Domestic Effects of Offshoring High-skilled Jobs: Complementarities in Knowledge Production

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Abstract

We provide evidence on how changes in the use of high-skilled workers (inventors) in a foreign location affect a firm’s domestic use of the same type of worker. We exploit rich data that provide variation in the location of inventors within multinational firms across industries and countries to control for confounding firm-time and industry factors. We find that a 10% increase in the use of foreign inventors leads to a 1.9% increase in the use of domestic inventors. Our results suggest that foreign and domestic inventors are complementary in the production of knowledge.

1. Introduction

There has been substantial growth in multinational firms’ foreign activity. This is true not only for production activities but also for high-skilled, innovative activities such as research and development (R&D). European multinational firms conducted close to half of their R&D offshore in 2004, almost double the amount from a decade before.¹ The increasingly global nature of research activities has raised concerns that demand for high-skilled workers abroad will lead firms to reduce demand for high-skilled workers at home (Freeman, 2006). Governments have a particular interest in attracting and maintaining demand for high-skilled workers, because their activities directly contribute to growth in knowledge economies and they are associated with important positive externalities, including knowledge spillovers (Jaffe et al., 1993) and social externalities (Moretti, 2010).

Our contribution in this paper is to provide robust empirical evidence on how changes in the use of high-skill workers in foreign affiliates of multinational companies affect the domestic use of the same type of workers by those firms. That is, we ask the following question: when a multinational firm uses more workers outside of their home country how does this affect that firm’s demand for workers at home. The answer depends on whether workers in different locations are substitutable or complementary in production.

To answer this question we use detailed data on the patent applications of 736 European multinationals and their affiliates in 18 European countries and the USA between 1991 and 2005. This data allows us to implement an empirical strategy that

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exploits within-firm–industry variation in the growth of knowledge workers at home and abroad across different industries. Crucially, this allows us to control for possibly confounding factors that may drive growth in demand for workers both at home and abroad.

From firms’ patent applications we observe all of the inventors that created the technology underlying the application, including where they were located. Inventors engaged in the creation of new technologies are an important type of high-skilled worker. Patent applications vary within firm in two crucial dimensions: the industries in which the technology is used and the location of the inventors that created that technology (more details of the data used are given in section 3). Between 1991 and 2005 there was a decrease in the proportion of inventors located in the home country of European multinationals, from 70.7% to 65% on average, with considerable variation across multinationals headquartered in different countries. This has been driven by a higher growth rate in the aggregate number of foreign inventors (36%) relative to the growth rate in the aggregate number of domestic inventors (15%). Figure 1 shows that there is a positive correlation between the growth in the number of inventors at home and abroad. However, this correlation does not necessarily reflect a complementarity, as it will be affected by unobserved firm-level factors, such as demand or technology shocks, that simultaneously affect employment in all locations and may drive a positive correlation between employment in different locations, even when workers are substitutes in production.

The structure of our data is such that we are able to exploit within-firm variation in the growth of foreign inventors across industries to identify the effect of expansions of foreign inventors on the use of domestic inventors. Our identification strategy relies on the assumption that confounding factors are common across industries within a firm, conditional on common shocks across firms within an industry and under this assumption we can interpret this as a causal effect.

Figure 1. Growth of Domestic and Foreign Inventors of EU Multinational Firms

Note: The axes show normalized growth in domestic and foreign inventors. Each observation is the growth (log change) in inventors between two consecutive periods (1991–1995, 1996–2000, 2001–2005) for a parent firm in one of six industries. The number of observations is 3,117. The number of parent firms is 736.

Source: Authors’ calculation using PATSTAT matched to Amadeus and Derwent. See section 3.

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To allay concerns that there remain unobserved firm–industry-level shocks that affect demand for inventors both at home and abroad, we additionally take an instrumental variable approach. We follow Desai et al. (2009), who consider the relationship between domestic and foreign aggregate employment of US multinationals, and construct an instrument based on firm–industry weighted foreign gross domestic product (GDP) growth to explain exogenous changes in US multinational enterprises’ (MNEs’) production activities in foreign locations. We construct weights based on multinationals’ geographic distribution of inventors in a previous period. However, we note that it is difficult to identify a valid instrument that has sufficient exogenous variation for this type of empirical exercise. We demonstrate the bias that may arise from using an imperfect instrument and present analytical bounds on our instrumental variable (IV) estimates under weaker assumptions about the exogeneity of the instrument.

An alternative approach would be to use variation in the costs of employing foreign workers to estimate systems of labor demand in different locations (e.g. Harrison and McMillan (2011) for US manufacturing firms and Muendler and Becker (2010) for German multinationals). However, in our setting there is only limited and highly aggregate data available on wages paid to high-skill workers like inventors. It does not yield sufficient firm-location-level variation to apply this approach.

Our main estimate suggests that a 10% increase in the use of foreign inventors leads to a 1.9% increase in the use of home inventors. That is, our results are consistent with foreign and domestic inventors being complementary in the production of knowledge. The IV and IV bounds results support this main result.

We find that the complementarity is between inventors at home (in Western Europe), and inventors in other high-income Organisation for Economic Co-operation and Development (OECD) countries. We find no relationship between the use of inventors at home and those outside of the group of high-income OECD countries. Further, we find evidence that the extent of complementarities is higher between inventors within Western Europe than between those in Western Europe and the USA. This may reflect that inventors in Western Europe, who are geographically closer together, are more likely to work collaboratively in research teams.

Team-based research has become more prevalent, in part as a result of increasing technological complexity. Jones (2009) provides theoretical and empirical evidence that, as technology has advanced, successive generations of innovators have faced an increasing burden, needing to spend longer in education and narrowing their field of expertise, which has lead to a greater reliance on teamwork. There has also been a move towards more international research teams (Wuchty et al., 2007). There is evidence that knowledge now flows more easily across international borders (Griffith et al., 2010) and that networks between highly skilled individuals are particularly “important in determining patterns of intraregional and intra-firm knowledge flows” (Singh, 2005). Our results are consistent with the idea that the increase in foreign inventors is associated with the use of international teams, with Western European researchers working with researchers located in other high-income countries and specialized in the different types of knowledge needed to generated complex technologies. This is also consistent with the literature that emphasizes technology sourcing as a motivation for R&D offshoring (see, for instance, Griffith et al., 2006).

At the same time, evidence also suggests that geographical proximity to other researchers facilitates knowledge spillovers (Jaffe et al., 1993; Keller, 2002). Higher knowledge spillovers within Europe may be one reason for higher complementarities between European inventors. We return to this discussion in the Results section.
Our work is related to several strands of the literature. First, it is related to the literature on production offshoring and the impact of foreign employment on home employment. The results of that work are mixed. Muendler and Becker (2010) consider total employment by a sample of German multinationals and find that, conditional on investment abroad, workers located elsewhere in Europe are substitutes for workers in Germany. Desai et al. (2009) find evidence for complementarities between domestic and foreign aggregate employment of US multinationals. Harrison and McMillan (2011), who also consider US manufacturing firms, conclude that the impact of offshoring on domestic employment varies according to the motive for offshoring and the location of offshore activity. They find that domestic employees are substitutes (complements) for the employees of foreign affiliates engaged in similar (different) activities; they argue that accounting for the type and location of foreign worker is important.

These studies and others focus on aggregate employment or specifically on production or low-skilled workers, but much less is known about the relationship between demand for similarly high-skilled domestic and foreign workers, such as inventors. It is not clear, a priori, whether high-skilled workers are likely to be substitutes or complements, and there are reasons to think this relationship could be different to that of production workers. As highlighted above, there are important spillovers between workers, and these are likely to be highest when individuals are geographically close together, such that firms may substitute between different countries when choosing where to locate knowledge production. However, the non-rivalrous nature of knowledge may make complementarities more likely for high-skilled workers. Notably, workers involved in the production of intangible assets in different locations may exchange knowledge and increase each other’s productivity in ways that workers producing tangible assets may not be able to. That is, while in general a firm may substitute a foreign employee for a domestic one engaged in similar activities (as found by Harrison and McMillan, 2011), they may choose to combine domestic and foreign knowledge workers that work in similar activities and have complementary skills. Our work contributes to this literature by providing direct evidence on the relationship between high-skilled workers in different locations.

We also contribute to a related literature that considers whether total R&D activities at home and abroad are complements or substitutes. Hines (1995) finds that the domestic and foreign R&D of US multinationals are substitutes at the aggregate level. He exploits variation in royalty taxes, which affect the cost of importing technology. US-owned foreign affiliates are more R&D intensive if located in countries where imported technology is more expensive, suggesting that (imported) US technology and foreign R&D are substitutes. In a closely related paper Hines and Jaffe (2001) exploit tax driven changes in the cost of performing R&D at home and abroad to show that there are complementarities between the domestic and foreign innovative activities of US multinational firms. D’Agostino et al. (2013) use regional-level data for OECD countries and asks whether there are complementarities between R&D in the home and foreign regions. They find evidence of complementarities between activities in medium/low technology sectors, but no evidence of complementarities in knowledge-intensive sectors.

The paper proceeds as follows. In section 2 we present a theoretical motivation and our empirical methodology. In section 3 we describe and discuss the data. In section 4 we present econometric estimates and robustness checks. A final section concludes.
2. Theoretical Motivation and Empirical Methodology

Our interest is to estimate the causal effect of a change in the number of inventors used in foreign locations on the number used by the same firm in their home country. The result will depend on whether domestic and foreign inventors are complements or substitutes in the production of knowledge.

Our empirical strategy derives from the following simple theoretical model, which is analogous to that used in Desai et al. (2009). A multinational firm \( i \) generates an industry-specific \( (j) \) knowledge output \( K \) by using inventors located in the home country \( I_h \) and abroad \( I_a \) at a cost \( C(I_h, I_a) \). We assume that the production of knowledge is separable across broad industries and from the production of final output. We consider the intensive margin for firms that already employ inventors in multiple locations. In an extension to Desai et al. (2009), we explicitly allow that firm \( F_i \) and industry \( T_j \)-specific factors may affect revenues, \( R \). In each period \( t \) the firm’s profit maximization problem is:

\[
\max_{I_{ij}^h, I_{ij}^a} R \left( K \left( I_{ij}^h, I_{ij}^a \right), F_i, T_j \right) - C \left( I_{ij}^h, I_{ij}^a \right) .
\]  

(1)

For a given cost of employing domestic inventors, a change in the cost of employing foreign inventors will affect the demand for foreign inventors and, in turn, the demand for domestic inventors in the following way:

\[
dI_{ij}^h = \left[ \frac{\partial R}{\partial K_{ij}^h} \frac{\partial^2 K_{ij}^h}{\partial I_{ij}^h \partial I_{ij}^a} dI_{ij}^a + \frac{\partial R}{\partial K_{ij}^h} \frac{\partial K_{ij}^h}{\partial I_{ij}^h} dF_i + \frac{\partial K_{ij}^h}{\partial I_{ij}^a} \frac{\partial R}{\partial F_i} dT_j \right]
\]

\[- \left[ \frac{\partial R}{\partial K_{ij}^h} \frac{\partial^2 K_{ij}^h}{\partial I_{ij}^h \partial I_{ij}^a} \right]^2 .
\]

(2)

Equation (2) is derived by totally differentiating the first order condition for profit maximization; see Desai et al. (2009), equations (1)–(4).

Under standard assumptions, the denominator in (2) is positive, and the sign of the relationship between a change in foreign inventors (\( dI_{ij}^a \)) and a change in domestic inventors (\( dI_{ij}^h \)) is ambiguous, and will be determined by the first bracket in the numerator. If there is complementarity in knowledge production then \( \partial^2 K / \partial I_{ij}^h \partial I_{ij}^a > 0 \), and the first term will be positive. Assuming that there are diminishing returns to knowledge (i.e. \( \partial^2 R / \partial K^2 \leq 0 \)) the second term is non-positive. Therefore, an overall positive effect requires inventors at home and abroad to be sufficiently complementary in knowledge production. Put another way, it requires that the scale effect that results from a fall in the cost of doing research abroad is sufficient to outweigh the substitution effect.

We estimate the empirical counterpart to equation (2), which relates growth in inventors at home (\( \Delta \ln I_{ij}^h \)), the left-hand side of equation (2), to the growth rate in foreign inventors (\( \Delta \ln I_{ij}^a \)), the first term on the right-hand side of equation (2),

\[
\Delta \ln I_{ij}^h = \beta \Delta \ln I_{ij}^a + \delta_1 + \omega_1 + \gamma_1 + u_{ijt} .
\]  

(3)
The firm–time effects $\gamma_{jt}$ correspond to the second term on the right-hand side of equation (2), and will directly control for shocks to demand or to productivity that are common across industries within a firm–period. We are able to control for this effect by exploiting within-firm variation in the growth of inventors at home and abroad across different industries. This is one of our main contributions. Time effects $\delta_t$ control for common time trends. The industry–time effects $\omega_{jt}$ correspond to the final term on the right-hand side of equation (2), and will control for cost, price or technology shocks that vary across industries and over time but are common across firms within an industry time period. As demonstrated in equation (2), controlling for these factors is critical because they may simultaneously affect growth in inventors at home and abroad in ways that do not reflect complementarity in production. The coefficient of interest $\beta$ reflects the quantity elasticity of domestic inventors with respect to foreign inventors. That is, it shows the percent change in the use of domestic inventors for a 1% increase in foreign inventors.

The key identifying assumption underlying this approach is that shocks to the change in demand for home inventors in one firm–industry–period are not correlated with changes in demand for foreign inventors, conditional on firm and industry shocks. We can implement this approach as a result of the rich data we have on comparable activities across firms, industries and (parent and host) countries over time. We discuss the data in more detail in the next section.

One possible concern with this approach is that there may remain firm–industry-specific shocks that are not controlled for, or that there is a reverse causality between domestic and foreign inventors. To address this we use an instrument for foreign inventor growth with a view to capturing that part of foreign growth that can be viewed as exogenous with respect to how many inventors are used at home (and therefore abstracting from the effects of unobserved shocks). Ideally we would instrument growth in foreign inventors using a firm–industry–location-level measure of exogenous changes in the costs or productivity of inventors in that location. To the best of our knowledge such data is not available, but we are able to construct a proxy for this. We follow the approach of Desai et al. (2009) and use a firm–industry–time-specific measure of exposure to foreign GDP growth as an instrument for foreign employment growth. Specifically, the instrument $Z_{ijt}$ comprises foreign country-specific measures $X_{ct}$ —in particular, growth in GDP per capita ($X=\Delta \ln GDP$)—weighted based on the geographic distribution of each firm’s foreign inventors in industry $j$ ($I_{ij}^a$) in the previous period:

$$Z_{ijt} = \sum_{c \in C_{ijt-1}} \frac{I_{ijt}^a}{\sum_c I_{ijt-1}^a} X_{ct}, \quad (4)$$

where each country $c$ belongs to the set of all countries in which the firm had inventors in the previous period ($C_{ijt-1}$).

The motivation for this instrument is that changes in economic activity in foreign countries will reflect changes in the productivity of workers in those locations, and hence (exogenous) changes in the real employment costs. Firms with inventors in countries that later experience relatively high growth are more likely to experience a decrease in their cost of doing research. We also construct a similar instrument using the (firm weighted) growth in a country’s statutory corporate tax rate. Being located in a country that substantially cuts its tax rate should make it more likely that the cost of doing research will fall.
### Table 1. Descriptive Statistics

| Parent country | Number of firms | Number of inventors | Growth in inventors |
|----------------|-----------------|---------------------|---------------------|
|                | Total at home   | Total abroad        |                     |
|                | Mean            | Standard deviation  |                     |
|                | Home inventors  | Foreign inventors   |                     |
|                | Mean            | Standard deviation  |                     |
|                | Home inventors  | Foreign inventors   |                     |
|                | Mean            | Standard deviation  |                     |
| # notes | | | |

|                | (1)  | (2)  | (3)  | (4)  | (5)  | (6)  | (7)  | (8)  | (9)  | (10) | (11) |
|----------------|------|------|------|------|------|------|------|------|------|------|------|
| Belgium        | 39   | 12,964 | 11,974 | 103  | 182  | 95   | 193  | 0.32 | 1.14 | 0.26 | 1.30 |
| Denmark        | 36   | 11,488 | 6,386 | 120  | 329  | 67   | 209  | 0.49 | 0.99 | 0.56 | 1.04 |
| Finland        | 24   | 16,757 | 6,481 | 258  | 1206 | 100  | 471  | 0.30 | 0.92 | 0.53 | 1.37 |
| France         | 79   | 73,407 | 52,858 | 282  | 581  | 203  | 615  | 0.41 | 1.14 | 0.37 | 1.10 |
| Germany        | 262  | 332,118 | 63,065 | 425  | 1509 | 81   | 289  | 0.30 | 1.15 | 0.29 | 1.15 |
| Italy          | 50   | 11,603 | 2,718 | 86   | 162  | 20   | 28   | 0.15 | 1.19 | -0.01 | 1.18 |
| Netherlands    | 44   | 59,579 | 49,844 | 451  | 1843 | 378  | 1064 | 0.11 | 1.11 | 0.32 | 1.12 |
| Norway         | 10   | 1,656  | 895   | 57   | 76   | 31   | 71   | 0.01 | 0.89 | 0.39 | 1.08 |
| Sweden         | 55   | 21,355 | 14,931 | 140  | 556  | 98   | 516  | 0.56 | 1.07 | 0.38 | 1.17 |
| UK             | 137  | 39,010 | 82,312 | 94   | 268  | 198  | 1139 | 0.04 | 1.09 | 0.13 | 1.13 |
| **Total**      | 736  | 579,937 | 291,464 | 264  | 1078 | 133  | 651  | 0.27 | 1.12 | 0.28 | 1.16 |

**Notes:** Columns (2) and (3) provide a count of the number of inventors (counted once per patent–industry, as in estimation) according to the country of the parent firm and whether the inventor is located in the same (home) or different country (abroad). Columns (4)–(7) show the mean and standard deviation of the distribution of the number of inventors at home and abroad across firm–industries. Columns (8)–(11) show the distribution across firm–industries of the growth of inventors at home (\(\Delta \ln I_{hijt}\)) and abroad (\(\Delta \ln I_{aht}\)).

**Sources:** Authors’ calculation using matched data from Amadeus, Icarus, PATSTAT and Derwent Innovation Index.
We estimate equation (3) using data on 198,980 patent applications filed by 736 multinationals headquartered in 10 European countries over the period 1991–2005. These data are from the Worldwide Patent Statistical Database (PATSTAT) matched to information on the corporate structure of firms from Amadeus and are described in Abramovsky et al. (2008). Importantly, this allows us to observe patent applications filed directly by a multinational firm, or via any of its affiliates located in the USA or in any of 18 European countries (the ten listed in the first column of Table 1 plus Czech Republic, Greece, Ireland, Luxembourg, Poland, Portugal, Spain and Switzerland).

We classify patent applications based on their technology and industry of application using the Derwent Innovation Index, which is compiled by Thompson for commercial purposes. Applications are assigned to at least one of six broad industry groups (chemical, chemical materials, pharmaceuticals, communications and computing, electrical and electronics, and engineering). An individual patent application can be classified into multiple industries, recognizing that some technologies will have more than one possible application. In our sample, 52% of patent applications are assigned to only one industry, 37% to two industries and fewer than 1% to more than three industries.

The data include information on all of the inventors that worked on creating the technology underlying a patent application, including where they were located (their residential address). There are often multiple inventors listed on a patent application and they can be resident in different countries. In our sample, 38% of patent applications have at least one inventor abroad. Thirty per cent list only inventors outside of the parent firm’s home country. Of these 93% are located in a single (foreign) country. Just 8% of patent applications list inventors at home and abroad. Of these, 90% have inventors in two foreign countries.

The inventors listed on a patent application are counted as many times as the industries associated with the patent. However, as discussed below in section 4, our results are robust to alternatively fractionally counting inventors (or to removing all industry variation).

One of the key advantages of using data on inventors to measure high-skilled workers is that they provide a consistent, firm-level, measure of the location of workers who are engaged in similar activities. Patent applications have been used for this purpose in a number of applications.5

In estimation, the unit of observation will be the count of inventors at the firm–industry–period level. Our identification strategy exploits differences in the growth of the number of inventors at home and abroad across different industries within a firm, as well as across firms within an industry. Our focus therefore is on the 736 large firms that have filed a body of patent applications with inventors in more than one country, in at least two different industries and with a change in the use of domestic or foreign inventors across at least one of the periods 1991–1995, 1996–2000 and 2001–2005. These firms represent a small proportion of total firms in our dataset (2.3%) but account for the majority of domestic inventors (60.7%) and foreign inventors (79.7%).6 Table 1 shows the distribution of firms across countries (column 1). Columns (2) and (3) show the associated number of inventors at home and abroad.7 The remaining columns describe the variation across firms in the number and growth rates of inventors at home and abroad at the firm–industry–period level. There is substantial variation across across parent countries, within parent countries across firms and between domestic and foreign locations. This is the variation that we exploit in our estimation.
Table 2. Location of Foreign Inventors, by Country of Parent Firm and Period

| Parent country | Home | France | Germany | UK | Other Western Europe | US | Other developed | Eastern Europe | Emerging economies | All others | Total foreign |
|----------------|------|--------|---------|----|----------------------|----|------------------|---------------|-------------------|------------|---------------|
|                | (1)  | (2)    | (3)     | (4) | (5)                  | (6) | (7)              | (8)           | (9)               | (10)       | (11)          |
| 1991–1995      |      |        |         |    |                      |     |                  |               |                   |            |               |
| Belgium        | 60.3 | 4.13   | 39.86   | 20.91 | 15.78                | 17.79 | 0.58            | 0.11           | 0.37              | 0.48       | 100           |
| Denmark        | 72.6 | 1.15   | 5.48    | 6.35 | 33.04                | 38.82 | 12.12           | 2.31           | 0.29              | 0.43       | 100           |
| Finland        | 85.5 | 2.41   | 9.62    | 39.86 | 23.37                | 17.53 | 5.84            | 0.69           | 0.69              | 0          | 100           |
| France         | 55.6 | –      | 49.32   | 6.14 | 14.67                | 26.55 | 2.03            | 0.21           | 0.99              | 0.09       | 100           |
| Germany        | 86.9 | 7.86   | –       | 8.94 | 27.39                | 46.58 | 6.55            | 1.44           | 0.66              | 0.58       | 100           |
| Italy          | 79.5 | 23.95  | 19.13   | 10.99 | 12.5                 | 27.11 | 5.72            | 0.15           | 0.3               | 0.15       | 100           |
| Netherlands    | 57.7 | 10.31  | 19.35   | 20.65 | 11.99                | 33.15 | 3.05            | 0.5            | 0.7               | 0.29       | 100           |
| Norway         | 81.5 | 4.81   | 33.65   | 14.42 | 36.54                | 7.69  | 0               | 1.92           | 0.96              | 0          | 100           |
| Sweden         | 69.7 | 4.6    | 24.11   | 11.44 | 18.39                | 34.71 | 3.94            | 1.97           | 0.19              | 0.66       | 100           |
| UK             | 43.0 | 2.09   | 3.73    | –    | 13.67                | 74.93 | 3.56            | 0.73           | 0.79              | 0.49       | 100           |
| Total          | 70.7 | 4.49   | 19.15   | 8.3  | 17.24                | 45.17 | 3.8             | 0.74           | 0.74              | 0.37       | 100           |
| 2001–2005      |      |        |         |    |                      |     |                  |               |                   |            |               |
| Belgium        | 48.3 | 9.26   | 32.52   | 7.94 | 28.54                | 18.15 | 1.32            | 0.67           | 1.23              | 0.36       | 100           |
| Denmark        | 71.8 | 1.96   | 16.94   | 6.3  | 17.06                | 50.54 | 3.21            | 2.26           | 1.37              | 0.36       | 100           |
| Finland        | 69.6 | 0.96   | 15.25   | 11.96| 20.65                | 36.5  | 5.86            | 2.7            | 5.47              | 0.66       | 100           |
| France         | 57.1 | –      | 29.65   | 3.77 | 21.08                | 35.07 | 4.82            | 1.73           | 3.5               | 0.38       | 100           |
Table 2. Continued

| Parent country | Home | France | Germany | UK | Other Western Europe | US | Other developed Europe | Eastern Europe | Emerging economies | All others | Total foreign |
|----------------|------|--------|---------|----|----------------------|----|------------------------|----------------|-------------------|------------|---------------|
| Germany        | 83.6 | 11.58  | –       | 8.42 | 32                   | 34.93 | 6.04                   | 1.92           | 2.63              | 2.49       | 100           |
| Italy          | 81.1 | 22.62  | 20.3    | 8.58 | 25.52                | 14.39 | 2.78                   | 2.67           | 2.67              | 0.46       | 100           |
| Netherlands    | 52.8 | 14.36  | 28.86   | 13.77 | 9.96                 | 26.33 | 2.92                   | 0.43           | 2.93              | 0.44       | 100           |
| Norway         | 57.1 | 20.27  | 35.62   | 4.38 | 30.96                | 7.12  | 0.82                   | 0              | 0.55              | 0.27       | 100           |
| Sweden         | 55.0 | 6.19   | 30.47   | 7.08 | 30.54                | 18.22 | 4.32                   | 1.6            | 1                 | 0.58       | 100           |
| UK             | 29.3 | 1.58   | 4.41    | –   | 11.33                | 75.32 | 3.99                   | 0.81           | 1.73              | 0.83       | 100           |
| Total          | 65.0 | 6.36   | 15.9    | 6.1 | 19.46                | 43.12 | 4.32                   | 1.28           | 2.5               | 0.96       | 100           |

Notes: Each row shows the percentage of inventors listed on patent applications filed by parent firms in the relevant country and included in the main sample (column (5) Table 1). Column (1) shows the percentage of inventors located in the home country. Columns (2)–(10) show the percentage of foreign inventors in each country group; columns (2)–(10) sum to column (11), 100%. “Other Western Europe” includes Austria, Belgium, Denmark, Finland, Greece, Iceland, Ireland, Italy, Luxembourg, the Netherlands, Norway, Portugal, Spain and Sweden. “Other Developed” includes Australia, Canada, Israel and Japan. “Eastern Europe” includes Belarus, Bulgaria, Czech Republic, Hungary, Latvia, Lithuania, Poland, Republic of Moldova, Romania, Russia, Slovakia, Ukraine and Estonia. “Emerging Economies” includes South Africa, Brazil, China, India, Singapore, Taiwan and Korea.

Sources: Authors’ calculation using matched data from Amadeus, Icarus and PATSTAT.
Table 2 shows the distribution of inventors across countries, by the country of the parent firm. We split our data into three 5-year time periods; the top panel shows the data for the first of these while the bottom panel shows the data for the last. Each row describes where inventors on patent applications made by parent firms from that country are located; column (1) shows the proportion located in the home country; columns (2)–(10) show the proportion in the other countries. Across all parent firms, the proportion of inventors located in the parent firms’ home countries fell from 70% in 1991–1995 to 65% in 2001–2005. Most countries saw a reduction in the proportion of inventors located at home, but this was particularly marked for Finland, Norway, Sweden and the UK.

The majority of foreign inventors in both periods were located in Western Europe or the USA. However, there is variation across parent countries and over time. For example, in both periods UK parent firms locate a particularly high share of inventors in the USA. Germany is a popular location for the inventors working on patent applications made by Belgian, French and Norwegian parent firms, and has attracted a higher share of the inventors listed on the patent applications of Danish and Dutch parent firms in the later period. The share of inventors associated with Belgian, Finnish and Dutch parent firms working in the UK has fallen substantially over time.8

Table 3 presents estimates of equation (3). We regress growth in the number of inventors located at home on growth in those abroad. The regression is at the firm–industry–period level. The first three columns present ordinary least squares (OLS) estimates where we vary the way in which we control for time and industry shocks; this makes little difference to the result. The OLS estimates suggest a positive effect of growth abroad on that at home. However, we expect an upward bias in these results as a result of unobserved shocks to firm demand or technology that are likely to be positively correlated across locations, either because of omitted variables or reverse causality.
In columns (4) and (5) we use firm and firm–time effects respectively to control for confounding factors. In line with our expectations, the coefficient is reduced below the OLS estimate. In our main result (column 5), the estimate of $\beta$ suggests that a 10% increase in the use of foreign inventors leads to a 1.9% increase in the use of domestic inventors. This is consistent with domestic and foreign inventors being sufficiently complementary in the production of knowledge at the firm level that the scale effect dominates the substitution effect.

To provide a sense of magnitude, our result means that every additional 13 foreign inventors listed in patent applications (10% of 133) leads to an additional five domestic inventors (1.9% of 264) being listed, when evaluated at the mean level of inventors at the firm–industry–period level (Table 1).

**Instrumental Variable Results**

As discussed in section 2, the key identifying assumption underlying the estimates presented in Table 3 is that shocks to the change in demand for home inventors in one firm–industry–period are not correlated with demand for foreign inventors conditional on firm and industry shocks. To address concerns that there may be additional firm–industry-specific shocks that we are not able to control for we instrument foreign inventor growth with firm–industry-specific measures of exposure to foreign GDP growth and changes in statutory tax rates (calculated according to equation (4)).

The instrumental variable results are shown in Table 4. Column (1) is the equivalent specification to our main result (column (5) in Table 3), but with the growth in foreign inventors instrumented with firm weighted foreign GDP growth. Column (3) adds the firm weighted growth in the statutory tax rate as an additional instrument. The instruments are powerful and have significant explanatory power in the first stage; the growth in GDP per capita (or decreases in tax rates) of countries in which firms’ previously used inventors is positively associated with growth in the number of inventors used in foreign locations. The IV estimates yield a positive coefficient on foreign inventor growth, which is statistically the same as our main estimate (column (5) in Table 3). This suggests that evidence of complementarities between foreign and domestic inventors remain after further controlling for firm–industry unobserved shocks.

However, it is worth noting that the IV point estimates are higher than the main fixed effect result and this is at odds with the expected direction of bias in OLS results. One possible interpretation is that we have identified a local average treatment effect (Imbens and Angrist, 1994). An alternative explanation, and one that we think plausible, is that the instrument is not strictly exogenous (it is imperfect). If, for example, foreign growth directly stimulates knowledge demand, or if the locations of inventors (i.e. the weights) are based on expectations of future growth, then the instrument will not be strictly exogenous. This concern is inherent to this type of instrument (although commonly overlooked).

Nevo and Rosen (2011) show that when an instrument is imperfect an IV strategy may not even identify the sign of bias, and develop a method for using the information in an instrument that is imperfect but less endogenous than the endogenous regressor. Assuming the instruments are imperfect, we use this method, which requires weaker assumptions about the correlation between the instrument and the error term. The main assumptions we need are (i) the correlation between the instrument and the error is positive; (ii) the correlation between the growth of foreign inventors and the error is positive; (iii) the instrument is less endogenous than the regressor (we provide a summary of this approach in the Appendix). Under these minimal assumptions we
can identify an upper analytical bound on the true estimate. These are shown in columns (2) and (4) of Table 4. The magnitude of the upper bound is below that of the IV estimate, although our main results, the IV results and the analytical upper bounds statistically are not significantly different. We take this as reassurance that our main point estimate (0.19 shown in the last column of Table 3) is robust to these identification concerns.

We also note that the bias in the IV is found to be larger when we do not control for firm or firm–period fixed effects.11 This suggests that using only an IV approach would lead to an overestimate of the degree of complementarities.

Table 4. Instrumental Variable Results

| Dependent variable: growth in home inventors, $\Delta \ln I_{ijt}^h$ | (1) | (2) | (3) | (4) |
|---------------------------------------------------------------|-----|-----|-----|-----|
| $\Delta \ln I_{ijt}^a$ | 0.323 | 0.163 | 0.310 | 0.199 |
| Instrument: | | | | |
| Firm weighted foreign GDP per capita growth | Y | Y | Y | Y |
| Firm weighted foreign statutory tax rate growth | | | | |
| $R^2$ | 0.05 | 0.05 | | |
| First stages | | | | |
| Dependent variable: growth in foreign inventors, $\Delta \ln I_{ijt}^a$ | | | | |
| Firm weighted foreign GDP per capita growth | 4.094 | 3.392 | | |
| Firm weighted foreign statutory tax rate growth | (1.035)** | (1.026)** | | |
| F-test | 15.64 | 11.34 | | |
| p-value | 0.00 | 0.00 | | |
| $R^2$ | 0.077 | 0.77 | | |
| Observations | 3,117 | 3,117 | | |

Notes: See notes to Table 1. All regression include time effects ($\delta_t$), industry–time effects ($x_{jt}$) and firm–time effects ($\gamma_{it}$). In column (1) the instrument used combines country-specific measures of growth in GDP per capita with firm–industry-specific country weights based on the geographic distribution of each firm’s foreign inventors in the previous period (as per equation (4)). Column (2) reports an analytical bound calculated following Nevo and Rosen (2011). The upper bound is the 2SLS estimate when a weighted combination of the original regressor and the instrument is used as an instrument. The upper bound of the confidence interval on this 2SLS estimate provides the upper bound on the confidence interval of the bound (reported in square brackets). Columns (3) and (4) repeat this exercise but where firm weighted foreign statutory tax rate growth is additionally used as an instrument. Robust standard errors are clustered at the firm level. *,**,***Denote significance at 10%, 5% and 1% levels, respectively.

Source: The instruments are constructed as indicates by equation (5). Weights are authors’ calculation using PATSTAT matched to Amadeus and Derwent. See section 3. GDP data is taken from OECD.stat and the measure used is “Per head, US$, constant prices, constant PPPs, OECD base year.” Statutory tax rates come from a number of sources, including PKF worldwide tax guides, KPMG tax profiles, OECD Tax Database and Institute for Fiscal Studies’ records.
Complementarities with High-income Countries

Table 5 considers whether the relationship between domestic and foreign inventors varies according to the location of the foreign inventors. That is, we estimate the effect of growth in foreign inventors in a subset of specific countries. The column headings in Table 5 indicate the group of foreign locations being considered.

To do this exercise we cannot use our full sample; not all firms have inventors in the subgroups of foreign countries being considered. We therefore work with a subset of the main sample. Table 5 considers four sets of foreign locations. Odd numbered columns show our main specification on the sub-sample under consideration for comparison. In all sub-samples, we find that the impact of all foreign inventors is not statistically different from our main result. Even numbered columns consider the impact of growth only in inventors in the country or group of countries of interest.

In the first two columns we focus on firms that have foreign inventors in high-income OECD countries. Column (1) shows that for these firms, the effect of growth in all foreign inventors on growth in domestic inventors is 0.17 very similar to our main result (0.19). Column (2) shows the relationship between growth in foreign inventors located in high-income OECD countries and domestic inventors. The results are again very similar to those for all foreign inventors. In columns (3)–(4) we split inventors into two groups: high-income OECD countries and the rest of the countries (i.e. all host countries in our sample that are not high-income OECD countries). The sample size is significantly reduced, since not many firms have inventors located in countries outside the group of high-income OECD ones. Despite this drop in the sample size, we continue to find the same positive relationship between all inventors abroad and domestic inventors (column 3). More interestingly, when we include all inventors split in the two groups according to income, we continue to find complementarities with high-income OECD countries, but no relationship with inventors outside this group of countries. This may suggest evidence that there are greater synergies between high-skilled workers located in similar countries. This may in turn reflect that these workers are likely to have similar levels of skills and may specialize in complementary technology areas. This finding is compatible with evidence that inventors located in China and working on patent applications held by Western European multinationals are less likely to work in research teams with European inventors than is the case for other European inventors (Griffith and Miller, 2011). However, we note that because relatively few inventors in our sample are located in countries outside of the group of high-income OECD countries, we are limited in what we can conclude about the relationship with inventors in emerging and developing countries.

Columns (5)–(6) consider the impact of foreign inventors located in USA and columns (7)–(8) consider foreign inventors located in Western Europe. In both cases there remains significant evidence of complementarities. However, the point estimate is larger for inventors located in Western Europe. This may suggest that complementarities are higher for inventors that are geographically close together and specifically that inventors in Western Europe are more likely to work collaboratively in research teams than inventors in Europe and the USA. This would be consistent with evidence, highlighted in the introduction, that geographical proximity remains important for knowledge exchange and spillovers.

Robustness Checks

Our main identification strategy exploits a unique feature of the patents data: we observe firms operating in multiple industries. We can use this to control for shocks
Table 5. Heterogeneity across Foreign Host Countries

| Dependent variable: growth in home inventors, $\Delta \ln I^h_{ijt}$ | Firms with inventors in OECD high-income countries | Firms with inventors in OECD high-income countries and outside this group | Firms with inventors in USA | Firms with inventors in Western Europe |
|---|---|---|---|---|
| Growth in foreign inventors, $\Delta \ln I^a_{ijt}$ | 0.169 (0.030)*** | 0.151 (0.070)** | 0.185 (0.048)** | 0.194 (0.036)*** |
| Growth in foreign inventors in: | | | | |
| High-income OECD countries† | 0.167 (0.029)*** | 0.151 (0.058)** | | |
| Countries outside high-income OECD countries† | | | | |
| USA | | | 0.095 (0.036)*** | |
| Western Europe | | | | 0.139 (0.034)*** |
| Observations | 2,891 | 2,891 | 748 | 748 | 0.85 | 0.85 | 0.81 | 0.82 |
| $R^2$ | 0.83 | 0.83 | 0.88 | 0.88 | 1,402 | 1,402 | 2,398 | 2,398 |

Notes: All regression include time effects ($\delta_t$), industry–time effects ($\alpha_{jt}$) and firm–time effects ($\gamma_{it}$). The samples vary according to the number of firms that have inventors in the country of group of countries being considered (as indicated in the column headings). †High-income OECD countries are defined according to the World Bank definition (available: http://data.worldbank.org/about/country–and-lending–groups). Robust standard errors are clustered at the firm level. *,**,***Denote significance at 10%, 5% and 1% levels, respectively.
that are common across industries within a firm. Our main results are robust to changing the number of industry groups from six to three and to fractionally counting inventors that appear in a patent application that is relevant to more than one industry. In Table 5 we also show that our result is robust to not using the industry-level variation at all. The results shown in Table 6 are based on a firm–period-level regression. Time effects are identified from differences across firms within a period. Each firm–period can be associated with multiple industries according to the industries of the patent applications filed in that period. Industry–period dummies therefore capture shocks that are common across firms that operate in an industry. The firm effects are identified because firms are observed in two periods. In this specification we cannot control for common shocks within a firm–period. The result in column (2) is very similar to our main result (0.189 vs 0.187). The IV results are also very similar to those reported in Table 4, although we lose significance in the first stage. Our main sample allows us both to control for more firm-level shocks and to create an instrument with more accurate firm-level weights. However, our key results are not driven by our specific sample construction.

5. Conclusion

This paper contributes to the empirical literature on the impact of the offshoring of high-skilled workers on employment in the home country at the firm level. We also contribute to the understanding of how the internationalization of research activities

| Dependent variable: growth in home inventors, $\Delta \ln I^h_{it}$ | (1) | (2) | (3) | (4) |
|-----------------------------|-----|-----|-----|-----|
| OLS                         |     |     |     |     |
| Growth in foreign inventors, $\Delta \ln I^a_{it}$ | 0.336 | 0.189 | 0.359 | 0.245 |
| Time effects, $\delta_t$     | Y   | Y   | Y   | Y   |
| Industry-time effects, $\omega_{jt}$ | Y   | Y   | Y   | Y   |
| Firm effects, $\gamma_i$    |     | Y   | Y   | Y   |
| Observations                | 1,732 | 1,732 | 1,732 | 1,732 |
| $R^2$                       | 0.22 | 0.82 | 0.29 | 0.32 |

First stages

| Dependent variable: growth in home inventors, $\Delta \ln I^h_{ijt}$ |     |     |     |     |
|---------------------------------------------------------------------|-----|-----|-----|-----|
| Firm weighted foreign GDP per capita growth                         |     |     |     |     |
|                                                                   | 5.945* | 6.421* |     |      |
|                                                                   | (3.533) | (3.490) |     |      |
| Firm weighted foreign statutory tax rate growth                     | 1.444 |     | (1.738) |      |
|                                                                   |      |     |      |      |
| F-test                                                              | 2.83 | 1.93 |      |      |
| p-value                                                             | 0.09 | 0.15 |      |      |
| $R^2$                                                               | 0.70 | 0.70 |      |      |
| Observations                                                        | 1,732 | 1,732 |      |      |

Notes: Instruments used in columns (3) and (4) are the same as those used in Table 4 except the instrument weights are defined at the firm level and NOT at the firm–industry level. Robust standard errors are clustered at the firm level. *, **, ***Denote significance at 10%, 5% and 1% levels, respectively.
of multinational firms has affected the extent to which they produce knowledge in their home countries. We find evidence of the existence of complementarities between high-skilled domestic and foreign workers at the intensive margin in the production of knowledge that are statistically and economically important. This result is driven in particular by domestic and offshore activity that is located in high-income countries. This is consistent with some existing evidence on the complementarities between home and foreign R&D for US and European multinational firms.

We use within-firm variation in the growth of inventors across industries to control for confounding factors. We show that our results are robust to a previously used IV strategy, but also that it is difficult to find strictly exogenous instruments. We show that analytical bounds on our IV estimate are consistent with our main estimates. This, and other robustness tests, supports our main result that a 10% increase in the use of foreign inventors leads to a 1.9% increase in the use of domestic inventors. We believe that our results are relevant for a broader class of workers, including any that are engaged in the creation of intangible knowledge-based assets.

Our results are relevant for the public policy debate about the impact of offshoring innovative activities on domestic innovative activities in developed countries, in particular, in the European area. European policy makers have set targets to increase the amount of innovative activities that take place in their countries. Success has been limited. The EU missed its 2010 Lisbon target to R&D undertaken in the EU to 3% of GDP by 2010 (van Pottelsberghe, 2008). The latest figures show that business expenditure on R&D in the EU-15 amounts to 1.36% of GDP compared with 1.95% in the USA and 1.51% in China.12 Foray and van Ark (2007) cite concerns “about the increasing numbers of European companies which are basing their R&D operations outside Europe, at the same time as the number of overseas companies carrying out their R&D in Europe is falling.” Our work speaks directly to these policy concerns, and specifically to whether as firms employ more high-skilled workers abroad there will be detrimental effects on the employment of inventors at home. Our results suggest that firms conducting innovative activities offshore need not come at the expense of their innovative activities at home, conditional on multinational firms maintaining innovative operations both at home and abroad. The challenges for governments in developed countries relate not to devising policies to deter offshore investment in innovative activities, but to ensuring that investment at home is sufficient to foster a high-skilled workforce that can engage, both competitively and collaboratively with workers in other locations, in creating new knowledge.

Appendix

Nevo and Rosen (2011) set out a method for calculating the analytical bounds of the true parameter in the case when an instrument is potentially imperfect. An imperfect instrument is one that has power to explain independent variation in the potentially endogenous variable but may not be independent of the error term. In our context we employ instruments that are significant in explaining firm–industry–period-level growth in foreign inventors but may not be strictly exogenous with regards to firm–industry–period shocks.

Nevo and Rosen (2011) show how it is possible to relax the strict exogeneity assumption required of two stage least squares (2SLS) (i.e. corr(z_{ijt}, u_{ijt}) = 0) and under alternative assumptions use information contained in an imperfect instrument to identify bounds on the true estimate. The two key assumptions we make are:13
ASSUMPTION 1.

\[ \text{corr}(\Delta D_{ijt}, u_{ijt}) \times \text{corr}(z_{ijt}, u_{ijt}) \geq 0 \]

i.e. the correlation between the (possibly imperfect) instrument and the error has the same sign as the correlation between the endogenous regressor and the error. We assume both correlations are positive. We think that it is plausible that any firm–industry shocks in \( u_{ijt} \) will be positively correlated with growth in inventors abroad. For example, a firm–industry demand shock could trigger an increase in demand for inventors in that industry in all locations. Likewise we think it plausible that if GDP growth in foreign locations is correlated with the error term, the correlation will be positive.

ASSUMPTION 2.

\[ |\text{corr}(\Delta D_{ijt}, u_{ijt})| \geq |\text{corr}(z_{ijt}, u_{ijt})| \]

i.e. the instrument is less endogenous than the regressor. We think this is a reasonable assumption—the correlation between the instrument and the error terms should be no as high as the correlation between the endogenous variable and the error term, given that there might be other firm–industry-specific omitted factors affecting \( \Delta D_{ijt} \).

We believe these two assumptions to be less demanding in this setting than strict exogeneity and therefore more palatable. Under these assumptions the true \( \beta \) lies in an open interval that is bounded from above by a 2SLS estimate. Specifically, given that we assume both correlations from Assumption 1 are positive, the true \( \beta \) lies in the region \( B^* \), where \( B^* = (\infty, \min \{ \beta_{IV}, \beta_{IVV1} \}) \). \( \beta_{IV} \) is the 2SLS for \( \beta \) using the \( Z_{ijt} \) as an instrument (reported in columns (1) and (3) in Table 4). \( \beta_{IVV1} \) is the probability limit of the traditional 2SLS estimator for \( \beta \) when \( V(1) = \sigma_Z \Delta D_{ijt} - \sigma_{\Delta D_{ijt}} Z \) is used as an instrument for \( \Delta D_{ijt} \), where \( \sigma_Z \) is the variance of the instrument \( Z \) and \( \sigma_{\Delta D_{ijt}} \) is the variance of the potentially endogenous regressor (growth in foreign inventors). In each of the IV bounds results reported in columns (2) and (4) of Table 4 (which differ according to which set of instruments is used) we find that \( \beta_{IVV1} < \beta_{IV} \), therefore \( \beta_{IVV1} \) is reported as the upper bound. The reported upper bounds of the confidence intervals are the upper bounds of the confidence intervals on the \( \beta_{IV} \) 2SLS estimates.

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Notes

1. The share of R&D spending made by European multinationals outside their home country has increased from 26% in 1995 to 44% in 2004 (OECD, 2008). A report to the European Commission documents a similar trend between 2003 and 2007 (Dachs et al., 2012).

2. See Table 2 of this paper. There has also been a decrease in the proportion of MNEs that employ all of their inventors at home, see Table 12 in Abramovsky et al. (2008).

3. Commonly, research has found that foreign competition from low-wage economies displaces low-skills workers in developed countries (Braconier and Ekholm, 2000; Antras et al., 2006; Simpson, 2011). In contrast, there is evidence that the increase in low-skilled jobs in developing countries may have positive effects on R&D jobs in developed countries (Criscuolo et al., 2010).

4. Assuming $\frac{\partial R}{\partial K} > 0$, $\frac{\partial^2 R}{\partial K^2} \leq 0$ and $\frac{\partial^2 K}{\partial I_{ij}^2} < 0$.

5. See, for instance, Griliches et al. (1984), Griliches (1990) and Hines and Jaffe (2001). Breschi and Lissoni (2009) and Nicholas (2009) provide applications of this type of data to look at the mobility of high-skilled workers and co-invention networks and the role of spatial diversity in invention.

6. It is widely known that innovative activity is highly concentrated in a small number of large multinational firms (Griliches, 1990; Criscuolo et al., 2010).

7. Again, we note that inventors are counted once per patent–industry. However, the qualitative conclusions from Table 1 remain if we instead ignore industry-level variation and count inventors once per patent application.

8. Abramovsky et al. (2008) (see section 6) further discuss the geography of European multinational’s innovative activities and how this has changed over time.

9. We have experimented with a large range of possible instruments, including (but not limited to) measures of R&D intensity in a country, the availability of research workers and high-skilled graduates, and measures of the tax burden. We have found that these instruments lack sufficient variation to produce precise results in the second stage (point estimates remain similar but standard errors are much larger). Results are available from the authors upon request.

10. Nevo and Rosen (2011) show that a 2SLS estimator using an imperfect instrument will fail to capture the direction of bias when the instrument and endogenous variable are positively correlated (as is the case with weighted GDP per capita growth and growth in foreign inventors).

11. The equivalent coefficient to that in Table 4 column (1) without fixed effects is 0.739 (standard error: 0.130), where again the bounds analysis suggests that this estimate is biased upwards.

12. Source: Main Science and Technology Indicators (accessed 2014); Business Expenditure on R&D (BERD) as a proportion of GDP. Figures refer to 2012.

13. As with a standard IV estimator, we have to also assume that all variables are identically and independently distributed and that all variables except the growth in foreign inventors are exogenous.