Offshoring high-skilled jobs: EU multinationals and domestic employment of inventors

Laura Abramovsky[†], Rachel Griffith[§], and Helen Miller*

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Abstract: Firms increasingly conduct research activities in many locations. Policy makers have expressed concern that this might displace high-skilled employment in the home country, where research has traditionally been focused. We provide empirical estimates of the impact that increasing the use of inventors (high-skilled researchers) abroad has on a firm's use of inventors at home. We identify this from within firm variation across industries. We consider an instrumental variables approach to tackle possible concerns about correlated shocks within firm-industry across locations. A commonly used instrumenting approach yields imperfect instruments; we adopt the approach of Nevo and Rosen (2011), which enables us to identify bounds on the estimate. While we cannot rule out the possibility that foreign inventors displace home inventors, our main result suggests that a 10% increase in the number of inventors abroad results in a 1.9% increase in the number of inventors at home.

JEL: F21; F23; O3; H3

Keywords: multinational firms, offshoring, innovation and patents

Correspondence: labramovsky@ifs.org.uk; rgriffith@ifs.org.uk; hmiller@ifs.org.uk

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[†] Institute for Fiscal Studies and University College London
[§] Institute for Fiscal Studies and University of Manchester
* Institute for Fiscal Studies

1 Introduction

There has been an expansion in the amount of high-tech investment and innovative activities carried out by US and European multinationals offshore.[1] Innovation activities in foreign research and development (R&D) centres are not only concerned with local product adaptation, but also with developing state-of-the-art technology (see, *inter alia*, Cantwell and Odile (1999), Zedtwitz and Gassman (2002), Branstetter (2006), Griffith and Miller (2011) and the references therein). Examples abound. For instance, in 2001 the UK-based GlaxoSmithkline opened its first R&D facility in Spain to come up with new drugs specifically designed for illnesses prevalent in developing countries.[2] Concern has been expressed by policy makers and in the media that, as firms employ more high-skilled foreign workers the employment opportunities for high-skilled workers at home will be reduced.[3]

Our contribution in this paper is to provide empirical estimates of the impact that increasing the use of inventors (high-skilled researchers) abroad has on a firm's use of inventors at home. Our identification strategy uses within firm variation across industries, allowing us to control for many confounding factors. In order to control for possible correlated within firm shocks at industry level we take a commonly used instrumenting approach. We show that this yields imperfect instruments and we adopt the empirical approach of Nevo and Rosen (2011), which enables us to identify bounds on the true estimate. While we cannot rule out the possibility that foreign inventors displace home inventors, our main result suggests that a 10% increase in the number of inventors abroad results in a 1.9% increase in the number of inventors at home.

There is a substantial body of evidence that foreign competition from low-wage economies can displace low-skills workers in developed countries (see, inter alia, Braconier and Ekholm (2000), Antras et al (2006), Harrison and McMillan (2011), and Simpson (2011)). However, there is little evidence on whether overseas employment of high-skill workers displaces the domestic employment of high-skilled workers. There are important reasons to believe that the relationship between high-skilled workers in different locations may be different to that of

[1] See UNCTAD (2005) and OECD (2008). For example, business sector R&D expenditure by affiliates abroad as a percentage of domestic R&D increased in many OECD countries in the ten years to 2005 (OECD 2008, Figure 1.5). e.g. in Germany it went from around 18% to about 25%.

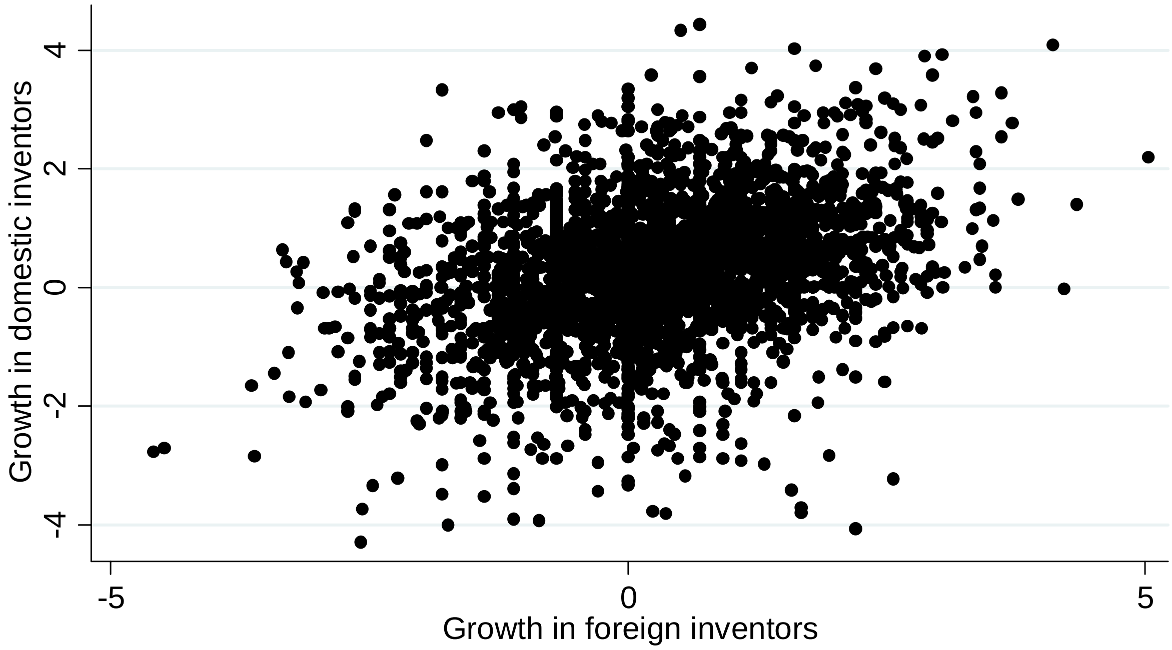
[2] http://www.globalhealthprogress.org/programs/ProgramDetail.php?id=774&parent=programs, last accessed 29th November 2011.

[3] See, for instance, Freeman (2006, 2009) and OECD (2007). Such concerns have also been widely publicised in the media. For two examples see: “Nightmare Scenarios”, The Economist, 5 October 2006; “How to Keep Your Job Onshore”, BusinessWeek, 20 August 2007.

low-skilled workers. Researchers in foreign locations may have expertise or knowledge that increases the research capacity or marginal product of home researchers. The recent literature has emphasised the increase in collaboration (e.g. Jones (2009)) and the importance of international research networks that combine researchers from a number of countries (Wuchty et al (2007)).[4] If foreign and domestic researchers are sufficiently complementary in the production of knowledge, then an increase in the employment of foreign researchers may increase the employment of domestic researchers.

We use data on the patenting activity of large European multinational firms to investigate this relationship. The raw correlation between the growth in the number of inventors located abroad (foreign inventors) and growth in the number of inventors based in the home country is positive, see Figure 1 (details of the data used are given in section 3). Of course, there are many potential confounding factors that may explain this raw correlation; it could arise simply because firms that have experienced positive demand shocks are increasing activity in all locations.

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



Note: The vertical and horizontal axes of the figure show normalised growth in domestic and foreign inventors respectively. Foreign inventors are defined as those located outside of a firm's home country. Each observation is the growth, defined as the log change, in inventors between two consecutive periods (1991-1995, 1996-2000, 2001-2005) for a parent firm in a specific industry. Inventors can be classified in at least one of six industries: Chemicals, Chemical Materials, Communications and Computing, Electrical and Electronics, Engineering and Pharmaceuticals. The number of observations is 3117. The number of parent firms is 736.
Source: Authors' calculation using PATSTAT matched to Amadeus and Derwent.

[4] See also Economist Intelligence Unit (2007) "Sharing the idea. The emergence of global innovation networks."

Our main empirical strategy relies on the identifying assumption that shocks to demand are common across industries within a firm-time period, and we rely on unobserved (exogenous) changes in the relative cost of employing foreign inventors to shift the optimal number of foreign inventors that a firm wants to employ. We observe firms operating in multiple industries and, within industry, operating in multiple countries. We use differential changes in the pattern of location of inventors within firms across industries.

A key concern with this approach is that it does not control for firm-industry specific shocks that are correlated across locations. To address this we take an instrumental variables approach akin to Card (2001), which exploits differential exposure to foreign cost shocks proxied by the extent of a firm's activities in the location in previous periods; this approach is used by Desai, Foley and Hines (2009) to investigate the impact of manufacturing activity at home and abroad. This IV estimate yields an implausibly high estimate. We postulate that this is because this is an imperfect instrument, in the sense that it has power but is not strictly exogenous. Drawing on recent work by Nevo and Rosen (2011), and under what we believe to be more palatable assumptions, we are able to show that the standard IV estimates are substantially upward biased, and we are able to estimate a bound on the true parameter. The bound does not rule out the possibility that the expansion in the use of foreign inventors has a modest impact on stimulating the domestic use of inventors at home within multinational firms, but nor does it rule out the possibility that it displaces them.

Our paper contributes to the growing empirical literature on the impact of multinationals' offshore activity on their home economy. This empirical literature has generally considered multinational firms from a single home country operating in manufacturing industries; although there is considerable variation in the methodologies and data used. We summarise the most relevant examples when discussing our results in the section 5. Most closely related is Desai, Foley and Hines (2009), which considers the effect of expansions of activity abroad on home activity (the intensive margin, that is conditional on location) of US multinationals operating in manufacturing industries and finds evidence that foreign investment stimulates domestic activity.[5] Another closely related paper is Harrison and McMillan (2011), which finds no effect on overall domestic labour demand of US manufacturing multinationals of changes in the wages that their affiliates pay in high-income countries. They do, however,

[5] In another context, Bresnahan et al (2002) also look at the relationship between two inputs (information communication technologies and high-skilled workers) and interpret a positive relationship as evidence of complementarities in production.

find a positive association between R&D expenditure in low- and high-income countries as a percentage of parent's sales and domestic labour demand.

The rest of the paper is organised as follows. Section 2 discusses the theoretical background and predictions. Section 3 describes the data. Section 4 describes our empirical strategy and identification issues. Section 5 presents our empirical results, and a final section summarises and discusses our findings.

2 Theoretical motivation

The impact of a multinational firm expanding its research activity offshore on research activity at home will depend on the degree of complementarity between these activities. Consider a firm that has operations in just two locations, home and abroad, and consider the effect of a decrease in the relative cost of inventors abroad on the number of inventors employed at home conditional on location; there will be two offsetting effects: a substitution and a scale effect. The substitution effect will be non-positive, as the firm substitutes towards the relatively cheaper foreign inventors. If the total amount of worldwide research activity (knowledge creation) of the firm were fixed then an increase in the use of offshore researchers would necessarily reduce the number at home. However, the decreased cost of producing knowledge will increase the firm's optimal knowledge output, and so produce a non-negative effect on the number of inventors employed at home, as the firm increases the scale of technology investment. Combining the substitution and scale effects, an overall positive impact of a change in the number of inventors abroad on the number at home requires that the scale effect outweighs the substitution effect. This in turn requires that inventors at home and abroad are sufficiently complementary in the production of knowledge – the substitution effect is smaller and the scale effect larger the greater the interaction in production.

To see this more clearly, and to understand the economic mechanisms underlying our empirical strategy, we draw on Desai et al (2009) and consider the following simple model. A multinational firm, *i,* generates an industry, *j,* specific knowledge output, $K \ (I_{ij,}^{h} I_{ij}^{a})$, by employing inventors, *I,* located in the home country, *h,* and abroad, a. We assume that the production of knowledge is separable across industries and from the production of final output. We allow the revenue, *R*, that a firm derives from its knowledge output in an industry to be affected by firm specific factors, F_i, such as changes in the worldwide demand for their final product, and industry specific factors, $T_{j,}$ such as a worldwide increase in the applicability of technologies used in an industry. Firms face a cost, $C(I_{ij,}^{h} I_{ij}^{a})$, of using inventors, which differs across firms, industries and countries. The firm's problem is therefore to choose the number of inventors at home and abroad to maximise profits:

$$max_{I_{ij}^{h} I_{ij}^{a}} R_{ij}\left(K \quad (I_{ij,}^{h} I_{ij}^{a}), F_i, T_j\right) - C\left(I_{ij}^{h}, I_{ij}^{a}\right) \tag{1}$$

The first-order conditions for the choice of inventors are:

$$\frac{\partial R}{\partial K_{ij}} \frac{\partial K_{ij}}{\partial I_{ij}^{a}} = C'_{\mathrm{I^a}} \tag{2}$$

$$\frac{\partial R}{\partial K_{ij}} \frac{\partial K_{ij}}{\partial I_{ij}^{h}} = C'_{\mathrm{I^h}} \tag{3}$$

From equations (2) and (3) we see that a change in foreign costs $C'_{\mathrm{I^a}}$ directly affects the number of inventors abroad and indirectly affects the number at home by affecting the optimal knowledge output, $K_{ij.}$ To see the relationship between growth in inventors at home (dI_{ij}^{h}) and abroad (dI_{ij}^{a}), we totally differentiate (3), setting the change in the cost of employing inventors at home to 0, ($C'_{\mathrm{I^h}} = 0$), to obtain:

$$dI_{ij}^{h} = \frac{\left[\frac{\partial R}{\partial K_{ij}} \frac{\partial^2 K_{ij}}{\partial I_{ij}^{h} \partial I_{ij}^{a}} + \frac{\partial^2 R}{\partial K_{ij}^2} \frac{\partial K_{ij}}{\partial I_{ij}^{h}} \frac{\partial K_{ij}}{\partial I_{ij}^{a}}\right] dI_{ij}^{a} + \frac{\partial K_{ij}}{\partial I_{ij}^{h}} \frac{\partial^2 R}{\partial K_{ij} \partial F_i} dF_i + \frac{\partial K_{ij}}{\partial I_{ij}^{h}} \frac{\partial^2 R}{\partial K_{ij} \partial T_j} dT_j}{-\left[\frac{\partial R}{\partial K_{ij}} \frac{\partial^2 K_{ij}}{\partial I_{ij}^{h\,2}} + \frac{\partial^2 R}{\partial K_{ij}^2} \left(\frac{\partial K_{ij}}{\partial I_{ij}^{h}}\right)^2\right]}. \tag{4}$$

The first term in the numerator reflects the impact of an exogenous change in foreign inventors on domestic inventors. The second term reflects the effect of firm specific factors, and the third term the impact of industry specific factors that can drive demand for knowledge at the firm-industry level.

Equation (4) shows that the sign of the relationship between dI_{ij}^{h} and dI_{ij}^{a} is ambiguous. Under the assumption that revenue is increasing with knowledge ($\partial R / \partial K_{ij} > 0$), but at a diminishing rate ($\partial^2 R / \partial {K_{ij}}^2 \leq 0$) and that there are diminishing marginal returns in the production of knowledge ($\partial^2 K_{ij} / \partial {I_{ij}^{h}}^2 < 0$) the denominator of (4) is positive. The sign of the affect of dI_{ij}^{a} on dI_{ij}^{h}, is therefore determined by the first bracket in the numerator. Given the assumptions above, the first term in that bracket will be positive only if $\partial^2 K_{ij} / dI_{ij}^h dI_{ij}^a > 0$. That is, if inventors at home and abroad are complementary in the production of knowledge. The second term in the bracket will be non-positive, because $\partial^2 R / \partial K_{ij}{}^2 \leq 0$. Combined, the first bracket will have a positive sign if and only if the first term outweighs the second, which in turn requires that inventors at home and abroad are *sufficiently* complementary in the production of knowledge. Whether this is the case is an empirical question. Furthermore, equation (4) suggests that industry (T_j) and firm (F_i) level variables, such as a positive firm level demand or industry level shock, could lead to an expansion of both inputs even if they are unrelated in production (i.e. if the first bracket in the numerator is zero).

We investigate the relationship between growth in inventors at home and abroad by estimating the empirical relationship suggested by (4). We discuss the empirical implementation of this specification further below, after introducing the data.

3 Data

3.1 Firm-level data

We use information on the inventors employed by large European multinational firms. We observe firms that have innovative activities in multiple industries and, within industries, both in their home country and in at least one foreign country (abroad). Our analysis is conditional on location choice. We use within firm variation in the change in inventors at home and abroad across different industries. Our identifying assumption is that the differential rates of within-firm changes (above the trends that are common across industries) represent changes that are not driven by firm-level shocks (that simultaneously determine employment of inventors at home and abroad).

Inventors are measured as those listed on European Patent Office (EPO) patent applications filed over the period 1991-2005.[6] These data provide information on all of the inventors that created the technology underlying a patent application, including where they were located (their residential address). We start with all patent applications made by corporate entities in European countries or the US. We match these firms, which may be subsidiaries of larger

[6] Data are recorded in the EPO's Worldwide Patent Statistical Database (PATSTAT). We use patent applications (not only granted patents) and the application priority date, which is the date closest to the point of invention.

firms, to their ultimate parent firm using information from accounts data and a range of out sources.[7] The result is information on the inventors, located anywhere in the world, listed on the patent applications filed directly or indirectly (via an associated US or European subsidiary) by European firms located in any of ten European countries.[8] Column (1) of Table 1 shows the total number of parent firms (many of which are associated with multiple subsidiaries) that file at least one patent application in the period 1991-2005 and have been matched to accounts data. Column (2) shows how the 32,590 firms are distributed across countries. We define inventors as being located abroad (at home) if they are in a different (the same) country as the headquarters of the parent firm.

Patent applications are an attractive measure of research activity because they provide a consistent measure of the location of inventors at the firm level across all countries. Patents have been used for this purpose in a number of applications.[9]

We classify patent applications (and therefore inventors) into industry groups using the Derwent Innovation Index, which is compiled by Thompson for commercial purposes and classifies patent applications according to the industries in which the invention has an application.[10] We use six broad industry groups: Chemicals, Chemical Materials, Communications and Computing, Electrical and Electronics, Engineering and Pharmaceuticals. An individual patent application can be classified into multiple industries, recognising that some technologies will have more than one possible application. In such cases, we allow the associated inventors to enter the measures of firm-industry growth for each relevant industry group.

Our interest in this paper is to consider the impact of firms expanding offshore activities on activities at home. We consider this at the intensive margin. That is, we look at changes in inventors for firms that are already operating at home and abroad, thereby abstracting from

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[7] We have matched the corporate applicants (i.e. excluding individuals, universities and research institutions) of EPO patent applications from a number of European countries and the US to firms listed in Bureau van Dijk's Amadeus and Icarus databases. In analysis, we use those firms that we have successfully matched to accounts data; matching rates vary by country. See Abramovsky *et al* (2008) for discussion of the matching process and resulting data.

[8] Firms are headquartered in one of the following ten countries: Belgium, Denmark, Finland, France, Germany, Italy, Netherlands, Norway, Sweden and UK.

[9] See, for instance, Griliches et al. (1984) and Griliches (1990). Breschi and Lissoni (2009) and Nicholas (2009) provide recent application 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.

[10] See Abramovsky et al (2008), section 5, for more details on this industry classification. Note that this is distinct from firm level industry classifications (such as NACE codes) which provide a broad measure of the primary industry in which a firm operates and from classifications attached to patent applications by patent offices (IPC codes) which document the embodied technology.

the initial decision over whether to put any inventors offshore. Across the period 1991-2005, we see that 81% of firms conduct no innovative activity offshore – for these firms all inventors are based in the firm's home country. On average these tend to be smaller firms in terms of the total number of patent applications filed across 1991-2005; at the median, firms with no inventors offshore file 5 patent applications while those with at least one inventor offshore file 1,397.

Column (3) of Table 1 shows the number of firms that are associated with a change in inventors both at home and in at least one foreign location between 2 consecutive 5-year periods (1991-1995, 1996-2000, 2001-2005). There are 1,241 such firms, distributed across countries as shown in column (4). For these firms we observe variation in the growth in inventors at home and abroad across firms and, in some cases, across two periods within a firm.

The variation in our data that allows us to identify the relationship between inventors at home and abroad comes from large multinationals that operate in multiple industries. It is widely know that innovative activities generally, and patenting specifically, is highly concentrated in large multinational firms.[11] We focus our attention on those firms that change their employment of inventors both at home and abroad in at least two different industries, in at least one period. Our main estimation sample therefore comprises 736 large European multinational firms, see column (5) of Table 1. Although these firms represent only a small proportion of total firms (2.3%) they account for the majority of patenting activities: 60.7% of inventors located in firms' home countries and 79.7% of the inventors located offshore. We observe variation in the growth in inventors at home and abroad across firms and, across industries within firms. In some cases we also observe firms in two periods.

This selection of firms is a restriction. We assume that whether a firm innovates at home and abroad in two or more industries in each of two consecutive periods is not systematically related to the relationship between foreign and home inventors. In the results section, we report that results for the larger sample of firms as a robustness check (column (3) in Table 1), showing that we find comparable results.

[11] UNCTAD (2005) figures show that more two-thirds of world business R&D is carried out by multinational firms. See also Bloom and Van Reenen (2002) and Criscuolo, Haskel, and Slaughter (2010).

Table 1: Number of firms, by country of parent firm, 1991-2005

	All firms		Firms with growth in inventors at home and abroad		Main estimation sample: Firms that innovate at home and abroad in two or more industries in each of two consecutive periods				
Parent country	Number of firms (1)	Distribution across countries (2)	Number of firms (3)	Distribution across countries (4)	Number of firms (5)	Distribution across countries (6)	% of all parent firms = (5)/(1) (7)	% of all home activity (8)	% of all foreign activity (9)
Belgium	787	*2.4*	57	*4.6*	39	*5.3*	5.0	70.5	74.9
Denmark	1,024	*3.1*	59	*4.8*	36	*4.89*	3.5	59.7	47.6
Finland	939	*2.9*	39	*3.1*	24	*3.26*	2.6	61.9	75.0
France	3,330	*10.2*	128	*10.3*	79	*10.73*	2.4	66.4	85.4
Germany	10,710	*32.9*	475	*38.3*	262	*35.6*	2.4	63.6	78.8
Italy	5,062	*15.5*	84	*6.8*	50	*6.79*	1.0	22.8	43.6
Netherlands	2,026	*6.2*	71	*5.7*	44	*5.98*	2.2	79.0	65.2
Norway	686	*2.1*	21	*1.7*	10	*1.36*	1.5	32.4	47.3
Sweden	1,932	*5.9*	92	*7.4*	55	*7.47*	2.8	55.7	70.6
UK	6,094	*18.7*	215	*17.3*	137	*18.61*	2.2	46.7	75.4
Total	32,590	*100*	1,241	*100*	736	*100*	2.3	60.7	79.7

Notes: Column (1) shows the total number of parent firms that have filed at least one patent application across 1991-2005 and have been matched to firm accounts data. Column (3) shows those firms that are associated a change in inventors in both the parent firm's home country and at least one other country between 2 consecutive periods. These firms underlie Figure 1. Column (5) shows those firms that change their employment of inventors both at home and abroad in at least two different industries. This is our main estimation sample. Columns (2), (4) and (6) show the distribution of firms across parent countries. Column (7) shows the proportion of all firms that are included in the main sample. Column (8) shows the inventors located in firms' home countries (home inventors) and included in our sample (i.e. listed on the patent applications of firms in column (5)) as a proportion of the total home inventors associated the full sample (column (1)). Column (9) produces the equivalent proportion for inventors located outside of firms' home countries (foreign inventors).
Sources: Authors' calculation using matched data from Amadeus, Icarus, PATSTAT and Derwent Innovation Index.

Table 2 shows the distribution of the foreign inventors in our sample across countries, by country of the parent firm.[12] Each inventor is counted once per patent (independently of the number of industries in which inventors has been classified).[13] The first row, for example, shows the proportion of the inventors located outside of Belgium but listed on the patent applications of Belgium firms that are located in each of the countries or country groups displayed in the columns. We see that the majority of foreign inventors in our sample were located in Western Europe (47%) or the US (46%). Very few were located in emerging economies. While emerging economies have become a more important locations for western multinationals innovative activities over time they still represent a small proportion of total activity (Griffith and Miller (2011), OECD (2008)).

Table 2: Distribution of location of foreign inventors, by country of parent firm, 1991-2005

	Location of foreign inventors									
Parent country	France	Germany	UK	Other Western Europe	US	Other Developed	Eastern Europe	Emerging Economies	All others	Total
Belgium	6.8	33.4	15.3	22.4	19.7	1.1	0.4	0.7	0.4	100
Denmark	1.5	11.4	5.0	27.5	46.7	4.3	2.7	0.8	0.2	100
Finland	1.0	16.7	17.1	21.0	32.0	5.1	2.4	3.8	0.9	100
France	-	35.3	4.6	19.2	34.3	3.1	1.4	2.0	0.3	100
Germany	9.5	-	8.3	30.9	39.9	6.1	1.7	1.9	1.7	100
Italy	22.6	20.6	10.0	17.6	21.4	3.6	2.0	1.3	0.9	100
Netherlands	12.3	26.1	14.9	10.5	29.9	3.3	0.5	2.1	0.4	100
Norway	15.3	39.6	7.2	27.1	8.8	0.9	0.4	0.6	0.2	100
Sweden	5.1	26.4	7.3	26.4	26.9	5.3	1.4	0.8	0.5	100
UK	2.1	4.1	-	12.1	75.5	3.4	0.8	1.3	0.6	100
Total	5.3	16.0	6.5	19.2	45.5	4.0	1.2	1.7	0.7	100

Notes: Each row shows the percentage of foreign inventors listed on patent applications filed by firms in the parent country indicated by the row and located in each country/country group. Included inventors are those in the main estimation sample. 'Other Western Europe' includes Austria, Belgium, Denmark, Finland, Greece, Iceland, Ireland, Italy, Luxembourg, 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 Estonia. 'Emerging Economies' includes South Africa, Brazil, China, India, Singapore, Taiwan and Korea.
Sources: Authors' calculation using matched data from Amadeus, Icarus and PATSTAT.

[12] Across the period 1991-2005, for all firms in our main sample, 67% of inventors were located in firms' home countries. This figure represents a fall from 70% in 1991-1995 to 65% in 2001-2005. There are substantial differences across the country of the parent firm in the extent to which activity is conducted at home.

[13] In the main sample, inventors are counted as many times as there are industries associated with the patent application on which they are listed. The patterns in Table 2 are not changed by counting inventors in that way.

3.2 Country level data

We also use country level data to proxy for the foreign costs of employing inventors. As discussed below, we use this as an instrument for changes in inventors abroad.

We use GDP per capita measured in US $ at constant prices and using constant PPPs and a 2005 base year. Data are from http://stats.oecd.org (measure: GDP, US $, constant prices, constant PPPs, OECD base year). We calculate growth as the log change across two periods in the mean of GDP per capita across the 5 years within a period. For the countries for which we do not have GDP data (which make up only a small fraction of inventors locations) we use the value for the EU27.

4 Empirical approach and identification strategy

4.1 Main empirical specification

Our interest is in estimating how the growth in the number of inventors a firm employs at home changes in response to an exogenous increase in the number of foreign inventors employed. Equation (4) suggested that there are two potentially confounding factors that may drive a positive association other than complementary in production: firm specific and industry specific factors that will potentially affect the employment of inventors in all countries. As a result simple OLS regression of the change in inventors at home on the change in inventors abroad will be biased. We estimate the following empirical counterpart of equation (4), which relates changes in inventors at home (ΔI_{ijt}^{h}) to changes in foreign inventors (ΔI_{ijt}^{a}), controlling for these confounding factors.

$$\Delta I_{ijt}^{h} = \beta \Delta I_{ijt}^{a} + \gamma_{it} + \delta_{j} + \varphi_{t} + u_{ijt} \qquad (6)$$

Firm-period effects are captured by γ_{it}, industry effects by δ_{j}, and common macro shocks by φ_{t}. We introduce a time, *t,* subscript here to indicate that some firms are observed in more than one period. Identification comes from variation in growth in inventors within individual firms (across industries and time), within industries (across firms) and over time. Using this approach we are able to control for many potentially confounding factors that may generate an association due to factors other than complementary in production, for example, shocks to firm demand or industry level demand or cost shocks.

Within a firm, at the industry level, the optimal number of foreign inventors relative to home inventors will be affected by exogenous changes in the cost of using foreign inventors (e.g. the wages Glaxo Smithkline pays to inventors working in pharmaceuticals in Spain) or in the return of using these inventors (say, for example, because a new public lab is established near a firm's R&D facility). We expect differential trends in the exogenous changes that drive the relative attractiveness of inventors across locations within industries. We compare trends in the use of inventors at home and abroad across industries within firms in order to isolate the effect of such exogenous variation. Put another way, we are able to control (using firm-time effects) for any firm-level shocks (that simultaneously determine the employment of inventors at home and abroad) that are common across different industries within a firm, and industry level effects to control for industry level shocks.

We define changes in inventors ($\Delta \mathrm{I}_{\mathrm{ijt}}$) as the log difference in the number of inventors, because the distribution of percentages changes is skewed (so better approximated by a log normal than a normal distribution), and because these have been shown to have nicer properties than the ordinary percentage to measure relative changes (Tornqvist et al (1985)).

The coefficient of interest, β, reflects the change in growth of domestic inventors for a one percentage point increase in the growth of foreign inventors.[14] A positive β would suggest that foreign activity does not displace home activity and be consistent with inventors at home and abroad being sufficiently complementary in the production of knowledge that, in response to an exogenous change in the costs of employing foreign inventors, the number of domestic inventors increases.

We assume that the idiosyncratic error term, u_{ijt}, which will capture firm-industry-year specific shocks, is heteroskedastic, thereby allowing for arbitrary correlation of shocks within a firm, and across technologies and periods; we adjust standard errors accordingly by clustering them at the firm level.

[14] Growth in the number of inventors (ΔI_{ijt}^{x} for *x=h,a*) is defined as the log changes in the number of inventors (i_{ijt}): $\Delta I_{ijt}^{x} = ln\left(i_{ijt}^{x}\right) - ln(i_{ijt-1}^{x})$. Therefore $\beta = \frac{\delta \Delta I_{ijt}^{h}}{\delta \Delta I_{ijt}^{a}} = \frac{\delta ln\left((i_{ijt}^{h}/i_{ijt-1}^{h})\right)}{\delta ln\left((i_{ijt}^{a}/i_{ijt-1}^{a})\right)}$ is the percentage change in the ratio of home inventors across two periods ($i_{ijt}^{h}/i_{ijt-1}^{h}$) for a one percent change in the ratio of foreign inventors across two periods ($i_{ijt}^{a}/i_{ijt-1}^{a}$).

4.2 *Identification*

A potential concern with our main empirical specification is that it does not account for firm-industry specific shocks that may lead to growth in inventors both at home and abroad. To address this we use an instrumental variable (IV) strategy, akin to the approach taken in Card (2001) and also used in Desai, Foley and Hines (2009), which exploits differential expose to changes in costs associated with employing foreign inventors.[15]

As in Desai, Foley and Hines (2009), we posit that changes in foreign countries' economic activity reflect changes in the productivity of workers in these locations, and hence changes in the real cost of employing them, that can be treated as exogenous to a multinational firm.

Firms will have different exposure to these shocks. We proxy this exposure using the geographic distribution of a firm's inventors in the previous period. This yields a firm-technology specific instruments for the growth in foreign inventors that combines country-specific measures of GDP per capita with firm-industry-specific country weights. The resulting instruments, Z_{ijt}, are :

$$Z_{ijt} = \sum_{c \epsilon ijt} \frac{I^{a}_{ijct-1}}{\sum_c I^{a}_{ijt-1}} \Delta GDP_{ct} \tag{5}$$

These weighted averages of foreign GDP growth will be used as instruments to capture exogenous changes of foreign employment of inventors. The location of foreign activity differs significantly across firms and within firms across industries. We assume that the distribution of activity in the previous period captures the firm exposure to cost shocks in that country, and that it is exogenous to any subsequent changes in domestic research activity.

We expect those firms that had inventors in countries that later experienced high growth are more likely to experience a decrease in their cost of doing research in that location and therefore to increase their investment in knowledge. Since the distribution of inventors across countries differs across firms and, within firms, across technologies, we expect different rates of growth of foreign activities, and correspondingly different outcomes from home inventors.

A concern we have is that this instrument is imperfect, in the sense that it has power to explain independent variation in inventors employed abroad, but that lagged inventor shares

[15] To empirically identify the effect of changes in the use of foreign inventors we would like ideally to measure exogenous changes in the cost of or return to using foreign inventors at the firm-location-technology level that would directly affect the number of foreign inventors, but not the number of home inventors. We have not been able to obtain such data.

may not be independent of the error term. For example, this could be true if foreign economic growth directly stimulates demand for firms' knowledge output and, as a consequence, inventor demand in all locations or if firms that were planning rapid expansion abroad were more likely to *choose* to locate in foreign countries that were growing - i.e. the initial distribution of inventors across foreign countries is endogenous to current domestic activities. To the extent that these factors are firm or industry specific and not firm-industry specific, they will be controlled for with firm and industry fixed effects.

We allow for the possibility of our instrument being imperfect. Nevo and Rosen (2011) set out a method for indentifying analytical bounds on parameters in the presence of imperfect instruments.

Let z_{ijt} denote our instrument. The standard IV assumptions require that the correlation between the instrument and the endogenous variable, $corr(\Delta I_{ijt}^{a}, z_{ijt})$, is significant and that the instrument is strictly exogenous, $corr(z_{ijt}, u_{ijt}) = 0$. It is the second (untestable) condition that raises concerns. Nevo and Rosen show (Lemma 2) that when an instrument and the endogenous variable are positively correlated, 2SLS using an imperfect instrument (i.e. where $corr(z_{ijt}, u_{ijt}) \neq 0$) will not even necessarily reveal the direction of the bias in an OLS estimator. However, it is possible to relax the strict exogeneity assumption and under alternative, and we believe more palatable in this setting, assumptions we are able to use information contained in the instrument to identify bounds on the true estimate. There are two key assumptions:[16]

1) $corr(\Delta I_{ijt}^{a}, u_{ijt}) * corr(z_{ijt}, u_{ijt}) \geq 0$

i.e. the correlation between the instrument and the error has the same sign as the correlation between the endogenous regressor and the error (assumption A3 in Nevo and Rosen). 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, as discussed before.

2) $|corr(\Delta I_{ijt}^{a}, u_{ijt})| \geq |corr(z_{ijt}, u_{ijt})|$

[16] 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 changes in foreign inventors are exogenous (Assumptions A1 and A2 in Nevo and Rosen).

i.e. the instrument is less endogenous than the regressor (assumption A4 in Nevo and Rosen). We think this is a reasonable assumption – the correlation between the instrument and the error terms should be not 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 ΔI^{a}_{ijt}.

Under these assumptions Nevo and Rosen show that the true β lies in the region B^{*}, where $B^{*} = (-\infty, \min\{\beta^{IV}, \beta^{IV}_{V(1)}\}]$ and β^{IV}_{V1} is the probability limit of the traditional 2SLS estimator for β when $V(1) = \sigma_{z}\Delta I^{a} - \sigma_{\Delta I^{a}} z$ is used as an instrument for ΔI^{a}. That is, β lies in an open bound that has a 2SLS estimate as the upper bound.

5 Results

Table 2 provide summary statistics for the dependent and explanatory variables and instrument we use. We see that at both the mean and median, growth in inventors abroad is similar to growth in inventors at home. There is substantial variation in the growth of inventors at home and abroad at the parent firm-industry level (the standard deviation is more than double the mean). Not surprisingly, the average growth in the firm-weighted measures of foreign GDP per capita, used in our IV specifications, is considerably lower than the variable it is used to instrument for, growth in foreign inventors.

Table 2. Descriptive statistics

	Min	Mean	Median	Max	Standard Deviation
Change in Domestic Inventors ΔI^{h}_{ijt}	-4.29	0.27	0.29	4.43	1.12
Change in Foreign Inventors ΔI^{a}_{ijt}	-4.58	0.28	0.29	5.03	1.16
Firm weighted change in foreign GDP per capita	-0.01	0.07	0.07	0.36	0.05

Notes: Notes: Number of observations (firm-industry-period) is 3117.
Sources: Authors' calculation using matched data from Amadeus, Icarus and PATSTAT, and OECD's Main Science and Technology Indicators.

Table 3 shows the results from estimating equation 5. Column 1 includes industry and time effects. Column 2 adds firm effects and column 3 adds firm-time effects. In all cases we find a positive estimate of β. The point estimate of β is reduced – and is statistically lower at the 5% level - with the addition of firm effects. There are no statistical differences between the results with firm and firm-time effects. Overall, this is in line with our expectations – the firm and firm-time effects are operating to net out unobservable factors such as demand shocks or productivity shocks that drive a positive correlation between changes in inventors at home and abroad. This suggests that foreign activity does not displace home activity, and can be interpreted as evidence that inventors at home and abroad are sufficiently complementary in the production of knowledge. Using the results of column (3) as our main point of reference, this means that an increase in 10% in inventors abroad there will be a 1.9% in inventors at home.

We believe that the estimate in column (3) already nets out many of the most important confounding factors and therefore reflects the exogenous effect of changes in the use of foreign inventors on domestic inventors. However, the coefficient reported in column (3) would still be positively biased in the presence of significant firm-industry specific shocks that simultaneously affect growth in inventors at home and abroad.

In columns (4)-(6) we instrument changes in inventors abroad using firm-industry-time specific measures of foreign GDP growth. We repeat the pattern of effects across the three columns. The associated first stages are shown in columns (1)-(3) of Table 4. We see that the instrument has significant explanatory power; the growth in the GDP per capita of countries in which firms previously employed inventors is positively associated with growth in the number of inventors employed in foreign locations.

The IV results in Table 3 suggest a substantial *increase* in the estimate of β. Although we note that the IV estimate is much less precise, so it is not statistically different from the OLS estimate, the point estimate with firm-period fixed effects is much higher relative to the estimates in columns (1)-(3), e.g. it is around 75% higher when comparing column (6) to (3). We find this result puzzling: we expect a positive correlation between the endogenous variable and the error term and therefore upward bias in the OLS coefficient. This pattern was also observed in Desai et al (2009).

Our explanation of this result is that the instrument is imperfect, in which case 2SLS does not necessarily reveal even the sign of the bias in the OLS estimate.[17]

[17] Another reason why the IV point estimate might be higher than the OLS estimate is if the relationship between inventors at home and abroad is heterogeneous across firms and technologies. The standard IV estimate will capture the impact for those firm for which we observe variation in the instrument (the so-called "local average treatment effect"). This could lead to IV estimates that are higher than OLS ones.

Following Nevo and Rosen (2011) we calculate bounds, based on the assumptions 1 and 2 discussed above. For each category of fixed effects, we calculate the 2SLS estimator using $V(1) = \sigma_z \Delta I^a - \sigma_{\Delta I^a} z$ as an instrument for ΔI^a. Recall that the true β lies in the region B^*, where $B^* = (-\infty, \min\{\beta^{IV}, \beta^{IV}_{V(1)}\}]$. We find that in each case $\beta^{IV}_{V1} < \beta^{IV}$, therefore β^{IV}_{V1} determines the upper bound. The associated bounds are reported in columns (7) and (9) of Table 3. Considering column (9) we can conclude that $\beta \leq 0.164$. The confidence interval of the bound includes the estimate in column (3) (our main estimate) but not the IV estimate in column (6).

This is an important result. It shows that (under the relevant assumptions) the OLS estimator, accounting for firm level effects, performs better than the 2SLS estimator.

If one believes that there are significant firm-industry specific shocks (in addition to firm-time shocks), our results suggest that we cannot reject a positive relationship, but given that we are only able to identify an open bound, it does not rule out a zero or negative relationship.

The results in tables 3 and 4 are based in a sample of multinational patenting firms that operate in multiple industries. One may be concerned that selecting this sample of firms is problematic. As a robustness check, Table 5 presents results using a larger sample of firms that display growth at home and abroad in at least one industry (those in column (3) of Table 1). We calculate growth in inventors at the firm level (rather than at the firm-industry level) and exploit variation in growth across firms and across time. The drawback of using this sample is that we cannot control for firm fixed effects.

Column (1) of Table 5 presents the OLS result, which is similar to the OLS result without firm effects using our more restrictive sample. The same is true when IV and Nevo and Rosen methods are applied in columns (2) and (3) respectively. The results are similar to columns (4) and (7) of Table 3.

Table 3: Effects of growth in foreign inventors on growth in domestic inventors; main sample

Dependent variable: growth in home inventors, ΔI^{h}_{ijt}	(1) OLS	(2) OLS	(3) OLS	(4) IV	(5) IV	(6) IV	(7) IV bounds	(8) IV bounds	(9) IV bounds
Growth in foreign inventors, ΔI^{a}_{ijt}	0.33	0.211	0.19	0.651	0.34	0.329	(-∞, 0.269]	(-∞, 0.184]	(-∞, 0.164]
	[0.025]**	[0.033]**	[0.027]**	[0.155]**	[0.11]**	[0.149]*			
	(0.281 - 0.379)**	(0.146 - 0.276)**	(0.136 - 0.244)**	(0.347 - 0.955)**	(0.124 - 0.556)**	(0.038 - 0.621)*	(-∞, 0. 342)	(-∞, 0. 257)	(-∞, 0.230)
Industry and time effects, δ_j, φ_t	yes	yes	yes	yes	yes	yes	yes	yes	yes
Firm effects, γ_i	no	yes	yes	no	yes	yes	no	yes	yes
Firm-time effects, γ_{it}	no	no	yes	no	no	yes	no	no	yes
R-squared	0.191	0.655	0.82	0.092	0.183	0.042			
Joint significance of instruments									
F statistic				39.33	33.44	16.03	0.19		
P value				0.00	0.00	0.00			

Notes: The number of observations (firm-industry-period) is 3117. There are 736 firms (i) and 1,035 firm-time (it) effects. Robust standard errors clustered at the firm level are displayed in squared brackets. 95% confidence intervals are displayed in brackets. Columns (7)-(9) report confidence intervals for the bound results. The upper bound of the confidence interval is the upper bound of the confidence interval on the β^{IV}_{V1} *estimate. In columns (4)-(6) the instrument is a firm-industry- period weighted measure of foreign GDP per capita. * significant at 5%; ** significant at 1%.*

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Table 4: Growth in foreign inventors and changes in foreign costs: first stages

Dependent variable: growth in foreign inventors	(1) IV: GDP	(2) IV: GDP, FE Firm	(3) IV: GDP, FE Firm-Period
Firm-weighted growth in foreign GDP	3.913	6.468	4.138
	(0.624)**	(1.118)**	(1.033)**
Industry and time effects	yes	yes	yes
Firm effects	no	yes	yes
Firm-time effects	no	no	yes
Observations	3117	3117	3117
R-squared	0.11	0.56	0.77
Joint significance of instruments			
F statistic	39.33	33.44	16.03
P value	0.00	0.00	0.00

Notes: See notes to Table 3. Columns (1)-(3) correspond to the first stages of the 2SLS estimates reported in columns (4)-(6) respectively in Table 3.

Table 5: Effects of growth in foreign inventors on growth in domestic inventors

Dependent variable: growth in home inventors, ΔI_{it}^{h}	(1) OLS	(2) IV	(3) IV bounds
Growth in foreign inventors, ΔI_{it}^{a}	0.337	0.458	(-∞, 0.32]
	[0.024]**	[0.195]*	(-∞, 0.393)
	(0.289 - 0.385)**	(0.076 - 0.840)*	
Industry and time effects, δ_j, φ_t	yes	Yes	yes
R-squared	0.22	0.21	
Joint significance of instruments			
F statistic			
P value			

Notes: Growth in inventors is calculated at the firm-period level. Number of observations (firm-period) is 1,732. There are 1,241 firms (*i*). Robust standard errors clustered at the firm level are displayed in squared brackets. 95% confidence intervals are displayed in brackets. * significant at 5%; ** significant at 1%. Columns 3 reports confidence intervals for the bound results.
Sources:

How do these results compare to other results in the literature that look at the within-firm effects of using foreign inputs on the demand for domestic inputs? There is no clear evidence on whether overseas employment of high-skill workers displaces the domestic employment of this type of workers within multinational firms. To date much of the empirical literature has considered the impact of multinationals' decisions to use foreign capital or employees in the production of manufactured goods. There are important differences in the methods used, data and time periods covered. A key difference is whether studies use data on foreign wages and produce estimates of cross-price elasticities or estimates of the constant output elasticity of substitution, or use data on growth in activities at home and abroad and look at the impact of using foreign inputs on the demand for domestic inputs. Another key difference is whether the type of foreign investment is being considered, i.e. whether foreign investment is of a horizontal or vertical nature.

Harrison and McMillan (2011) estimate the marginal effect of changes in foreign wages on home employment using micro data on US multinationals for the period 1982-1999, conditional on investment abroad and using a standard labour demand equation. They find that home employment in the US is increased when foreign wages decrease in low-wage countries for firms that engage in vertical foreign investment (VFDI), which is consistent with the idea of complementarities between inputs abroad and home. However, they find no effect of foreign wages in high-wage countries on US employment of these multinationals, but they do not distinguish employment at home by skill level. Muendler and Becker (2010) estimate constant output elasticities of substitutions in simultaneous system of share equations derived from a translog cost function. They consider labour at home and in different foreign regions for German multinationals and find that, conditional on investment abroad, distant regions (potentially those with low wages and lower skills relative to Germany) do not substitute for labour at home, which is consistent with the findings of Harrison and McMillan (2011). Borga (2005) looks at the correlation between employment of US multinationals at home and abroad, but does not control for common shocks or characteristics that may drive both trends simultaneously. Desai et al (2009) look at the impact of expansions of activity abroad on home activity of US multinationals. They use an instrument variable approach to isolate exogenous variation in expansion in foreign activities, using firm specific weighted growth rates in foreign gross domestic product per capita as an instrument. Similar to our findings, they find that firms that expand abroad also simultaneously expand their domestic activities.

6 Summary and discussion

Our contribution in this paper has been to provide empirical estimates of the relationship between European multinational’s employment of inventors (high skilled researchers) at home and abroad. It is motivated by concerns that, as firms employ more high skilled workers abroad, there will be detrimental effects on the employment of inventors at home.

Identification of the effect of growth in foreign inventors on growth in home inventors comes from the fact that we observe the same firm operating in multiple industries and multiple time periods. This allows us to for common correlated firm-level shocks. However, this strategy relies on the assumption that there are not shocks at the firm-industry level that are correlated within a firm across locations. To address this concern we use a standard instrumental variables approach that relies on variation in the intensity of exposure to shocks to foreign costs. Our results raise concerns that this instrument is imperfect – that is, it is a significant predictor of growth in foreign inventors but is not strictly exogenous. We allow for this possibility by estimating a bound for our coefficient of interest under a set of assumptions that we find more plausible.

Our main result suggests that a 10% increase in the number of inventors abroad results in a 1.9% increase in the number of inventors at home. The bounds we estimate do not rule out this estimate, but we also cannot reject the proposition that increasing the use of foreign inventors will displace domestic inventors.

A positive relationship is consistent with complementarities in production and suggests that growth in foreign inventors stimulates the growth of inventors at home. Because we estimate the reduced form relationship between inventors at home and abroad we do not identify the direct mechanism by which they are related. We cannot rule out that a positive relationship between employment abroad and at home is due to other factors than complementarities.

We also note two other important caveats that we have not addressed. First, we do not consider the decision of firms to start offshoring high skilled researchers – our analysis identifies the relationship between growth in inventors at home and aboard for large firms which already operate in multiple countries (see Harrison an McMillan (2011). Second, we do not consider the effect of multinational firms' expansions abroad on other domestic activities within firms, including other innovative activities such as development, or on other firms (see Braconier and Ekholm (2000)).

Our results speak to a number of policy related concerns. We speak directly to concerns that Western European multinationals will substitute away from high skilled researchers in home countries towards those located abroad. Similar concerns have been raised (and studied) in relation to other groups of workers. The key difference in this context is that high skilled researchers are associated with the innovations and technological advances that underpin growth in developed economies. They are also intrinsically linked to the important spillovers that arise in the creation of new ideas – inventors embody tacit knowledge that others, often those in close geographical proximity, benefit from. For these reason, governments are keen to encourage firms to undertake innovative activities in their countries.

There are also long running concerns over the relatively low investment in R&D in Western European countries compared to the US and, more recently China.[18] There are a number of possible reasons for this.[19] Our results suggest that, over the previous two decades, this trend has not necessarily been the direct result of European multinational's moving innovative activities offshore.

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[18] In 2000 the Lisbon Agenda set an explicit target to increase R&D undertaken in the EU to 3 per cent of GDP by 2010. This target has been missed: the latest figures (2007) show that business expenditure on R&D in the EU-15 amounts to 1.2% of GDP, compared with 1.9% in the US and 1.1% in China. As emphasized before, this is a major concern in Western European countries, since investment in technology is a key factor in cross-country differences in economic growth and income (see Acemoglu 2008).

[19] For example, supply side factors such as a shortage in the supply of workers with the right type of skills or demand side factors that may result in lower demand-driven innovations (see, for example, Soete (2010)).

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