period.

IV. DATA AND MEASUREMENT

The main dataset for our regression analysis is a panel of publicly listed firms in OECD countries in 20 manufacturing and services industries between 2003 and 2012.¹³ The data source is the Orbis database by Bureau van Dijk. OECD countries are a good sample of countries to study the knowledge spillovers because they represent a dominant share of patenting and R&D worldwide.¹⁴ Furthermore, there has been increasing support for private

¹³ See Appendix Table A1 for industry definition and Table A2 for variable sources and definitions.

¹⁴ For example, in 2010, 96 percent of all Triadic patent families—patent families filed at EPO, the Japan Patent Office (JPO) and the United States Patent and Trademark Office (USPTO)—are invented in OECD countries in 2009. Domestic expenditure on R&D as a percentage of GDP is on average 2.4 percent among OECD countries, higher than EU27 (1.9 percent) and BRIC countries (1.3 percent, excluding India where data is not available). Source: OECD (2013).

(continued...)

R&D among OECD countries over the last two decades (Chen and Dauchy, 2018; OECD, 2016).

We use R&D expenditure prior to 2009 to construct firm-level R&D stock from 2009 to 2013 using the permanent inventory method. We delete firms with missing values on relevant accounting information including employees, capital, operating revenue, or less than 3 years of reported R&D expenditure. These steps yield a baseline sample of 11,858 firms.

Our key variable of interest is the share of a firm's innovation activities in foreign countries, denoted by W_i^f . We construct this measure following the Griffith et al. (2006) method.¹⁵ We measure W_i^f as the proportion of the firm's total worldwide patents that are invented in foreign countries between 1997 and 2006. We use the average of the presample period to construct the location measures because a firm's geography of innovation is persistent over time. Year to year fluctuations in patenting is unlikely to reflect the change in innovation locations. We identify the location of innovation by the country of residence of patent inventors. For patents with multiple inventors, we assign the source country on a pro rata basis.¹⁶ We similarly construct the share of a firm's innovation activity in its own country, denoted by W_i^d . Because our regression analysis is from 2009 to 2013, our measures of the innovation location of firms are solely based on presample information. As discussed above, this ensures that they are not affected by shocks that affect firm-level output and inputs in the same period.¹⁷

To calculate the domestic and foreign R&D stocks in the firm's industry, we use data on R&D expenditure from various sources including the OECD, Eurostat, the National Science Foundation (NSF), and the Japanese Ministry of Internal Affairs and Communications (MIC). As with firm-level data, we use the permanent inventory method to construct R&D stocks. The advantage of using this approach is that R&D stocks are comparable across firms, industries, and countries. We do not include R&D stocks from non-OECD countries because firms in our sample have very limited knowledge linkage with non-OECD countries: Only one percent of the patents are invented in non-OECD countries. Furthermore, data on industrial-level R&D stocks are limited for non-OECD countries.

¹⁵ One difference between our measure and that in Griffith et al. (2006) is that we consider all inventors of a patent whereas Griffith et al. (2006) only considers the lead inventor.

¹⁶ For patents with multiple inventors, the pro rata share is calculated as the number of patents with inventors from a country (group) divided by the firm's total number of patents. Note that the share can be greater than one if inventors of the same patent are from different countries.

¹⁷ We focus on the post Global Financial Crisis period of 2009-2013 because the crisis may have potentially large and non-linear effects on productivity, which is out of the scope of our analysis. For similar considerations, use the pre-crisis period 1996-2006 (or 1987-1996 in our robustness check) for our pre-sample innovative location measure.

V. RESULTS

We organize our results as follows. We start by aggregating all countries in our sample in two groups based on aggregate R&D. This allows us to discuss the overall direction and effect of international technology sourcing from technology frontier countries and to non-frontier countries, and vice versa. The underlying assumption is that countries with more aggregate knowledge are closer to the technology frontier. The group of technology frontier countries include Japan (JP), Germany (DE), and the United States (US); the group of non-frontier countries include all other OECD countries. To better understand the multilateral nature of international technology sourcing, we then disaggregate results by each of the technology frontier countries. Finally, we provide robustness checks to examine whether our interpretation of patent share as representing the location of innovation activities is robust to alternative hypotheses and measurement issues.

A. Summary statistics

We present summary statistics in Table 1 for all firms, Table 2 for firms in technology frontier countries, Table 3 for firms in non-frontier countries, and Tables 4-6 for firms Germany, Japan, and the United States separately. Because these firms are publicly listed on a stock market, they tend to be innovative compared to an average firm, consistent with prior literature. Firms in our sample on average have 498 patents invented in technology frontier countries and 2,208 patents invented in non-frontier countries. Firms in technology frontier countries on average have more patents than firms in non-frontier countries. Firms in technology frontier countries on average have 662 patents invented in technology frontier countries and 2,983 patents invented in non-frontier countries, whereas firms in non-frontier countries on average have 236 patents invented in technology frontier countries and 964 patents invented in non-frontier countries.

Table 7 summarizes the average patents per firm by source and destination countries. On average, German firms hold more patents (9,057) than the average firm in the OECD (2,705), and more patents than Japanese (2,681) or U.S. firms (3,894). An average firm in OECD has about 20 percent of patents from technology frontier countries.

B. Baseline results

Table 8 reports results for firms in technology frontier countries. Table 9 reports results for firms in non-frontier countries. Column 1 shows a standard constant return to scale production function in labor and capital. The independent variable is firm output measured by the ratio of operating revenue to capital.¹⁸ Column 2 augments the model with aggregate R&D stocks. Columns 3 and 4 add our measures for innovation locations and their interaction with aggregate R&D stocks. The measures of innovation location are aggregated by technology frontiers and non-frontier countries, calculated as the proportion of a firm's total patents that are invented in technology frontier countries (denoted by $W^{frontier}_i$) and other

¹⁸ We use alternative output measures such as the sales to capital ratio or value added to capital ratio, and the results do not affect the gist of our findings.

countries (denoted by W^{other}_i) countries respectively between 1997 and 2006. The cross-interaction terms of innovation location and aggregate R&D are our main variables of interest. Column 4 also adds a battery of country-level variables capturing macroeconomic conditions, including GDP per capita, total factor productivity, and CPI inflation rate.¹⁹ All columns include country, industry, and year fixed effects.

In Tables 8 and 9, the coefficient on the labor-capital ratio is similar across specifications and close to aggregate labor share found in the literature. The labor share is smaller for firms in technology frontier countries (0.429) than in non-frontier countries (0.673), suggesting that firms in non-frontier countries are more labor intensive on average, consistent with the literature.²⁰ The estimated elasticity with respect to firm-specific R&D is positive and significant, suggesting a private return to R&D of about 18 percent for firms in technology frontier countries, which is very close to prior studies based on advanced countries.²¹ The return of R&D for firms in non-frontier countries is lower at 3.6 percent. Turning to our variables of interest, the interaction terms between innovation location and aggregate R&D stocks in technology frontier countries are significant at the 5-percent level across all specifications.

Besides the overall positive effect, the results show some interesting patterns in its direction and size. First, the interaction terms between innovation location and aggregate R&D stocks in non-frontier countries are not significant. Moreover, the spillovers from technology frontier countries' R&D to firms in these countries is larger than those to firms in non-frontier countries. One possible explanation to this difference is that domestic knowledge spillovers are easier than foreign knowledge spillovers. So, our estimation may simply be capturing domestic spillovers. An alternative explanation is that firms in technology frontier countries are better at absorbing knowledge, foreign and domestic alike. We will investigate these possibilities later using more disaggregated data.

C. Examining the multilateral and bilateral relationships

To further investigate the country origin of knowledge spillovers, we separately estimate the spillovers associated with technology sourcing from the technology frontier countries. In other words, we separate a firm's innovation activities in the three technology frontier countries, as well as corresponding interactions with aggregate R&D. Tables 10 and 11 show the results for firms in technology frontier countries and non-frontier countries, respectively. Results for firms in technology frontier countries show that the positive spillovers effect reported in Table 8 mainly reflect spillovers from Japan, followed by Germany. The coefficients on the interaction term with Japan aggregate R&D are positive and significant at the 1-percent level. It is larger than the coefficients on the interaction term with German

¹⁹ The source of GDP per capita and CPI inflation rate is the World Bank's World Development Index. The source of total factor productivity is the Penn World Table.

²⁰ Previous papers also find that labor share is lower in industries with higher TFP (Griffith et al. 2006).

²¹ Griffith et al. (2006) find a private excess rate of return among UK firms of about 14 percent on average. Griliches (1992) surveys the literature and shows a return range from 10 to over 50 percent.

aggregate R&D (positive and significant at the 5-percent level) and those with U.S. aggregate R&D (not significant).

The results for firms in non-frontier countries display a somewhat different picture, especially with regards to the role of the United States and Germany. Table 11 shows that for firms in non-frontier countries, the strongest spillovers effect comes from the United States. The coefficient on the interaction term with US R&D is 0.1, much larger than that from Table 8. This is followed by interaction term with Japanese R&D at about 0.08. In contrast, the interaction term with Germany R&D is not significant.

One may question whether the overall positive spillovers among technology frontier countries simply reflect domestic spillovers. To answer this question, we separate the sample of firms in technology frontier countries and distinguish domestic from foreign spillovers by source country. Table 12 reports the results. Columns 1, 2, and 3 show results for German firms, Japanese firms, and U.S. firms respectively. Different from Table 8, here we estimate all bilateral relationships between the technology frontier countries. For example, the interaction terms $W^{JP}_i * Ln(RD)^{JP}_{c,j,t}$ and $W^{US}_i * Ln(RD)^{US}_{c,j,t}$ in column 1 capture spillovers from Japanese and U.S. aggregate R&D to German firms. Our results show interesting differences between the three technology frontier countries. Column 1 shows that for German firms, spillovers from Japan is positive and significant at the 1-percent level, but spillovers from the United States is not significant. Column 2 shows that for Japanese firms, spillovers from Germany is positive and significant at the 1-percent level and spillovers from the United States is positive and significant at the 10-percent level. Column 3 shows that for U.S. firms, spillovers from Germany and Japan are both positive and significant at the 1-percent level. Turning to domestic spillovers, the interaction term of innovation location and domestic R&D is positive and significant at the 1-percent level for Japanese firms. It is not significant for German firms, suggesting that locating innovations domestically is not important for domestic spillovers for these firms. Interestingly, the interaction term of innovation location and domestic R&D is positive and significant for U.S. firms, suggesting that U.S. firms that locate more innovation domestically benefit proportionally less from domestic R&D. Overall, these results suggest our baseline result of the positive effect from technology sourcing among the technology frontier countries indeed reflects foreign spillovers for German and U.S. firms. For Japanese firms, it reflects both foreign and domestic spillovers.

Interesting differences also exist in the bilateral relationship between technology frontier and non-frontier countries. In our sample, thirteen non-frontier countries have bilateral relationship with all three frontier countries; six have more than 200 observations, which we use to estimate bilateral foreign spillovers. Our results suggest that frontier countries have positive spillovers to five of these six countries.²² Nevertheless, the source countries of foreign spillovers differ. For example, Japan and the United States are the main source for

²² See Appendix Table A3 for full regression results and Appendix Table A4 for a summary of results on bilateral spillovers that are statistically significant.

(continued...)

Finland, France, and the United Kingdom; whereas Germany is the main source for Australia and Korea.²³

Finally, we distinguish domestic spillovers from foreign spillover for all countries in our sample.²⁴ The results are shown in Table 13s. Column 1 reports the results for firms in technology frontier countries, column 2 for firms in non-frontier countries. Column 1 shows that for firms in technology frontier countries, the interaction term of innovation location and foreign R&D is positive and significant at the 5-percent level. The interaction term of innovation location and domestic R&D is positive and significant at the 10-percent level. It is about two-thirds the size of the foreign interaction term. This result suggests that foreign spillovers are more important than domestic spillovers for firms in technology frontier countries. For firms in non-frontier countries, column 2 shows that neither domestic or foreign technology driven spillover are significant. This result together with our baseline in Table 9 suggest that firms in non-frontier countries mostly benefit from technology frontier countries and much less so from other foreign countries.

D. Extensions

We consider several extensions to our main results. First, we investigate the possibility that firms may locate patents abroad for tax considerations. We examine whether profiting shifting can provide an explanation to why the spillovers effect from non-frontier countries is small in our baseline. Second, we use an alternative measure for firms' innovation locations using the total number of patents rather than patent shares. It addresses the concern that our baseline measure may simply reflect heterogeneous absorptive capacity of firms. Third, we investigate the robustness of our results with respect to the sample period of our location measure.

Profit shifting

In our baseline results, our interpretation of the source of a firm's patent inventors is that it reflects the location of innovation in a country. One concern is that firms locate their patents in a foreign country to take advantage of favorable tax treatment on intellectual properties or overall firm profits. Under this view, the location of intellectual property—including patents—is used strategically by firms to set transfer prices or use cost sharing agreements to shift profits. If this is the case, it would work against us finding strong knowledge spillovers because patents do not reflect a firm's foreign innovations and international technology sourcing. To test this possibility, we exclude three countries that are identified as tax havens in the literature—Ireland, Luxembourg, and Switzerland.²⁵ Excluding these three countries, the group of non-frontier countries becomes 28 countries (hereafter non-tax-haven non-

²³ Our result on positive spillovers from the United States to the United Kingdom is consistent with Griffith et al. 2006.

²⁴ The foreign and domestic innovation location terms (W^{dom}_i and W^{for}_i) terms are not collinear because W^{for} reflects the proportion of the firm's innovation in OECD foreign countries but not in non-OECD countries.

²⁵ See Hines (2010) and Gravelle (2009).

frontier countries). Our results are presented in Tables 14 and 15, respectively for firms in technology frontier countries and in non-tax-haven non-frontier countries. In both samples, the interaction term with the aggregate R&D of technology frontier countries is almost identical to the baseline in Tables 8 and Table 9 respectively. The interaction terms with non-tax-haven non-frontier countries' aggregate R&D are not significant, similar to the baseline. Overall, profit shifting to tax havens countries does not seem to be an important explanation to why spillovers from non-frontier countries is relatively small.

Absorptive capacity

In our baseline, we use the share of patents invented in a country to measure innovation location. One concern is that firms with a higher share of foreign innovation activities are more innovative. So, the spillovers effect in our baseline result simply reflects the *absorptive capacity* of firms. In other words, more innovative firms absorb foreign knowledge more easily, regardless of technology sourcing. To investigate this possibility, we use an alternative measure that directly captures a firm's total innovation: the total number patents. The assumption is that firms with more patents also have higher absorptive capacity.

The results are presented in Table 16. Columns 1 to 3 present results for firms in technology frontier countries, and the last three columns present results for firms in non-frontier countries. For ease of comparison, columns 1 and 4 repeat the results from our benchmark regressions shown in column 4 of Tables 8 and 9, respectively for the two samples. Columns 2 and 5 replace our baseline location measure (W) with the alternative measure calculated as the firm's total number of patents (N , in thousands). For firms in technology frontier countries, the interaction term with the number of patents from technology frontier countries is positive and significant at the 1-percent level. However, when we combined both sets of variables, as shown in columns 3, the coefficient on the alternative measure becomes much smaller and significant only at the 10-percent level. In contrast, the interaction term with our baseline location measure ($W^{frontier}$) remains positive and significant and of similar magnitude as the baseline. Similarly, for firms in non-frontier countries, column 6 shows when we combined both sets of variables, the interaction term with the number of patents is not significant but the interaction term our baseline location measure remains significant and similar magnitude as the baseline. These results suggest that our baseline measure is more highly correlated with technology sourcing than the alternative measure. After controlling for absorptive capacity, our baseline result on the effect of technology sourcing remains.

Presample innovation location

To alleviate the concern that innovation locations are endogenous to firm output, we use patents in the presample period of 1997-2006 to calculate firms' innovation location in the baseline. To further mitigate the endogeneity problem arising from the fact that firms may innovate abroad in anticipation of positive shocks to productivity, we replace our benchmark measure with one (denoted by $W2$) that is based on patents from a much earlier period (1986-1996). The results are presented in Appendix Tables A5 and A6, respectively for firms in technology frontier and non-frontier countries. We find similar results with this alternative

measure. The interaction terms with the aggregate R&D of technology frontier countries remain positive and significant for both sample.

VI. CONCLUSION

In this paper, we use a comprehensive data to analyze the global network of corporate innovation, which has so far not been applied in the context of knowledge spillovers and firm productivity. Overall, we find strong evidence of international knowledge spillovers consistent with technology sourcing among OECD countries. Firms with stronger inventor presence in technology frontier countries benefit disproportionately more from their R&D. The evidence is broad-based, although its strength depends on the direction of technology sourcing. These results are consistent with the idea that knowledge externality is partially localized due to its tacit nature. Our findings underscore the importance of innovative FDI, especially in technology frontier countries.

Our results have interesting implications for policy. Optimal policy design aimed to stimulate innovation should take into account the benefit of global innovation. From the perspectives of technology frontier countries, the global knowledge externality is potentially large; from the perspective of non-frontier countries, outward innovative FDI should be encouraged and viewed as complements to domestic innovations.

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Figure 1. Innovation Network (1978-2013)

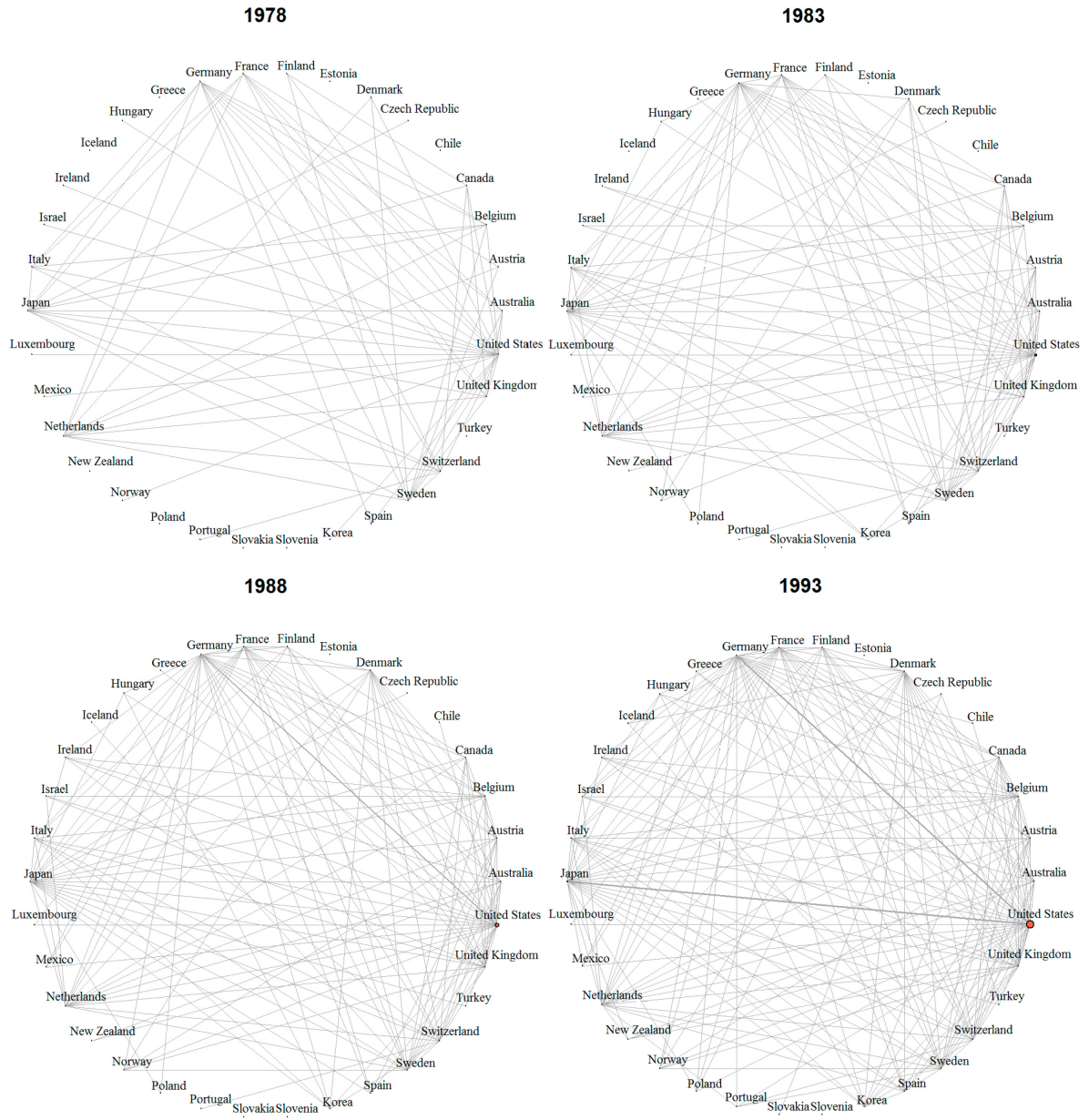
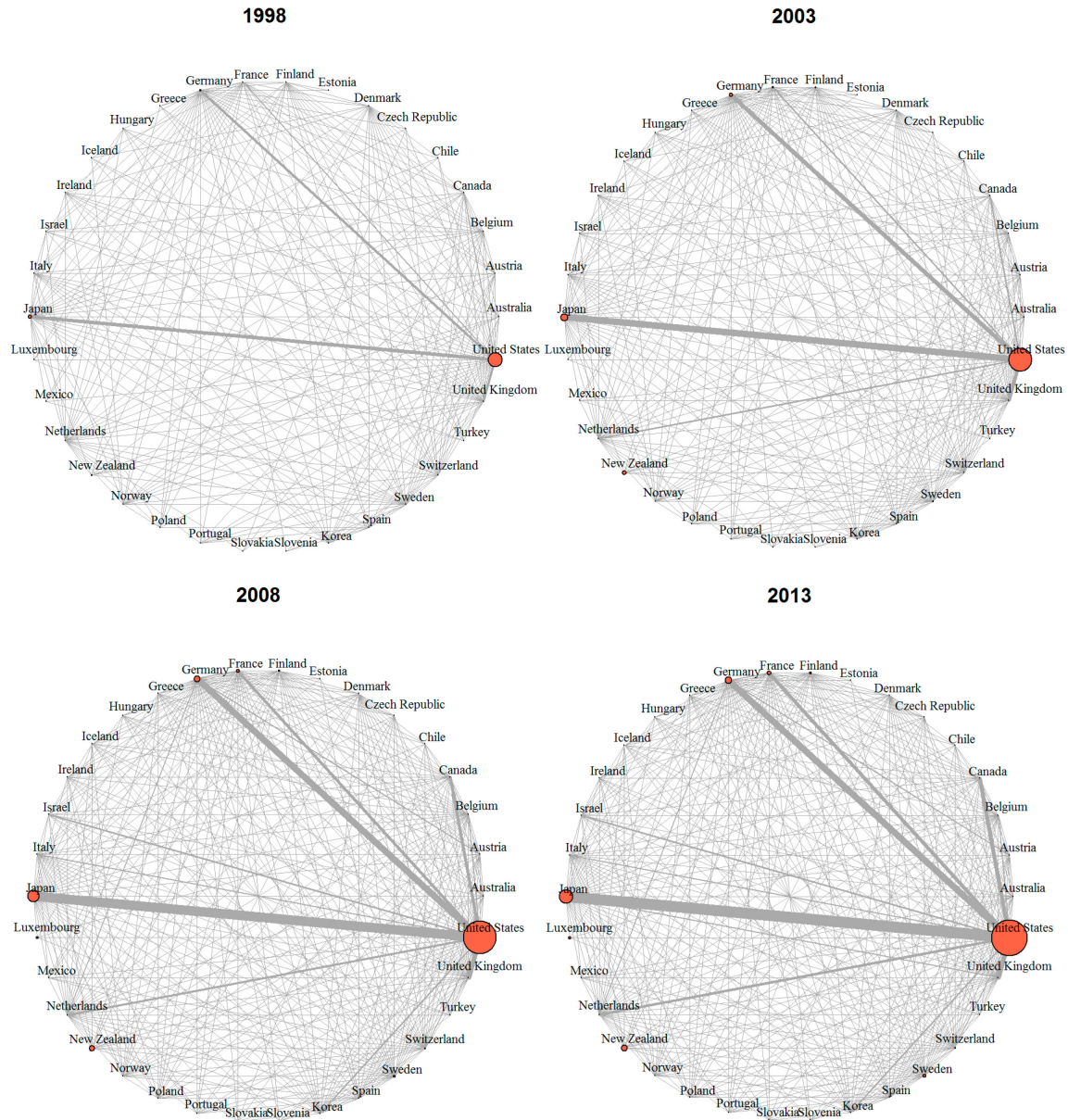
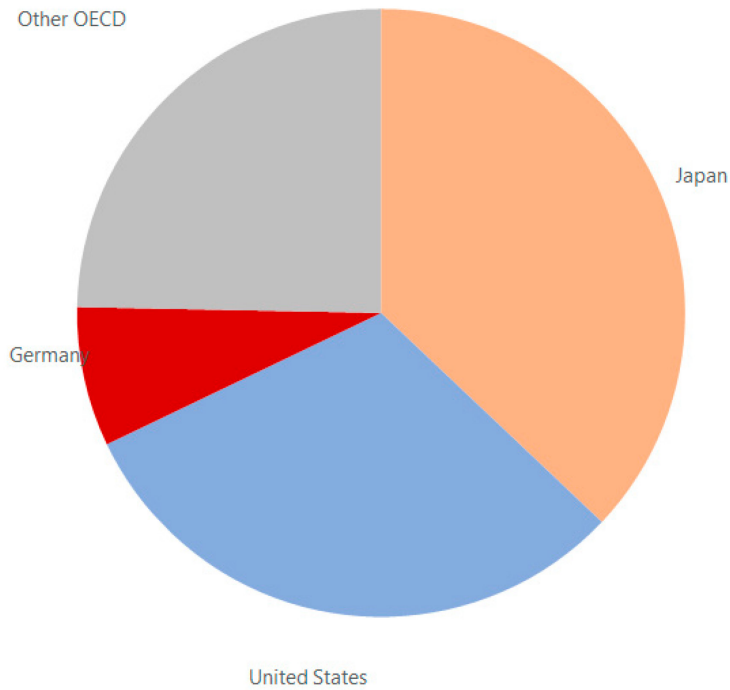


Figure 1. Innovation Network (1978-2013) (cont')



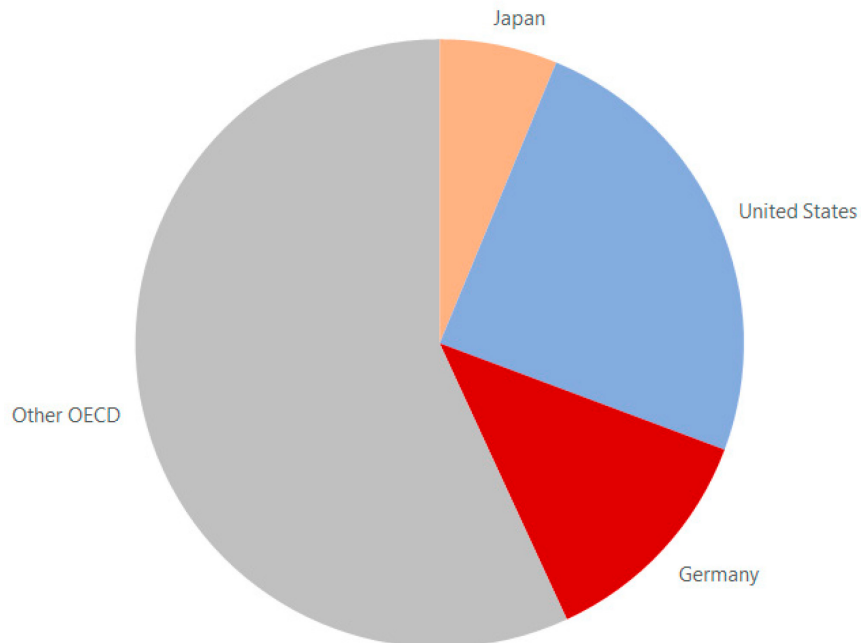
Notes: This figure plots source and destination countries of patents granted to firms in 34 OECD countries during 1978-2013. The source country is the country of residence of patent inventors and the destination country is the headquarter country of the firm that owns the patent. For patents with multiple inventors, we assign source countries on a pro rata basis. For any country i and country $j \neq i$, we calculate the total number of patents granted to country i that are invented in country j , and vice versa. The line weight is the average of the two directions. The size of a vertex represents the total number of patents invented in a country. Source: PATSTAT, Orbis, and authors' calculations.

Figure 2. Total Patents by Source Country (2013)



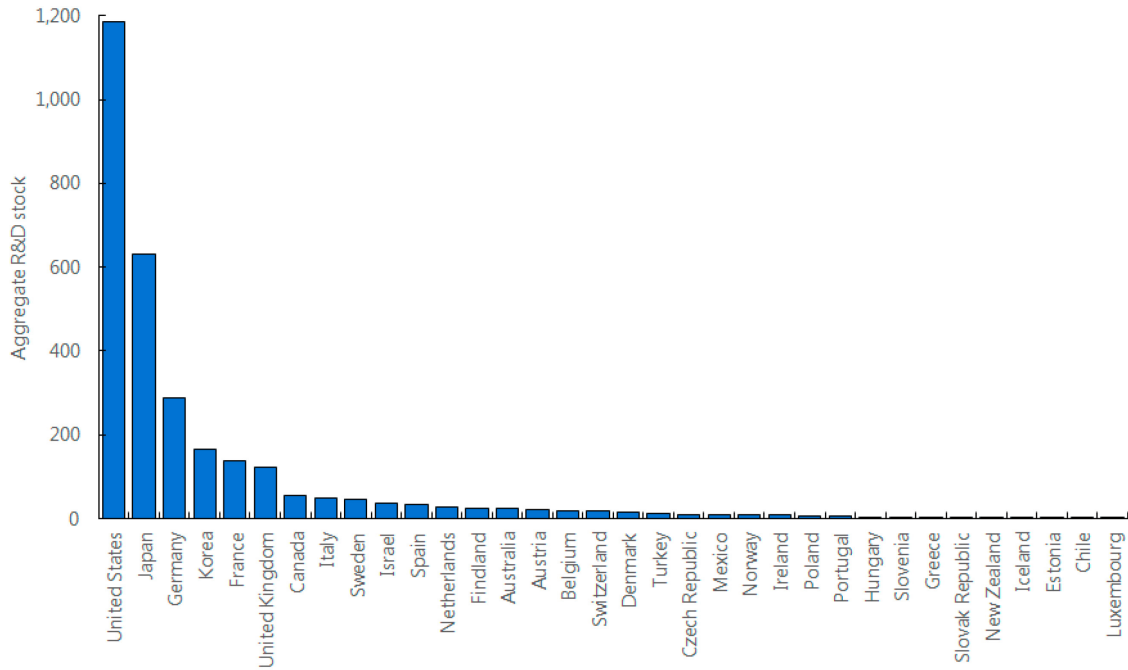
Notes: This figure plots the source country of all patents in 2013 that are matched to publicly listed firms in 34 OECD countries. Source: PATSTAT, Orbis, and authors' calculations.

Figure 3. Foreign Patents by Source Country (2013)



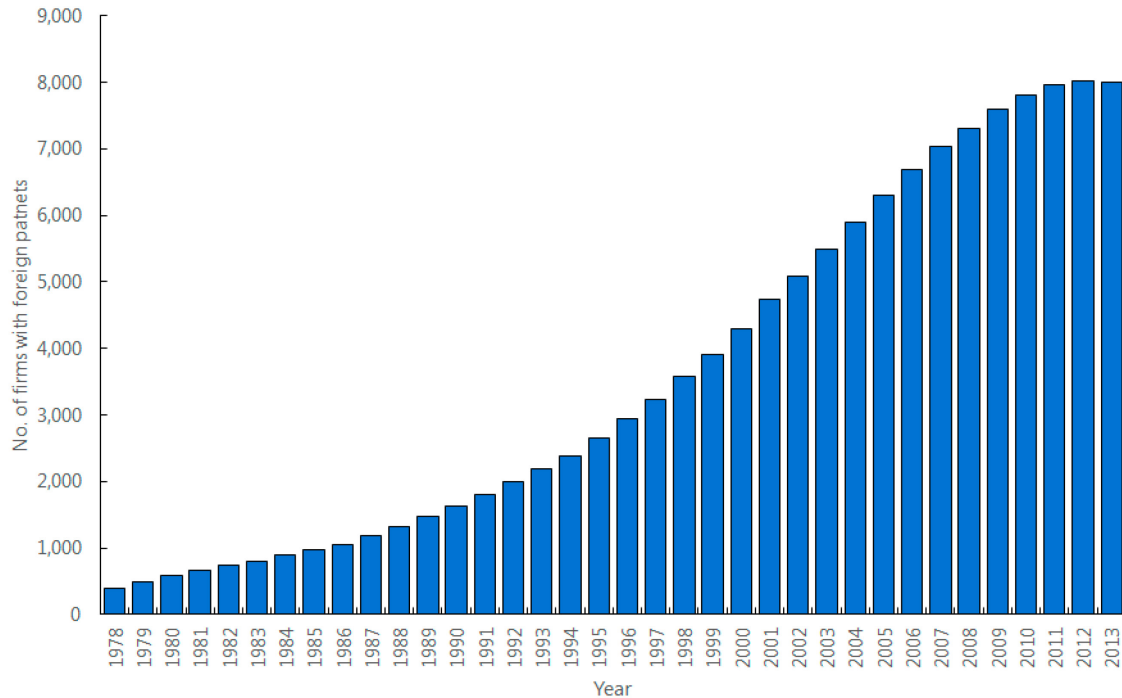
Notes: This figure plots the source country of all foreign patents in 2013 owned by publicly listed firms in 34 OECD countries. We refer to a patent as "foreign patent" if the source country is different from the destination country. Source: PATSTAT, Orbis, and authors' calculations.

Figure 4. Aggregate R&D Stock, 2013



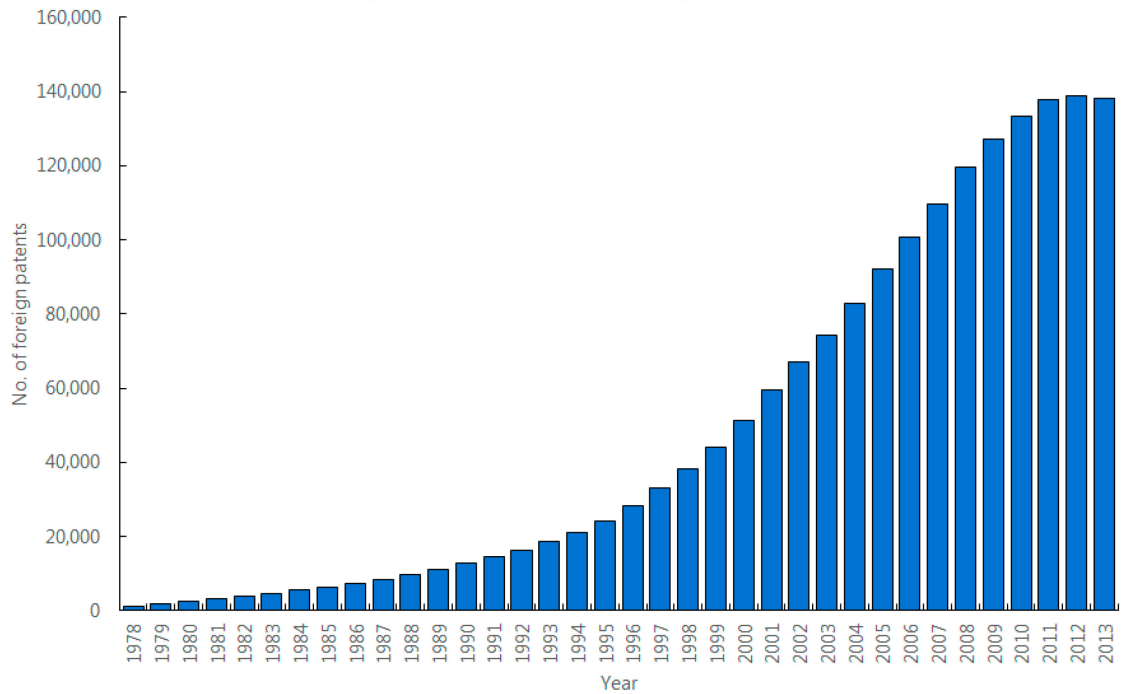
Notes: This figure aggregate R&D stock in 2013. R&D stocks are computed from R&D expenditure using the permanent inventory method. Source: OECD, Eurostat, National Science Foundation, Japanese Ministry of Internal Affairs and Communications, and authors' calculations.

Figure 5. Number of Firms with Foreign Patents



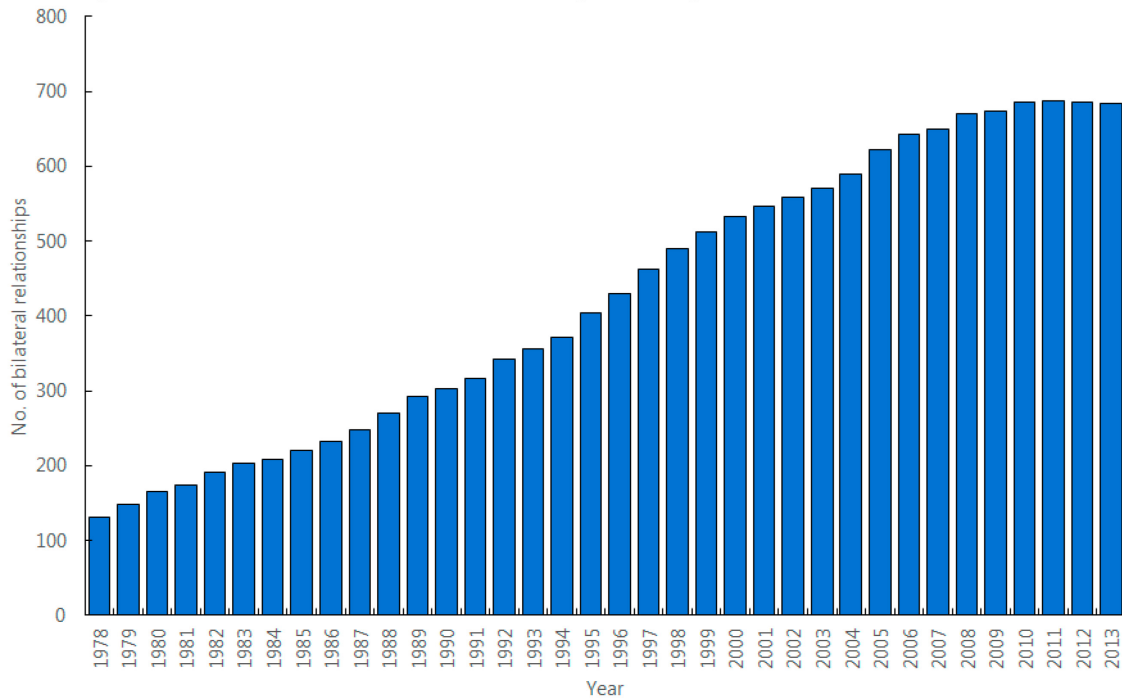
Notes: This figure plots the number of publicly listed firms in OECD countries with foreign patents. We refer to a patent as "foreign patent" if the source country is different from the destination country. Source: PATSTAT, Orbis, and authors' calculations.

Figure 6. Number of Foreign Patents



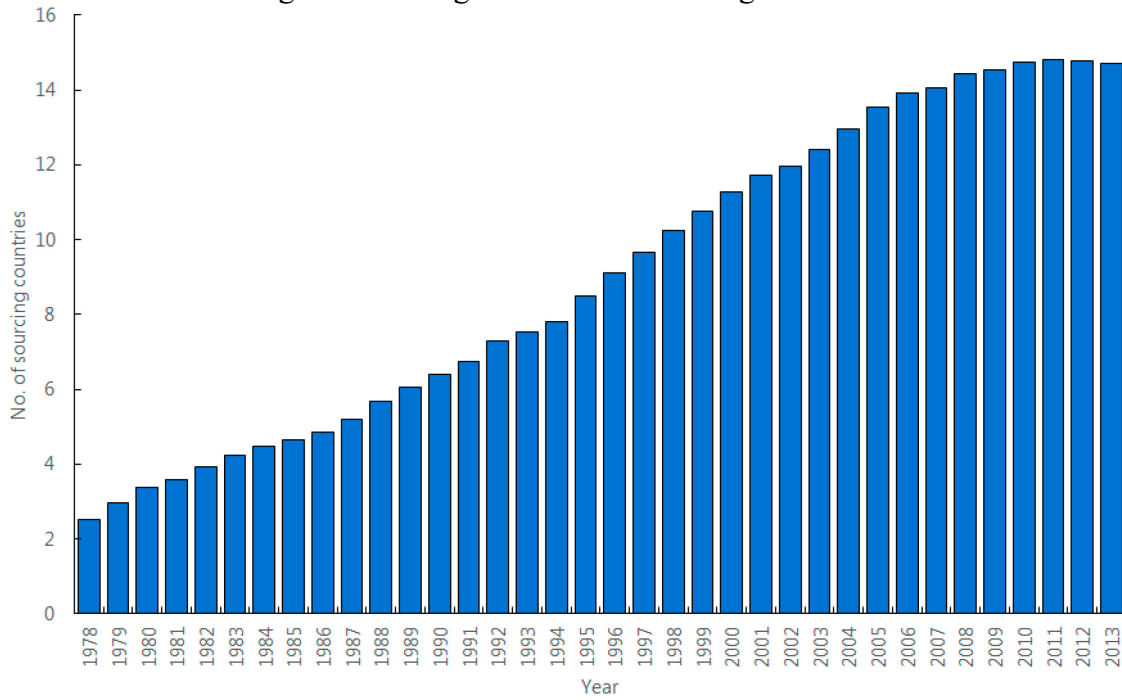
Notes: This figure plots the number of foreign patents owned by publicly listed firms in OECD. We refer to a patent as “foreign patent” if the source country is different from the destination country. Source: PATSTAT, Orbis, and authors’ calculations.

Figure 7. Number of Bilateral Knowledge Linkages Between OECD Countries



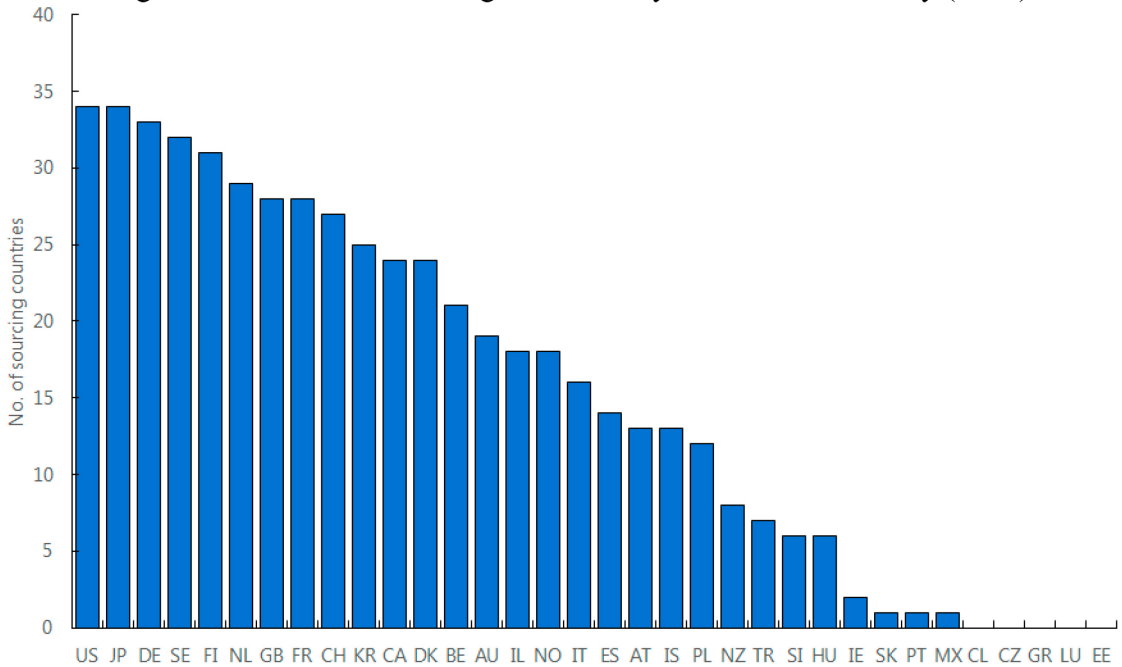
Notes: This figure plots the number of bilateral knowledge linkages between OECD countries. We consider a bilateral knowledge linkage exists between country i and country j if firms in country i have patents invented in country j , and vice versa. Source: PATSTAT, Orbis, and authors’ calculations.

Figure 8. Average Number of Sourcing Countries



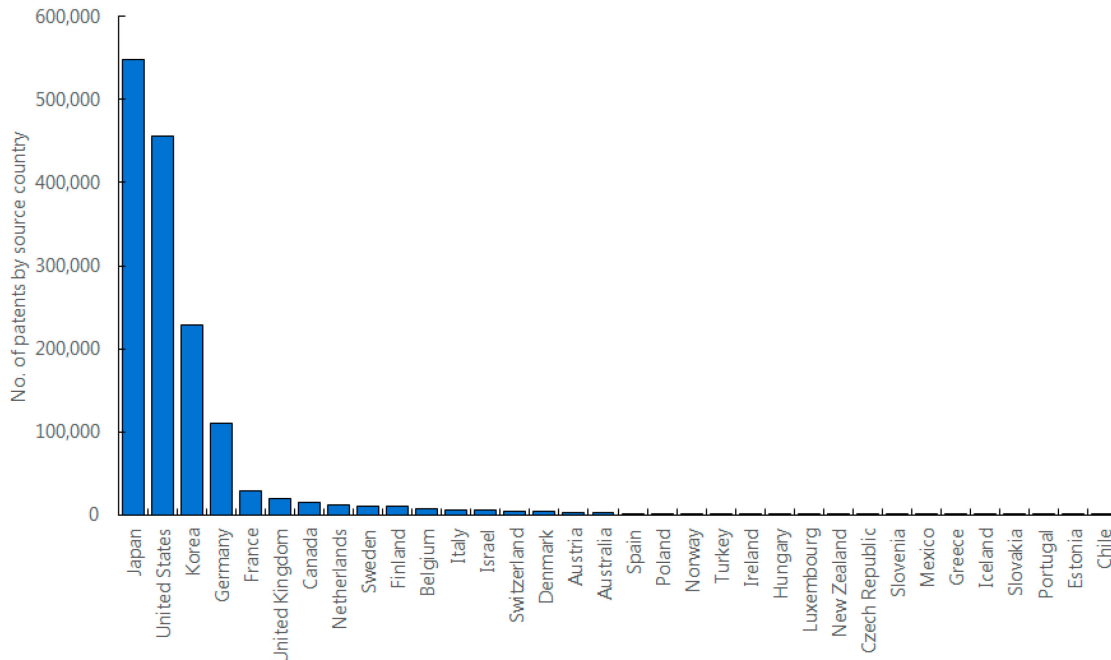
Notes: This figure plots the number of other OECD countries a country sources from over 1978-2013. Source: PATSTAT, Orbis, and authors' calculations.

Figure 9. Number of Sourcing Countries by Destination Country (2013)



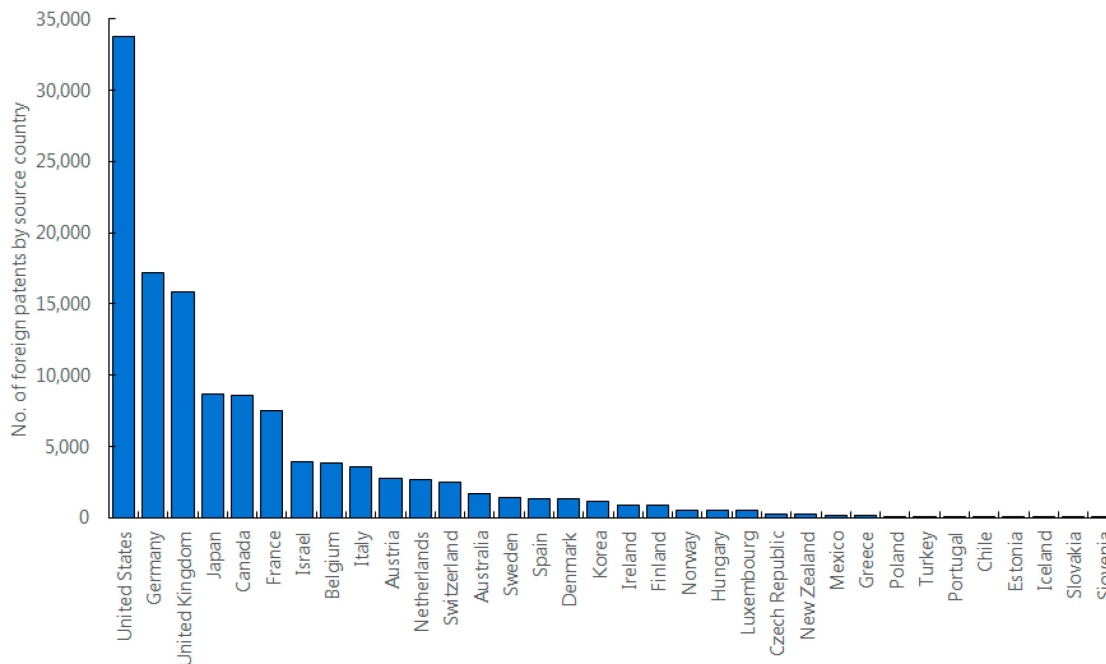
Notes: This figure plots the number of other OECD countries a country sources from in 2013. Source: PATSTAT, Orbis, and authors' calculations.

Figure 10. Number of Patents by Source Country (2013)



Notes: This figure plots the number of patents by source country in 2013. Source: PATSTAT, Orbis, and authors' calculations.

Figure 11. Number of Foreign Patents by Source Country (2013)



Notes: This figure plots the number of foreign patents by source country in 2013. We refer to a patent as "foreign patent" if the source country is different from the destination country. Source: PATSTAT, Orbis, and authors' calculations.

Table 1: Summary Statistics, All Countries

| <i>Variables:</i> | Obs | Mean | Std. Dev. | Min | Max |
|--|--------|--------|-----------|---------|-----------|
| $\ln\left(\frac{Y}{K}\right)_{i,t}$ | 22,043 | 1.344 | 2.403 | -11.513 | 8.882 |
| $\ln\left(\frac{L}{K}\right)_{i,t}$ | 22,043 | -3.795 | 1.463 | -12.089 | 3.700 |
| $\ln(RD)_{i,t}$ | 22,043 | 9.499 | 2.546 | -0.176 | 17.402 |
| $\ln(RD)^{frontier}_{c,j,t}$ | 22,043 | 11.613 | 0.935 | 9.212 | 12.716 |
| $\ln(RD)^{other}_{c,j,t}$ | 22,043 | 10.641 | 0.933 | 8.036 | 12.024 |
| $W^{frontier}_i$ | 22,043 | 0.698 | 0.862 | 0.000 | 3.000 |
| W^{other}_i | 22,043 | 0.994 | 2.553 | 0.000 | 29.000 |
| $W^{frontier}_i * \ln(RD)^{frontier}_{c,j,t}$ | 22,043 | 8.182 | 10.214 | 0.000 | 38.235 |
| $W^{other}_i * \ln(RD)^{other}_{c,j,t}$ | 22,043 | 10.628 | 27.741 | 0.000 | 337.937 |
| $W2^{frontier}_i$ | 22,043 | 0.541 | 0.856 | 0.000 | 3.000 |
| $W2^{other}_i$ | 22,043 | 0.801 | 2.506 | 0.000 | 29.000 |
| $W2^{frontier}_i * \ln(RD)^{frontier}_{c,j,t}$ | 22,043 | 6.329 | 10.118 | 0.000 | 38.235 |
| $W2^{other}_i * \ln(RD)^{other}_{c,j,t}$ | 22,043 | 8.535 | 27.157 | 0.000 | 337.937 |
| $N^{frontier}_i$ (thousands) | 22,043 | 0.498 | 4.518 | 0.000 | 173.699 |
| N^{other}_i (thousands) | 22,043 | 2.208 | 28.364 | 0.000 | 1100.094 |
| $N^{frontier}_i * \ln(RD)^{frontier}_{c,j,t}$ | 22,043 | 5.895 | 53.013 | 0.000 | 1963.225 |
| $N^{other}_i * \ln(RD)^{other}_{c,j,t}$ | 22,043 | 23.708 | 306.157 | 0.000 | 12714.680 |

Table 2: Summary Statistics: Frontier Countries

| <i>Variables:</i> | Obs | Mean | Std. Dev. | Min | Max |
|--|--------|--------|-----------|---------|-----------|
| $\ln\left(\frac{Y}{K}\right)_{i,t}$ | 13,572 | 1.203 | 2.794 | -11.513 | 8.412 |
| $\ln\left(\frac{L}{K}\right)_{i,t}$ | 13,572 | -3.752 | 1.450 | -11.513 | 3.700 |
| $\ln(RD)_{i,t}$ | 13,572 | 10.018 | 2.477 | 0.786 | 17.402 |
| $\ln(RD)^{frontier}_{c,j,t}$ | 13,572 | 11.638 | 0.918 | 9.212 | 12.716 |
| $\ln(RD)^{other}_{c,j,t}$ | 13,572 | 10.644 | 0.910 | 8.036 | 12.024 |
| $W^{frontier}_i$ | 13,572 | 0.982 | 0.868 | 0.000 | 3.000 |
| W^{other}_i | 13,572 | 1.027 | 2.853 | 0.000 | 29.000 |
| $W^{frontier}_i * \ln(RD)^{frontier}_{c,j,t}$ | 13,572 | 11.507 | 10.317 | 0.000 | 38.235 |
| $W^{other}_i * \ln(RD)^{other}_{c,j,t}$ | 13,572 | 10.967 | 30.850 | 0.000 | 330.427 |
| $W2^{frontier}_i$ | 13,572 | 0.768 | 0.926 | 0.000 | 3.000 |
| $W2^{other}_i$ | 13,572 | 0.915 | 2.785 | 0.000 | 29.000 |
| $W2^{frontier}_i * \ln(RD)^{frontier}_{c,j,t}$ | 13,572 | 8.968 | 10.950 | 0.000 | 38.235 |
| $W2^{other}_i * \ln(RD)^{other}_{c,j,t}$ | 13,572 | 9.727 | 30.021 | 0.000 | 330.427 |
| $N^{frontier}_i$ (thousands) | 13,572 | 0.662 | 4.680 | 0.000 | 115.439 |
| N^{other}_i (thousands) | 13,572 | 2.983 | 30.912 | 0.000 | 1077.429 |
| $N^{frontier}_i * \ln(RD)^{frontier}_{c,j,t}$ | 13,572 | 7.842 | 55.493 | 0.000 | 1384.402 |
| $N^{other}_i * \ln(RD)^{other}_{c,j,t}$ | 13,572 | 32.311 | 346.601 | 0.000 | 12714.680 |

Table 3: Summary Statistics: Non-Frontier Countries

| <i>Variables:</i> | Obs | Mean | Std. Dev. | Min | Max |
|---|-------|--------|-----------|---------|-----------|
| $Ln(\frac{Y}{K})_{i,t}$ | 8,471 | 1.570 | 1.563 | -11.513 | 8.882 |
| $Ln(\frac{L}{K})_{i,t}$ | 8,471 | -3.863 | 1.481 | -12.089 | 2.098 |
| $Ln(RD)_{i,t}$ | 8,471 | 8.667 | 2.432 | -0.176 | 17.093 |
| $Ln(RD)^{frontier}_{c,j,t}$ | 8,471 | 11.573 | 0.961 | 9.212 | 12.716 |
| $Ln(RD)^{other}_{c,j,t}$ | 8,471 | 10.635 | 0.969 | 8.036 | 12.024 |
| $W^{frontier}_i$ | 8,471 | 0.241 | 0.622 | 0.000 | 3.000 |
| W^{other}_i | 8,471 | 0.941 | 1.980 | 0.000 | 28.000 |
| $W^{frontier}_i * Ln(RD)^{frontier}_{c,j,t}$ | 8,471 | 2.856 | 7.405 | 0.000 | 38.235 |
| $W^{other}_i * Ln(RD)^{other}_{c,j,t}$ | 8,471 | 10.085 | 21.848 | 0.000 | 337.937 |
| $W2^{frontier}_i$ | 8,471 | 0.178 | 0.566 | 0.000 | 3.000 |
| $W2^{other}_i$ | 8,471 | 0.619 | 1.964 | 0.000 | 28.000 |
| $W2^{frontier}_i * Ln(RD)^{frontier}_{c,j,t}$ | 8,471 | 2.101 | 6.728 | 0.000 | 38.235 |
| $W2^{other}_i * Ln(RD)^{other}_{c,j,t}$ | 8,471 | 6.626 | 21.661 | 0.000 | 337.937 |
| $N^{frontier}_i$ (thousands) | 8,471 | 0.236 | 4.232 | 0.000 | 173.699 |
| N^{other}_i (thousands) | 8,471 | 0.964 | 23.665 | 0.000 | 1100.094 |
| $N^{frontier}_i * Ln(RD)^{frontier}_{c,j,t}$ | 8,471 | 2.775 | 48.619 | 0.000 | 1963.225 |
| $N^{other}_i * Ln(RD)^{other}_{c,j,t}$ | 8,471 | 9.925 | 226.132 | 0.000 | 10375.210 |

Table 4: Summary Statistics: Germany (DE)

| <i>Variables:</i> | Obs | Mean | Std. Dev. | Min | Max |
|---|-----|--------|-----------|--------|----------|
| $Ln(\frac{Y}{K})_{i,t}$ | 812 | 2.043 | 1.172 | -2.553 | 8.412 |
| $Ln(\frac{L}{K})_{i,t}$ | 812 | -3.415 | 1.253 | -8.704 | -0.048 |
| $Ln(RD)_{i,t}$ | 812 | 10.425 | 2.568 | 3.568 | 17.093 |
| $Ln(RD)^{DE}_{c,j,t}$ | 812 | 9.390 | 1.136 | 6.129 | 11.479 |
| $Ln(RD)^{other}_{c,j,t}$ | 812 | 10.695 | 0.930 | 8.036 | 12.024 |
| W^{DE}_i | 812 | 0.484 | 0.463 | 0.000 | 1.000 |
| W^{other}_i | 812 | 2.055 | 4.785 | 0.000 | 29.000 |
| $W^{DE}_i * Ln(RD)^{DE}_{c,j,t}$ | 812 | 4.682 | 4.555 | 0.000 | 11.495 |
| $W^{other}_i * Ln(RD)^{other}_{c,j,t}$ | 812 | 22.286 | 52.477 | 0.000 | 321.222 |
| $W2^{DE}_i$ | 812 | 0.279 | 0.424 | 0.000 | 1.000 |
| $W2^{other}_i$ | 812 | 1.752 | 4.602 | 0.000 | 29.000 |
| $W2^{DE}_i * Ln(RD)^{DE}_{c,j,t}$ | 812 | 2.699 | 4.159 | 0.000 | 11.495 |
| $W2^{other}_i * Ln(RD)^{other}_{c,j,t}$ | 812 | 18.955 | 50.329 | 0.000 | 321.222 |
| N^{DE}_i | 812 | 0.380 | 2.072 | 0.000 | 24.749 |
| N^{other}_i | 812 | 7.972 | 56.104 | 0.000 | 717.724 |
| $N^{DE}_i * Ln(RD)^{DE}_{c,j,t}$ | 812 | 3.965 | 21.626 | 0.000 | 257.275 |
| $N^{other}_i * Ln(RD)^{other}_{c,j,t}$ | 812 | 87.921 | 620.680 | 0.000 | 7949.959 |

Table 5: Summary Statistics: Japan (JP)

| <i>Variables:</i> | Obs | Mean | Std. Dev. | Min | Max |
|---|-------|--------|-----------|--------|----------|
| $\text{Ln}\left(\frac{Y}{K}\right)_{i,t}$ | 6,241 | 1.430 | 1.012 | -1.172 | 8.310 |
| $\text{Ln}\left(\frac{L}{K}\right)_{i,t}$ | 6,241 | -4.332 | 1.171 | -7.699 | 2.842 |
| $\text{Ln}(\text{RD})_{i,t}$ | 6,241 | 9.829 | 2.405 | 0.786 | 17.402 |
| $\text{Ln}(\text{RD})_{c,j,t}^{\text{JP}}$ | 6,241 | 10.086 | 1.167 | 7.496 | 11.584 |
| $\text{Ln}(\text{RD})_{c,j,t}^{\text{other}}$ | 6,241 | 10.496 | 0.954 | 8.036 | 12.024 |
| W_i^{JP} | 6,241 | 0.662 | 0.449 | 0.000 | 1.000 |
| W_i^{other} | 6,241 | 0.474 | 1.591 | 0.000 | 19.000 |
| $W_i^{\text{JP}} * \text{Ln}(\text{RD})_{c,j,t}^{\text{JP}}$ | 6,241 | 6.780 | 4.706 | 0.000 | 11.599 |
| $W_i^{\text{other}} * \text{Ln}(\text{RD})_{c,j,t}^{\text{other}}$ | 6,241 | 4.996 | 16.977 | 0.000 | 229.314 |
| $W2_i^{\text{JP}}$ | 6,241 | 0.517 | 0.473 | 0.000 | 1.000 |
| $W2_i^{\text{other}}$ | 6,241 | 0.465 | 1.588 | 0.000 | 19.000 |
| $W2_i^{\text{JP}} * \text{Ln}(\text{RD})_{c,j,t}^{\text{JP}}$ | 6,241 | 5.320 | 4.940 | 0.000 | 11.599 |
| $W2_i^{\text{other}} * \text{Ln}(\text{RD})_{c,j,t}^{\text{other}}$ | 6,241 | 4.907 | 16.940 | 0.000 | 229.314 |
| N_i^{JP} | 6,241 | 0.248 | 1.603 | 0.000 | 27.304 |
| N_i^{other} | 6,241 | 1.997 | 21.140 | 0.000 | 354.956 |
| $N_i^{\text{JP}} * \text{Ln}(\text{RD})_{c,j,t}^{\text{JP}}$ | 6,241 | 2.652 | 17.352 | 0.000 | 299.507 |
| $N_i^{\text{other}} * \text{Ln}(\text{RD})_{c,j,t}^{\text{other}}$ | 6,241 | 21.007 | 225.087 | 0.000 | 4194.340 |

Table 6: Summary Statistics: United States (US)

| <i>Variables:</i> | Obs | Mean | Std. Dev. | Min | Max |
|---|-------|--------|-----------|---------|-----------|
| $\text{Ln}\left(\frac{Y}{K}\right)_{i,t}$ | 6,519 | 0.882 | 3.855 | -11.513 | 8.066 |
| $\text{Ln}\left(\frac{L}{K}\right)_{i,t}$ | 6,519 | -3.239 | 1.506 | -11.513 | 3.700 |
| $\text{Ln}(\text{RD})_{i,t}$ | 6,519 | 10.147 | 2.519 | 0.840 | 17.387 |
| $\text{Ln}(\text{RD})_{c,j,t}^{\text{US}}$ | 6,519 | 11.283 | 0.976 | 7.675 | 12.246 |
| $\text{Ln}(\text{RD})_{c,j,t}^{\text{other}}$ | 6,519 | 10.780 | 0.840 | 8.036 | 12.024 |
| W_i^{US} | 6,519 | 0.588 | 0.449 | 0.000 | 1.000 |
| W_i^{other} | 6,519 | 1.428 | 3.330 | 0.000 | 28.000 |
| $W_i^{\text{US}} * \text{Ln}(\text{RD})_{c,j,t}^{\text{US}}$ | 6,519 | 6.663 | 5.113 | 0.000 | 12.265 |
| $W_i^{\text{other}} * \text{Ln}(\text{RD})_{c,j,t}^{\text{other}}$ | 6,519 | 15.274 | 35.977 | 0.000 | 330.427 |
| $W2_i^{\text{US}}$ | 6,519 | 0.328 | 0.429 | 0.000 | 1.000 |
| $W2_i^{\text{other}}$ | 6,519 | 1.241 | 3.273 | 0.000 | 28.000 |
| $W2_i^{\text{US}} * \text{Ln}(\text{RD})_{c,j,t}^{\text{US}}$ | 6,519 | 3.669 | 4.812 | 0.000 | 12.265 |
| $W2_i^{\text{other}} * \text{Ln}(\text{RD})_{c,j,t}^{\text{other}}$ | 6,519 | 13.192 | 35.239 | 0.000 | 330.427 |
| N_i^{US} | 6,519 | 0.209 | 1.444 | 0.000 | 38.480 |
| N_i^{other} | 6,519 | 3.306 | 34.146 | 0.000 | 1077.429 |
| $N_i^{\text{US}} * \text{Ln}(\text{RD})_{c,j,t}^{\text{US}}$ | 6,519 | 2.366 | 16.570 | 0.000 | 449.535 |
| $N_i^{\text{other}} * \text{Ln}(\text{RD})_{c,j,t}^{\text{other}}$ | 6,519 | 36.205 | 391.362 | 0.000 | 12714.680 |

Table 7: Average Number of Patents

| Destination Country | Source Country | | | | | |
|------------------------|----------------|-----|-----|--------------------|------------------------|-------|
| | DE | JP | US | Frontier countries | Non-frontier countries | All |
| DE | 380 | 336 | 370 | 1,086 | 7,972 | 9,057 |
| JP | 200 | 248 | 235 | 683 | 1,997 | 2,681 |
| US | 195 | 184 | 209 | 588 | 3,306 | 3,894 |
| Frontier countries | 208 | 223 | 231 | 662 | 2,983 | 3,645 |
| Non-frontier countries | 77 | 76 | 83 | 236 | 964 | 1,200 |
| All | 158 | 166 | 174 | 498 | 2,208 | 2,705 |

Notes: This table shows the average number of patents per firm by destination and source country. Frontier countries include Germany (DE), Japan (JP), and the United States (US). Non-frontier countries include all other OECD countries.

Table 8. R&D Augmented Production Function: Frontier Countries

| Dependent variable: $\ln\left(\frac{Y}{K}\right)_{i,t}$ | (1) | (2) | (3) | (4) |
|---|---------------------|---------------------|---------------------|---------------------|
| $\ln\left(\frac{L}{K}\right)_{i,t}$ | 0.429*** [0.035] | 0.429*** [0.035] | 0.434*** [0.035] | 0.435*** [0.035] |
| $\ln(RD)_{i,t}$ | 0.183*** [0.011] | 0.183*** [0.011] | 0.165*** [0.014] | 0.165*** [0.014] |
| $\ln(RD)^{frontier}_{c,j,t}$ | | 0.653 [0.724] | 0.591 [0.725] | 0.545 [0.732] |
| $\ln(RD)^{other}_{c,j,t}$ | | -0.539 [0.573] | -0.539 [0.573] | -0.507 [0.580] |
| $W^{frontier}_i$ | | | -0.847** [0.375] | -0.848** [0.375] |
| W^{other}_i | | | 0.009 [0.051] | 0.009 [0.051] |
| $W^{frontier}_i * \ln(RD)^{frontier}_{c,j,t}$ | | | 0.082** [0.033] | 0.082** [0.033] |
| $W^{other}_i * \ln(RD)^{other}_{c,j,t}$ | | | -0.001 [0.005] | -0.001 [0.005] |
| Country FE | Y | Y | Y | Y |
| Year FE | Y | Y | Y | Y |
| Industry-year FE | Y | Y | Y | Y |
| Country controls | N | N | N | Y |
| Observations | 13,572 | 13,572 | 13,572 | 13,572 |
| R-squared | 0.136 | 0.136 | 0.136 | 0.137 |

Notes: Frontier countries include Germany, Japan, and the United States. $\ln(Y/K)$ is the natural logarithm of revenue divided by capital. $\ln(L/K)$ is the natural logarithm of employee divided by capital. W is the share of a firm's innovation activities in a country (group). $\ln(RD)$ is the natural logarithm of R&D stock. The superscript denotes the level of aggregation. The superscript denotes the level of aggregation. All columns are estimated by OLS with country, year, and industry-year fixed effects. ***, **, and * indicate statistical significance at the 1, 5, and 10 percent levels, respectively. Country controls include: GDP per capita, total factor productivity, and CPI inflation.

Table 9. R&D Augmented Production Function: Non-Frontier Countries

| Dependent variable: $\ln\left(\frac{Y}{K}\right)_{i,t}$ | (1) | (2) | (3) | (4) |
|---|----------|----------|-----------|-----------|
| $\ln\left(\frac{L}{K}\right)_{i,t}$ | 0.673*** | 0.673*** | 0.675*** | 0.676*** |
| | [0.018] | [0.018] | [0.018] | [0.018] |
| $\ln(RD)_{i,t}$ | 0.036*** | 0.036*** | 0.032*** | 0.032*** |
| | [0.005] | [0.005] | [0.006] | [0.006] |
| $\ln(RD)^{frontier}_{c,j,t}$ | | 0.160 | 0.144 | 0.131 |
| | | [0.361] | [0.361] | [0.361] |
| $\ln(RD)^{other}_{c,j,t}$ | | -0.139 | -0.133 | -0.124 |
| | | [0.280] | [0.280] | [0.281] |
| $W^{gr^3}_i$ | | | -0.761*** | -0.760*** |
| | | | [0.291] | [0.291] |
| W^{other}_i | | | 0.049 | 0.049 |
| | | | [0.052] | [0.052] |
| $W^{frontier}_i * \ln(RD)^{frontier}_{c,j,t}$ | | | 0.067** | 0.067** |
| | | | [0.026] | [0.026] |
| $W^{other}_i * \ln(RD)^{other}_{c,j,t}$ | | | -0.004 | -0.004 |
| | | | [0.005] | [0.005] |
| Country FE | Y | Y | Y | Y |
| Year FE | Y | Y | Y | Y |
| Industry-year FE | Y | Y | Y | Y |
| Country controls | N | N | N | Y |
| Observations | 8,679 | 8,679 | 8,679 | 8,679 |
| R-squared | 0.410 | 0.410 | 0.412 | 0.412 |

Notes: Frontier countries include Germany, Japan, and the United States. $\ln(Y/K)$ is the natural logarithm of revenue divided by capital. $\ln(L/K)$ is the natural logarithm of employee divided by capital. W is the share of a firm's innovation activities in a country (group). $\ln(RD)$ is the natural logarithm of R&D stock. The superscript denotes the level of aggregation. The superscript denotes the level of aggregation. All columns are estimated by OLS with country, year, and industry-year fixed effects. ***, **, and * indicate statistical significance at the 1, 5, and 10 percent levels, respectively. Country controls include: GDP per capita, total factor productivity, and CPI inflation.

Table 10. R&D Augmented Production Function with Disaggregated Source Countries: Frontier Countries

| Dependent variable: $\ln\left(\frac{Y}{K}\right)_{i,t}$ | (1) | (2) | (3) | (4) |
|---|----------|----------|-----------|-----------|
| $\ln\left(\frac{L}{K}\right)_{i,t}$ | 0.429*** | 0.429*** | 0.422*** | 0.423*** |
| | [0.035] | [0.035] | [0.035] | [0.035] |
| $\ln(RD)_{i,t}$ | 0.183*** | 0.183*** | 0.162*** | 0.162*** |
| | [0.011] | [0.011] | [0.014] | [0.014] |
| $\ln(RD)^{DE}_{c,j,t}$ | | 2.935* | 2.489 | 2.471 |
| | | [1.721] | [1.710] | [1.685] |
| $\ln(RD)^{JP}_{c,j,t}$ | | -6.876* | -5.891 | -5.885 |
| | | [4.009] | [3.985] | [3.930] |
| $\ln(RD)^{US}_{c,j,t}$ | | -11.456 | -9.669 | -9.666 |
| | | [7.121] | [7.083] | [6.984] |
| $\ln(RD)^{other}_{c,j,t}$ | | 11.510 | 9.710 | 9.718 |
| | | [7.088] | [7.049] | [6.952] |
| W^{DE}_i | | | -1.040*** | -1.036*** |
| | | | [0.307] | [0.307] |
| W^{JP}_i | | | -2.158*** | -2.159*** |
| | | | [0.318] | [0.318] |
| W^{US}_i | | | 2.038*** | 2.035*** |
| | | | [0.485] | [0.485] |
| W^{other}_i | | | -0.077 | -0.077 |
| | | | [0.050] | [0.050] |
| $W^{DE}_i * \ln(RD)^{DE}_{c,j,t}$ | | | 0.106*** | 0.105*** |
| | | | [0.035] | [0.035] |
| $W^{JP}_i * \ln(RD)^{JP}_{c,j,t}$ | | | 0.174*** | 0.174*** |
| | | | [0.033] | [0.033] |
| $W^{US}_i * \ln(RD)^{US}_{c,j,t}$ | | | -0.135*** | -0.134*** |
| | | | [0.046] | [0.046] |
| $W^{other}_i * \ln(RD)^{other}_{c,j,t}$ | | | 0.008 | 0.008 |
| | | | [0.005] | [0.005] |
| Country FE | Y | Y | Y | Y |
| Year FE | Y | Y | Y | Y |
| Industry-year FE | Y | Y | Y | Y |
| Country controls | N | N | N | Y |
| Observations | 13,572 | 13,572 | 13,572 | 13,572 |
| R-squared | 0.136 | 0.136 | 0.145 | 0.145 |

Notes: Frontier countries include Germany (DE), Japan (JP), and the United States (US). $\ln(Y/K)$ is the natural logarithm of revenue divided by capital. $\ln(L/K)$ is the natural logarithm of employee divided by capital. W is the share of a firm's innovation activities in a country (group). $\ln(RD)$ is the natural logarithm of R&D stock. The superscript denotes the level of aggregation. The superscript denotes the level of aggregation. All columns are estimated by OLS with country, year, and industry-year fixed effects. ***, **, and * indicate statistical significance at the 1, 5, and 10 percent levels, respectively. Country controls include: GDP per capita, total factor productivity, and CPI inflation.

Table 11. R&D Augmented Production Function with Disaggregated Source Countries: Non-Frontier Countries

| Dependent variable: $\ln\left(\frac{Y}{K}\right)_{i,t}$ | (1) | (2) | (3) | (4) |
|---|----------|----------|----------|----------|
| $\ln\left(\frac{L}{K}\right)_{i,t}$ | 0.673*** | 0.673*** | 0.678*** | 0.678*** |
| | [0.018] | [0.018] | [0.018] | [0.018] |
| $\ln(RD)_{i,t}$ | 0.036*** | 0.036*** | 0.030*** | 0.029*** |
| | [0.005] | [0.005] | [0.006] | [0.006] |
| $\ln(RD)^{DE}_{c,j,t}$ | | 0.536 | 0.584 | 0.649 |
| | | [1.044] | [1.047] | [1.048] |
| $\ln(RD)^{JP}_{c,j,t}$ | | -1.323 | -1.435 | -1.593 |
| | | [2.427] | [2.435] | [2.438] |
| $\ln(RD)^{US}_{c,j,t}$ | | -2.146 | -2.347 | -2.623 |
| | | [4.309] | [4.321] | [4.324] |
| $\ln(RD)^{other}_{c,j,t}$ | | 2.175 | 2.370 | 2.648 |
| | | [4.283] | [4.296] | [4.299] |
| W^{DE}_i | | | -0.385 | -0.388 |
| | | | [0.330] | [0.330] |
| W^{JP}_i | | | -0.778** | -0.776** |
| | | | [0.382] | [0.382] |
| W^{US}_i | | | -1.075** | -1.076** |
| | | | [0.441] | [0.441] |
| W^{gr31}_i | | | 0.072 | 0.073 |
| | | | [0.049] | [0.049] |
| $W^{DE}_i * \ln(RD)^{DE}_{c,j,t}$ | | | 0.032 | 0.032 |
| | | | [0.039] | [0.039] |
| $W^{JP}_i * \ln(RD)^{JP}_{c,j,t}$ | | | 0.085** | 0.085** |
| | | | [0.038] | [0.038] |
| $W^{US}_i * \ln(RD)^{US}_{c,j,t}$ | | | 0.108** | 0.108** |
| | | | [0.042] | [0.043] |
| $W^{other}_i * \ln(RD)^{other}_{c,j,t}$ | | | -0.007 | -0.007 |
| | | | [0.005] | [0.005] |
| Country FE | Y | Y | Y | Y |
| Year FE | Y | Y | Y | Y |
| Industry-year FE | Y | Y | Y | Y |
| Country controls | N | N | N | Y |
| Observations | 8,679 | 8,679 | 8,679 | 8,679 |
| R-squared | 0.410 | 0.410 | 0.412 | 0.412 |

Notes: Frontier countries include Germany (DE), Japan (JP), and the United States (US). $\ln(Y/K)$ is the natural logarithm of revenue divided by capital. $\ln(L/K)$ is the natural logarithm of employee divided by capital. W is the share of a firm's innovation activities in a country (group). $\ln(RD)$ is the natural logarithm of R&D stock. The superscript denotes the level of aggregation. The superscript denotes the level of aggregation. All columns are estimated by OLS with country, year, and industry-year fixed effects. ***, **, and * indicate statistical significance at the 1, 5, and 10 percent levels, respectively. Country controls include: GDP per capita, total factor productivity, and CPI inflation.

Table 12. R&D Augmented Production Function with Disaggregated Source Countries: DE, JP, US

| <i>Dependent variable: $\text{Ln}(\frac{Y}{K})_{i,t}$</i> | (1) | (2) | (3) |
|--|-----------|-----------|-----------|
| <i>Sample</i> | DE | JP | US |
| $\text{Ln}(\frac{L}{K})_{i,t}$ | 0.743*** | 0.622*** | 0.457*** |
| | [0.019] | [0.008] | [0.043] |
| $\text{Ln}(\text{RD})_{i,t}$ | 0.000 | 0.006 | 0.333*** |
| | [0.010] | [0.005] | [0.023] |
| $\text{Ln}(\text{RD})^{DE}_{c,j,t}$ | -0.121*** | -0.285*** | -0.015 |
| | [0.042] | [0.012] | [0.075] |
| $\text{Ln}(\text{RD})^{JP}_{c,j,t}$ | 0.009 | -0.016 | -0.600*** |
| | [0.029] | [0.016] | [0.058] |
| $\text{Ln}(\text{RD})^{US}_{c,j,t}$ | -0.031 | 0.101*** | 0.407*** |
| | [0.034] | [0.011] | [0.108] |
| $\text{Ln}(\text{RD})^{other}_{c,j,t}$ | 0.245*** | 0.248*** | 0.204*** |
| | [0.040] | [0.017] | [0.074] |
| W^{DE}_i | 0.490 | -0.437*** | -2.299*** |
| | [0.337] | [0.142] | [0.614] |
| W^{JP}_i | -3.610*** | -0.606*** | -2.652*** |
| | [0.650] | [0.145] | [0.792] |
| W^{US}_i | 0.370 | -0.256** | 9.711*** |
| | [0.489] | [0.128] | [1.163] |
| W^{other}_i | -0.089* | -0.033 | -0.157** |
| | [0.046] | [0.038] | [0.063] |
| $W^{DE}_i * \text{Ln}(\text{RD})^{DE}_{c,j,t}$ | -0.055 | 0.042*** | 0.243*** |
| | [0.036] | [0.015] | [0.070] |
| $W^{JP}_i * \text{Ln}(\text{RD})^{JP}_{c,j,t}$ | 0.326*** | 0.051*** | 0.239*** |
| | [0.059] | [0.015] | [0.083] |
| $W^{US}_i * \text{Ln}(\text{RD})^{US}_{c,j,t}$ | -0.043 | 0.020* | -0.761*** |
| | [0.046] | [0.012] | [0.105] |
| $W^{other}_i * \text{Ln}(\text{RD})^{other}_{c,j,t}$ | 0.010** | 0.005 | 0.010* |
| | [0.004] | [0.004] | [0.006] |
| Country FE | Y | Y | Y |
| Year FE | Y | Y | Y |
| Country controls | Y | Y | Y |
| Observations | 1,042 | 7,819 | 8,049 |
| R-squared | 0.735 | 0.679 | 0.108 |

Notes: Frontier countries include Germany (DE), Japan (JP), and the United States (US). $\text{Ln}(Y/K)$ is the natural logarithm of revenue divided by capital. $\text{Ln}(L/K)$ is the natural logarithm of employee divided by capital. W is the share of a firm's innovation activities in a country (group). $\text{Ln}(\text{RD})$ is the natural logarithm of R&D stock. The superscript denotes the level of aggregation. The superscript denotes the level of aggregation. All columns are estimated by OLS with country and year fixed effects. ***, **, and * indicate statistical significance at the 1, 5, and 10 percent levels, respectively. Country controls include: GDP per capita, total factor productivity, and CPI inflation.

Table 13. R&D Augmented Production Function with Foreign and Domestic Innovation

| <i>Dependent variable: $\ln(\frac{Y}{K})_{i,t}$</i> | | |
|--|-----------|--------------|
| | (1) | (2) |
| <i>Sample</i> | Frontier | Non-Frontier |
| $\ln(\frac{L}{K})_{i,t}$ | 0.437*** | 0.674*** |
| | [0.035] | [0.018] |
| $\ln(RD)_{i,t}$ | 0.156*** | 0.036*** |
| | [0.013] | [0.006] |
| $\ln(RD)^{dom}_{c,j,t}$ | -0.044 | 0.072*** |
| | [0.083] | [0.027] |
| $\ln(RD)^{for}_{c,j,t}$ | 0.285 | -0.097 |
| | [0.246] | [0.072] |
| W^{dom}_i | -2.955*** | -0.148 |
| | [0.638] | [0.346] |
| W^{for}_i | -0.002 | 0.010*** |
| | [0.003] | [0.003] |
| $W^{dom}_i * \ln(RD)^{dom}_{c,j,t}$ | 0.115* | -0.015 |
| | [0.064] | [0.028] |
| $W^{for}_i * \ln(RD)^{for}_{c,j,t}$ | 0.184** | 0.016 |
| | [0.078] | [0.046] |
| Country FE | Y | Y |
| Year FE | Y | Y |
| Industry-year FE | Y | Y |
| Country controls | Y | Y |
| Observations | 13,572 | 8,679 |
| R-squared | 0.142 | 0.412 |

Notes: Frontier countries include Germany, Japan, and the United States. $\ln(Y/K)$ is the natural logarithm of revenue divided by capital. $\ln(L/K)$ is the natural logarithm of employee divided by capital. W is the share of a firm's innovation activities in a country (group). $\ln(RD)$ is the natural logarithm of R&D stock. The superscript denotes the level of aggregation. The superscript denotes the level of aggregation. All columns are estimated by OLS with country, year, and industry-year fixed effects. ***, **, and * indicate statistical significance at the 1, 5, and 10 percent levels, respectively. Country controls include: GDP per capita, total factor productivity, and CPI inflation.

Table 14. Profit Shifting: Frontier Countries

| Dependent variable: $\text{Ln}\left(\frac{Y}{K}\right)_{i,t}$ | (1) | (2) | (3) | (4) |
|--|---------------------|---------------------|---------------------|---------------------|
| $\text{Ln}\left(\frac{L}{K}\right)_{i,t}$ | 0.429*** [0.035] | 0.429*** [0.035] | 0.434*** [0.035] | 0.435*** [0.035] |
| $\text{Ln}(\text{RD})_{i,t}$ | 0.183*** [0.011] | 0.183*** [0.011] | 0.164*** [0.014] | 0.165*** [0.014] |
| $\text{Ln}(\text{RD})^{\text{frontier}}_{c,j,t}$ | | 0.669 [0.741] | 0.607 [0.742] | 0.561 [0.749] |
| $\text{Ln}(\text{RD})^{\text{non-tax-haven}}_{c,j,t}$ | | -0.532 [0.566] | -0.533 [0.567] | -0.501 [0.573] |
| W^{frontier}_i | | | -0.843** [0.376] | -0.845** [0.376] |
| $W^{\text{non-tax-haven}}_i$ | | | 0.009 [0.056] | 0.009 [0.056] |
| $W^{\text{frontier}}_i * \text{Ln}(\text{RD})^{\text{frontier}}_{c,j,t}$ | | | 0.081** [0.033] | 0.081** [0.033] |
| $W^{\text{non-tax-haven}}_{c,i} * \text{Ln}(\text{RD})^{\text{non-tax-haven}}_{c,j,t}$ | | | -0.001 [0.005] | -0.001 [0.005] |
| Country FE | Y | Y | Y | Y |
| Year FE | Y | Y | Y | Y |
| Industry-year FE | Y | Y | Y | Y |
| Country controls | N | N | N | Y |
| Observations | 13,572 | 13,572 | 13,572 | 13,572 |
| R-squared | 0.136 | 0.136 | 0.137 | 0.137 |

Notes: Frontier countries include Germany, Japan, and the United States. Non-tax-haven countries include all other OECD countries except Ireland, Luxembourg, and Switzerland. $\text{Ln}(Y/K)$ is the natural logarithm of revenue divided by capital. $\text{Ln}(L/K)$ is the natural logarithm of employee divided by capital. W is the share of a firm's innovation activities in a country (group). $\text{Ln}(\text{RD})$ is the natural logarithm of R&D stock. The superscript denotes the level of aggregation. All columns are estimated by OLS with country, year, and industry-year fixed effects. ***, **, and * indicate statistical significance at the 1, 5, and 10 percent levels, respectively. Country controls include: GDP per capita, total factor productivity, and CPI inflation.

Table 15. Profit Shifting: Non-Tax-Haven Non-Frontier Countries

| <i>Location Weights:</i> | Average share of patents (1997-2006) | | | |
|--|--------------------------------------|----------|----------|----------|
| <i>Dependent variable: $\ln(\frac{Y}{K})_{i,t}$</i> | (1) | (2) | (3) | (4) |
| $\ln(\frac{L}{K})_{i,t}$ | 0.671*** | 0.671*** | 0.674*** | 0.674*** |
| | [0.018] | [0.018] | [0.018] | [0.018] |
| $\ln(RD)_{i,t}$ | 0.036*** | 0.036*** | 0.032*** | 0.032*** |
| | [0.005] | [0.005] | [0.006] | [0.006] |
| $\ln(RD)^{frontier}_{c,j,t}$ | | 0.119 | 0.104 | 0.090 |
| | | [0.375] | [0.375] | [0.375] |
| $\ln(RD)^{non-tax-haven}_{c,j,t}$ | | -0.100 | -0.096 | -0.087 |
| | | [0.281] | [0.281] | [0.281] |
| $W^{frontier}_i$ | | | -0.734** | -0.733** |
| | | | [0.303] | [0.303] |
| $W^{non-tax-haven}_i$ | | | 0.024 | 0.025 |
| | | | [0.058] | [0.059] |
| $W^{frontier}_i * \ln(RD)^{frontier}_{c,j,t}$ | | | 0.065** | 0.065** |
| | | | [0.027] | [0.027] |
| $W^{non-tax-haven}_i * \ln(RD)^{non-tax-haven}_{c,j,t}$ | | | -0.002 | -0.002 |
| | | | [0.005] | [0.005] |
| Country FE | Y | Y | Y | Y |
| Year FE | Y | Y | Y | Y |
| Industry-year FE | Y | Y | Y | Y |
| Country controls | N | N | N | Y |
| Observations | 8,473 | 8,473 | 8,473 | 8,473 |
| R-squared | 0.406 | 0.406 | 0.406 | 0.407 |

Notes: Frontier countries include Germany, Japan, and the United States. Non-tax-haven countries include all other OECD countries except Ireland, Luxembourg, and Switzerland. $\ln(Y/K)$ is the natural logarithm of revenue divided by capital. $\ln(L/K)$ is the natural logarithm of employee divided by capital. W is the share of a firm's innovation activities in a country (group). $\ln(RD)$ is the natural logarithm of R&D stock. The superscript denotes the level of aggregation. The superscript denotes the level of aggregation. All columns are estimated by OLS with country, year, and industry-year fixed effects. ***, **, and * indicate statistical significance at the 1, 5, and 10 percent levels, respectively. Country controls include: GDP per capita, total factor productivity, and CPI inflation.

Table 16. Alternative Innovation Location Measure

| <i>Dependent variable:</i> | Frontier | | | Non-Frontier | | |
|--|----------|-----------|----------|--------------|----------|----------|
| $Ln(\frac{Y}{K})_{i,t}$ | (1) | (2) | (3) | (4) | (5) | (6) |
| $Ln(\frac{L}{K})_{i,t}$ | 0.435*** | 0.435*** | 0.441*** | 0.676*** | 0.673*** | 0.676*** |
| | [0.035] | [0.035] | [0.035] | [0.018] | [0.018] | [0.018] |
| $Ln(RD)_{i,t}$ | 0.165*** | 0.196*** | 0.169*** | 0.032*** | 0.035*** | 0.032*** |
| | [0.014] | [0.012] | [0.014] | [0.006] | [0.005] | [0.006] |
| $Ln(RD)^{frontier}_{c,j,t}$ | 0.545 | 0.590 | 0.527 | 0.131 | 0.148 | 0.130 |
| | [0.732] | [0.730] | [0.732] | [0.361] | [0.361] | [0.361] |
| $Ln(RD)^{other}_{c,j,t}$ | -0.507 | -0.488 | -0.485 | -0.124 | -0.131 | -0.126 |
| | [0.580] | [0.579] | [0.580] | [0.281] | [0.281] | [0.281] |
| $W^{frontier}_i$ | -0.848** | | -0.795** | -0.760*** | | -0.735** |
| | [0.375] | | [0.394] | [0.291] | | [0.331] |
| W^{other}_i | 0.009 | | 0.063 | 0.049 | | 0.010 |
| | [0.051] | | [0.066] | [0.052] | | [0.083] |
| $W^{frontier}_i * Ln(RD)^{frontier}_{c,j,t}$ | 0.082** | | 0.078** | 0.067** | | 0.065** |
| | [0.033] | | [0.035] | [0.026] | | [0.030] |
| $W^{other}_i * Ln(RD)^{other}_{c,j,t}$ | -0.001 | | -0.004 | -0.004 | | -0.001 |
| | [0.005] | | [0.006] | [0.005] | | [0.008] |
| $N^{frontier}_i$ | | -0.370*** | -0.185** | | -0.067 | 0.030 |
| | | [0.066] | [0.073] | | [0.053] | [0.062] |
| N^{other}_i | | 0.028*** | 0.018*** | | 0.002 | 0.004 |
| | | [0.005] | [0.006] | | [0.005] | [0.011] |
| $N^{frontier}_i * Ln(RD)^{frontier}_{c,j,t}$ | | 0.027*** | 0.011* | | 0.006 | -0.003 |
| | | [0.006] | [0.006] | | [0.004] | [0.005] |
| $N^{other}_i * Ln(RD)^{other}_{c,j,t}$ | | -0.002*** | -0.001** | | -0.000 | -0.000 |
| | | [0.000] | [0.001] | | [0.000] | [0.001] |
| Country FE | Y | Y | Y | Y | Y | Y |
| Year FE | Y | Y | Y | Y | Y | Y |
| Industry-year FE | Y | Y | Y | Y | Y | Y |
| Country controls | Y | Y | Y | Y | Y | Y |
| Observations | 13,572 | 13,572 | 13,572 | 8,679 | 8,679 | 8,679 |
| R-squared | 0.137 | 0.137 | 0.138 | 0.411 | 0.411 | 0.411 |

Notes: Frontier countries include Germany, Japan, and the United States. $Ln(Y/K)$ is the natural logarithm of revenue divided by capital. $Ln(L/K)$ is the natural logarithm of employee divided by capital. W is the share of a firm's innovation activities in a country (group). N is a firm's number of patents (in thousands). $Ln(RD)$ is the natural logarithm of R&D stock. The superscript denotes the level of aggregation. The superscript denotes the level of aggregation. All columns are estimated by OLS with country, year, and industry-year fixed effects. ***, **, and * indicate statistical significance at the 1, 5, and 10 percent levels, respectively. Country controls include: GDP per capita, total factor productivity, and CPI inflation.