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# Global engagement in R&D: a portrait of biopharmaceutical patenting firms

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**Abstract**

This paper provides a novel portrait of firms engaging in the international use of inventors. I focus on drug discovery activity of pharmaceutical and biotechnological firms head-quartered in Europe, over the period 1996-2005. An important part of the most high-valued added R&D activities are conducted by inventors, who are engaged in the creation of new technologies. I use a novel and particularly rich dataset that provides a comparable picture across host locations and over time of research activity of EU firms. The main results are that firm-level heterogeneity is a key feature in the internationalisation of inventors and this is similar to patterns from data analysing good and service traders and MNEs. Furthermore, host country distance characteristics are associated with the number of inventors in a similar fashion to patterns found in gravity models explaining good and service trade.

**Keywords:** International trade, multinational firms, inventors, R&D

**JEL classification: F14; F19; F23; O31**

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# 1 Introduction

Rising globalisation, led by falling costs of trade and of information and communication technologies (ICT), means that the complex trade-offs governing firms decisions to locate strategic activities such as research and development (R&D) have been changing over the last two decades. Historically, firms based in developed economies dominated global private R&D activities. More importantly, the traditional setting was that firms, including multinationals (MNE), co-located their R&D activities in a single location and within their headquarters due to a number of factors. These include economies of scale and scope, geographically mediated knowledge spillovers and home countries' relative advantage in terms of skilled researchers and supply of publicly generated state-of-the-art technology.[1] Weak intellectual property protection in developing countries, lack of skilled labour and research infrastructure and smaller markets also contributed to a home bias in the location of R&D activities of firms from developed countries. All these factors have been changing significantly[2] and resulted in the internationalisation of R&D and the increasing importance of emerging economies as host-economies attracting innovation activity.[3] R&D activities, and in particular the generation of new ideas, are at the top of the distribution of activities in terms of value-added and of spillovers generation. As such they are crucial for economic growth (see, for example, Romer (1986) and Aghion and Howitt (1997)). Given all this, it is unsurprising that there are increasing concerns about losing the comparative advantage in these activities developed economies have possessed historically. This has been reflected in the public policy debate,that had spurred a vast number of economic studies.[4]

The 2013 "EU Industrial R&D Investment Scoreboard"[5], which provides information about the top 2000 firms ranked in terms of the R&D spending worldwide, showed that firms headquartered in US, EU and Japan still dominate the ranking, but firms from emerging markets such as Brazil, China, Korea and Taiwan also form part of this group. The pharmaceutical and biotechnology industry is the top R&D investor, accounting for almost 20% of R&D spending of these 2000 firms,[6] and a similar share of total R&D spending by firms in EU. Firms operating in that industry exhibit a higher R&D intensity relative to other industries and

[1]For a brief revision of the motivations driving R&D location decisions and collaboration for innovation see, for instance, Abramovsky et al. (2007) and Abramovsky and Simpson (2011).

[2]For example, Abramovsky and Griffith (2006) look at the importance of ICT investment in enabling the purchase of business services from abroad, which include R&D services.

[3]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 recent report to the European Commission documents a similar trend between 2003 and 2007 for a selected group of developed countries for which they observe Business Expenditure on R&D (BERD) performed by domestic firms in foreign countries as a share of total BERD, Sweden and Switzerland, see Dachs et al. (2012).

[4]See, for example, the number of entries about offshoring and innovation recently posted in the well known European research-based policy-analysis blog voxeu http://www.voxeu.org/taxonomy/term/305. Many entries discuss the concerns that offshoring innovation activities will follow the offshoring of low-skilled activities to low-wage economies, although there is a lack of discussion about actual innovation offshoring. For instance, see "Does offshoring hurt domestic innovation activities?" by Dachs, Ebersberger, Kinkel and Som from 07 September 2013 shows evidence that firms engaged in production offshoring innovate more at home relative to comparable non-offshoring firms based on observables.

[5]EU (2013).

[6]The other two top sectors are Technology Hardware & Equipment and Automobiles & Parts, which together with pharmaceutical and biotechnology account for 50% of total R&D spending of the firms included in the R&D scoreboard.

this industry dominates the top 50 firms in this ranking. Furthermore, top R&D spenders have experienced an increase in the level of employment worldwide and in the number of greenfield projects (including R&D labs), led by EU firms, in a range of countries, including emerging countries. The Scoreboard data do not inform about the actual geographical distribution of the number of employees, or firm's R&D spending, and hence it is not possible to characterise the internationalisation of R&D activities beyond the number of new greenfield R&D projects using this data source. Furthermore, it is difficult to get data to measure R&D activities at the firm level consistently across firms and countries.

In this paper I fill this gap by providing a description of the geographic distribution of inventors engaged in drug discovery activity of biopharmaceutical firms head-quartered in Europe, over the period 1996-2005. An important part of the most high-valued added R&D activities are conducted by inventors, who are engaged in the creation of new technologies. I use a novel and particularly rich dataset that provides a comparable picture across host locations and over time of research activity of EU firms. In particular, the data matches firm level accounting data with information on the patents that those firms and their subsidiaries have applied for at the European Patents Office.[7] This allows me to distinguish between patenting firms that are purely domestic and those that are multinational (MNE)[8] and further divide firms according to their engagement in the usage of foreign inventors. I use the recent literature on international trade, which emphasizes the links between firm-level heterogeneity in productivity and firm's global engagement (see, for instance, Bernard et al. (2003) and Bernard et al. (2009) for US and Eaton et al. (2011) for French manufacturing firms trading goods and Breinlich and Criscuolo (2011) for UK firms trading services), to guide my exploration of the data.[9] I document how many firms are globally engaged in this dimension, how this relates to firm characteristics such as size and the quality of patents, with how many countries firms are engaged with, the characteristics of those countries, and the concentration of foreign inventors across firms.

To the best of my knowledge, little is known about the level of heterogeneity of innovative firms in terms of their internationalisation of their research activities at the extensive and intensive margins. The papers mentioned in the previous paragraph do not consider R&D activities explicitly. The use of foreign inventors can be seen as analogous to trade in services to the extent that firms are buying professional services produced by researchers either outside the firm or within the firm, through a foreign subsidiary, and contributing to the international flows of ideas and knowledge.[10] The first set of results show that firm-level heterogeneity is a key feature in the internationalisation of inventors. A small proportion of firms use foreign inventors but these firms are larger, account for the majority of drug discovery activity, and the value of their patent portfolio is higher for those that are also multinational firms. There are important differences across firms

[7] Abramovsky et al (2008) describe the data in detail, more information is provided in Section 2 of this Chapter.

[8] Multinational firms are defined as having at least a productive subsidiary outside the home country in the US or European countries.

[9] Melitz (2003) is among the seminal theoretical papers in this area.

[10] My measure of foreign inventors does not allow me to distinguish between these two types of transactions for MNE firms.

active in using foreign inventors for drug discovery activity in terms of number of foreign inventors used, the number of foreign locations they are present in and the number of inventors per location. The number of inventors is concentrated in a small number of globally engaged firms, and activity is also concetrated within firms in a small number of locations, even for those firms that operate in multiple foreign locations. The intensive margin is twice as important as the extensive margin in accounting for firm-level (number of inventors per foreign location) and country-level variation (number of inventors per firm) in the usage of foreign inventors. Second, in terms of the country characteristics, most of the foreign inventors are located in developed countries, with the US accounting for almost half of all foreign inventors. Finally, the number of inventors is higher in host countries have a stronger IPR protection, have a larger market, are contiguous to and share a common language with the firm's home country and is lower in countries that are geographically more distant to the firm's home country. When looking at variation in the locations within a firm, results also suggest that the number of inventors is higher in host countries that have a stronger production of academic research in exact sciences.

I find that the first set of results are very similar to the evidence presented in Breinlich and Criscuolo (2011) for UK services traders and to the characteristics of firms engaged in goods trade analysed, for example, in Bernard et al. (2009). This suggests that models such as Melitz (2003) are a good starting point for modelling the globalisation of drug discovery activity at the firm level, which some people refer to as offshoring of innovation activities.[11] Melitz (2003) builds a general equilibrium model with firm level exogenous productivity draws, combined with monopolistic competition and fixed costs of operating outside the home market. This determine which firms can afford the costs of engaging globally, either through good exports or through manufacturing subsidiaries. A key prediction is that trade liberalization forces the least productive firms to exit and expands the market-share of the most productive ones, resulting in an increase in average industry productivity. One way to adapt this model could be to apply it to the production of knowledge instead of manufacturing production.

The facts presented in this paper show that these are key aspects to consider when modelling the aggregate trends in the internationalisation of inventors and explaining adjustment mechanisms through which the decrease in the barriers to globalisation can impact aggregate patterns. Abramovsky et al. (2012) is a first step in the direction of answering this question by providing an empirical analysis of the firm-level effect of increases in the employment of foreign inventors on the home employment of such workers for multinational firms.

This paper relates to different strands of the literature. First, it contributes to the literature on international trade, by looking at the international trade of ideas and knowledge, and emphasizes the importance of

[11]Many economists, such as Breinlich and Criscuolo (2011) and Markusen and Strand (2009), argue that trade good models are a good starting point to model trade and more generally international engagement in services.

firm-level heterogeneity as discussed previously (see, Breinlich and Criscuolo (2011), Bernard et al. (2003), Bernard et al. (2009) and Eaton et al. (2011) among others). Second, it contributes to the literature about firms' choices over where to locate R&D abroad and the underlying drivers. For example, Belderbos et al. (2011) provide descriptive evidence on the location choices of new R&D hubs for 175 high-technology European, Japanese and US multinational firms and how this relates to countries research strength in the relevant field, in particular university-generated research. They also use foreign inventors to identify the new R&D locations. Abramovsky et al. (2008) describe how the propensity to locate research activity abroad (the extensive margin) and how much firms do in each location (the intensive margin) vary across time, country of origin and industry for European multinational firms. Finally, it contributes to the literature investigating the globalisation of pharmaceutical companies. For example, Cockburn and Slaughter (2010) provides a picture of US multinational firms operating in the biopharmaceutical industry and discuss the specific features of the industry. US multinational firms have increased home employment and value added proportionally more than employment and value added in their foreign subsidiaries, hence resulting in a higher concentration of activity in the US. They only have information about R&D expenditure of these firms for the year 2004, and he documents that this is also highly concentrated in the US.

The rest of the paper is structured as follows. Section 2 describes the data. Section 3 provides the set of novel stylised facts. Section 4 concludes.

# 2 Data and descriptive statistics

My main interest is to characterise the degree of internationalisation of drug discovery activities of biopharmaceutical firms and how this differs across firms at the extensive and intensive margin. In this section I describe the firm-level data I use for this analysis, how I define the sample of biopharmaceutical firms and provide information about the set of characteristics I use to describe the countries.

## 2.1 Firm and patent data

I use inventors listed in patents to capture firm's drug discovery activity. The data result from matching patents filed at the European Patent Office (EPO) to accounting and ownership data of European firms from the Amadeus database. It captures the worldwide activities of European firms, including those activities which are carried out by US-based or European-based subsidiaries in any of 18 European countries (the 11 listed in the first column of Table 2.1 plus Czech Republic, Greece, Ireland, Luxembourg, Poland, Portugal, Spain, Swizerland). The data and the matching process is described in more detail in Abramovsky et al.

(2008). The ownership information is fixed at a point in time (2004). Accounts data also provide the primary industry of the parent company, which I use to identify pharmaceutical and biotechnological firms.

Patent documents contain a mapping between the location of patent applicants (often firms) and that of inventors, many of which are located in a different country to the applicant firm. This provides a measure of the activities which firms undertake outside of the domestic market. However, the firms that apply for patents may themselves be subsidiaries of larger, often multinational, firms. The distinction between applicants and parent firms is not a trivial one; for example, around 25% of applicants which are associated with UK parent firms are based outside of the UK. The location of inventors listed in patents have been widely used as indicators of the location of inventive activity in the literature (see for example, Griliches (1990), Griliches et al. (1984) and Griffith et al. (2006) among others). Belderbos et al. (2011) provide more recent evidence that inventors listed in patents and their location are a good proxy for the location of R&D activity, by comparing the location of inventors with information on R&D facilities for Japanese multinational firms.

Patents are classified as drug related-patents using the Derwent (manual code) classification. A drug patent is one that belongs to any of the following pharmaceutical compounds, associated with multiple or with a single specific pharmaceutical activity like cancer treatment (the latter captured in category B14), and categories: "B01 Steroids"; "B02 Antibiotics"; "B03 Vitamins"; "B04 Natural products, polymers"; "B05 Miscellaneous (other organics and inorganic compounds)"; "B06 Heterocyclic fused ring"; "B07 Heterocyclics mononuclear"; "B08 Aromatics Polycarbocyclic"; "B09 Alicyclics Polycarbocyclic"; "B10 Aromatics and Cycloaliphatics (Mono and Bicuclic)"; "B11 Processes, Apparatus"; "B12 Diagnostic and Formulation Types"; "B14 Pharmaceutical activities".

I am also interested in looking at whether firms that use foreign inventors for their drug discovery activity are distinct in terms of the quality of their patents or the type of knowledge embedded in their patents. It is well recognised that patent value and quality present high degree of skewness (see, for instance, Pakes (1985) and Pakes (1986), Blundell et al. (1999), Lanjouw and Schankerman (2004) and Hall et al. (2007)). I observe whether a patent belongs to a triadic patent family, that is if the patent has been filed at each of the following offices: EPO, US Patent and Trademark Office, and the Japan Patent Office. There is a monetary cost to apply to all three offices, therefore this signals higher expected returns. Following the OECD (2012) and Griffith et al. (2014) I consider triadic patents as high quality patents. 50% of all patents belonging to the sample of firms in 2.1 are triadic and 48% drugs patents are triadic. I also examine whether firms globally engaged in drug discovery activity produce more basic knowledge as measured by whether the patent cites at least one academic publication.

## 2.2 Sample of biopharmaceutical firms

I define biopharmaceutical patenting firms active in drug discovery activity in each of the two periods (1996-2000 and 2001-2005) as (1) patenting firms operating in any of these two industries: Manufacture of basic pharmaceutical products (NACE Rev.1.1, primary code 24.41), or Manufacture of pharmaceutical preparations (NACE code 24.42) with at least one drug discovery patent; or (2) patenting firms operating in the production of R&D services (NACE code 73.10) or Management services (NACE cide 74.15) with 75% of their patents portfolio belonging to drug discovery. Firms in Management services include big players such as leading pharmaceutical firm Sanofi-Aventis.

Firms head-quartered in a country are classified into those which only operate in the national market and those which are 'multinational', where a firm is deemed to be a multinational if it has a productive subsidiary outside of the home country. A firm's foreign subsidiary is classed as productive if its assets, turnover and employment meet a set of criteria based on the European Union's definition of a small company. This information comes from the accounts data, Amadeus.

Table 2.1 below describes the sample of firms for 2001-2005 by country of origin, industry and multinational status. The last row shows that there are 704 patenting firms engaged in drug discovery activity and headquartered in Europe. The first column shows that almost half of the firms are concentrated in Germany (23%) and Great Britain (21%), followed by France (14.1%), Sweden (11.5%) and Italy (9.8%); a large share of the firms come from R&D services (63.2%); and only 14.2% operate multinationally. The last row show that these firms hold a total of 12,287 patents (column 2) and more than two thirds, or 8,642, are related to drug discovery (column 3). Looking at drug patents, more than half of these are owned by German (28.4%) and British (30.6%) firms, again followed by France (12.2%) and the Netherlands (9.1%). Drug patents are evenly distributed across industries. However, MNEs account for the majority of these patents (and even more of all patents in this sample) despite accounting for less than 15% of firms. This is reflected in the average number of patents per firm. The last column show that on average firms own 499 drug patents over the period 2001-2005. Multinational firms are almost 30 times bigger than domestic firms in terms of drug patents (and almost 50 times bigger in terms of any patents). Looking at the size of firms in terms of drug patents across countries, the biggest firms are headquartered in Great Britain (780), Germany (614), the Netherlands (263), and France (241). And firms in all industries except R&D services are bigger than the average. This suggests that firms operating in R&D services account for over half of all firms and a quarter of all drug patents but are usually small domestic and specialised (by definition, at least 75% of their patents are related to drug discovery activity) firms.

Table 2.1: *Sample of biopharmaceutical patenting firms, 2001-2005*

| | (1) Number of Firms (%) | (2) Number of Patents (%) | (3) Number of Drug Patents (%) | (4) Average Patents per firm | (5) Average Drug patents per firm |
|---|---|---|---|---|---|
| **Country of parent firm** | 100.0 | 100.0 | 100.0 | 971 | 499 |
| Belgium | 2.6 | 0.4 | 0.6 | 7 | 6 |
| Denmark | 6.0 | 4.2 | 5.3 | 72 | 63 |
| Finland | 2.3 | 1.2 | 1.5 | 25 | 21 |
| France | 14.1 | 9.5 | 12.2 | 261 | 241 |
| Germany | 23.0 | 36.6 | 28.4 | 1,631 | 614 |
| Great Britain | 21.0 | 26.2 | 30.6 | 922 | 780 |
| Italy | 9.8 | 4.8 | 5.3 | 46 | 31 |
| Netherlands | 3.7 | 11.7 | 9.1 | 470 | 263 |
| Norway | 1.4 | 0.3 | 0.3 | 7 | 7 |
| Spain | 4.7 | 2.4 | 3.0 | 62 | 56 |
| Sweden | 11.5 | 2.8 | 3.6 | 17 | 15 |
| **Parent firm industry** | 100.0 | 100.0 | 100.0 | 971 | 499 |
| Manuf. of basic pharm. products | 10.5 | 38.8 | 26.9 | 1,708 | 659 |
| Manuf. of pharm. preparations | 16.8 | 18.5 | 20.1 | 846 | 704 |
| R&D services | 63.2 | 20.3 | 26.2 | 25 | 22 |
| Management services | 9.5 | 22.5 | 26.8 | 560 | 463 |
| **Multinational firm** | 100.0 | 100.0 | 100.0 | 971 | 499 |
| No | 85.8 | 24.0 | 30.8 | 26 | 23 |
| Yes | 14.2 | 76.0 | 69.2 | 1,231 | 631 |
| ***Total*** | 704 | 12,287 | 8,642 | 971 | 499 |

Notes: Industry is the primary industry for parent firms based on NACE Rev.1.1. A firm is deemed to be a multinational if it has a productive subsidiary outside of the home country. A firm's foreign subsidiary is classed as productive if its assets, turnover and employment meet a set of criteria based on the European Union's definition of a small company.
Source: Authors' calculation using matched data from Amadeus, Icarus, PATSTAT and Derwent Innovation Index.

## 2.3 Country level variables

I also investigate the characteristics of the foreign countries the inventors are located in. There are 59 and 66 foreign countries in period 1995-2000 and 2001-2005 respectively in which firms in the sample have inventors listed in their drug patents. I focus on 40 countries, where I have consistent information on a range of key statistics shown in 2.2. These 40 countries account for over 98% of all foreign inventors in the sample in each period.

I follow the literature that investigates the different factors affecting the decision over where to locate innovation activity to guide the choice of variables. First, academic research publications in the chemical/pharmaceutical field and academic research publications in other fields related to exact sciences capture the basic research infrastructure produced by universities that may attract firms that source technology. These variables are a count of publications for the years 1994 and 1998, which are used for the periods 1996-2000 and 2001-2005 respectively.[12]

Second, Intellectual Property Rights (IPR) Protection for the years 1995 and 2000 is measured by the patent rights index from Park and Wagh (2002), which can take a value from 0 (weak protection) to 5 (strong

[12]Information comes from the Web of Science run by Thomson Scientific and the count includes scientific articles (articles, letters, notes or reviews only) with university-affiliated authors (at least one based in one of the 40 countries considered) published in peer-reviewed journals. These variables were kindly shared by Rene Belderbos, constructed for his paper Belderbos et al. (2011). See this paper for more details on these variables and how they assign each publication to a technology field.

Table 2.2: *Additional descriptive statistics*

| | Mean | Standard Deviation |
|---|---|---|
| *Firm-level regressions table 3.9* | | |
| Firm's patents | 44.46 | 214.86 |
| Log(Firm's patents) | 1.92 | 1.52 |
| Proportion of triadic patents | 0.40 | 0.33 |
| Log(Proportion of triadic patents) | -5.73 | 8.63 |
| *Country-level regressions table 3.9* | | |
| Distance (Kms.) | 3864.34 | 4436.61 |
| log(Distance) | 7.57 | 1.24 |
| GDP (current USD PPP billions) | 1296.25 | 2300.09 |
| log(GDP) | 6.08 | 1.59 |
| *Firm-level regressions - ALL firms - table 3.11* | | |
| Academic publications Chem/Pharma | 11.15 | 27.40 |
| All other academic publications | 15.69 | 37.07 |
| IPR Protection | 3.52 | 0.82 |
| GDP (current USD PPP billions) in t-1 | 736.99 | 1309.04 |
| GDP per capita (USD PPP) in t-1 | 16599.05 | 9773.25 |
| Contiguous countries (dummy) | 0.09 | 0.28 |
| Common official first language shared | 0.11 | 0.31 |
| Distance between capitals (Kms.) | 5096.69 | 4388.73 |
| *Firm-level regressions - MNE firms - table 3.11* | | |
| Academic publications Chem/Pharma | 11.01 | 27.22 |
| All other academic publications | 15.50 | 36.83 |
| IPR Protection | 3.51 | 0.82 |
| GDP (current USD PPP billions) in t-1 | 728.80 | 1294.43 |
| GDP per capita (USD) in t-1 | 16442.81 | 9686.77 |
| Contiguous countries (dummy) | 0.08 | 0.28 |
| Common official first language shared | 0.09 | 0.28 |
| Distance between capitals (Kms.) | 5085.74 | 4397.28 |

*Source:* See sources to tables 3.9 and 3.11

protection).[13] IPR protection in principle fosters innovation in a given country to the extent that provides monopoly rights to the developers of new ideas so that they can appropriate a larger share of the social returns generated by their research investment in a given market. This could be particularly important for foreign firms that are considering to carry out research activities in a host country.

Third, market size (GDP) and GDP per capita (average for the years in each of the two periods considered in the analysis: 1996-2000 and 2001-2005) aim to capture the market potential for the new drugs if the research activity is designed to be market specific. GDP per capita can also capture average wages and hence the cost of hiring inventors in a host country. These variables come from the World Economic Outlook Database (2014) produced by the International Monetary Fund. These variables are also common in gravity models used to explain international bilateral trade flows as a function of geographic and economic distance variables. I also use other gravity variables: a dummy variable that equals one if two countries are contiguous, a dummy variable that equals one if two countries share the official first language, and a distance variable (the distance between capitals measured in kilometres, the results are robust to using other more sophisticated distance variables). These gravity variables come from the *GeoDist* database (see Mayer and Zignago (2011)).

[13]From Park and Wagh (2002): "The index is based on five categories: (1) coverage (the subject matter that can be patented); (2) duration (the length of protection); (3) enforcement (the mechanisms for enforcing patent rights); (4) membership in international patent treaties; and (5) restrictions or limitations on the use of patent rights.)". See their chapter for more details.

# 3 Stylised facts

In this section I provide a set of stylised facts on firms engaging in the international use of inventors for the drug discovery activity.

## 3.1 Characteristics of users of foreign inventors for drug discovery activity

I am interested in how firms organise their drug discovery activity across locations.

Table 3.1: *Biopharmaceutical by location of inventors, 2001-2005*

| | Location of inventors listed in drug patents | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Only home | | | Home and abroad | | | Only abroad | | | Total | | |
| | No. firms | Col % | Row % | No. firms | Col % | Row % | No. firms | Col % | Row % | No. firms | Col % | Row % |
| **Country of parent firm** | | | | | | | | | | | | |
| Belgium | 8 | 1.8 | 44.4 | 9 | 4.1 | 50.0 | 1 | 3.1 | 5.6 | 18 | 2.6 | 100.0 |
| Denmark | 21 | 4.7 | 50.0 | 19 | 8.6 | 45.2 | 2 | 6.3 | 4.8 | 42 | 6.0 | 100.0 |
| Finland | 10 | 2.2 | 62.5 | 6 | 2.7 | 37.5 | 0 | 0.0 | 0.0 | 16 | 2.3 | 100.0 |
| France | 71 | 15.8 | 71.7 | 26 | 11.7 | 26.3 | 2 | 6.3 | 2.0 | 99 | 14.1 | 100.0 |
| Germany | 104 | 23.1 | 64.2 | 54 | 24.3 | 33.3 | 4 | 12.5 | 2.5 | 162 | 23.0 | 100.0 |
| Great Britain | 86 | 19.1 | 58.1 | 52 | 23.4 | 35.1 | 10 | 31.3 | 6.8 | 148 | 21.0 | 100.0 |
| Italy | 48 | 10.7 | 69.6 | 18 | 8.1 | 26.1 | 3 | 9.4 | 4.3 | 69 | 9.8 | 100.0 |
| Netherlands | 11 | 2.4 | 42.3 | 9 | 4.1 | 34.6 | 6 | 18.8 | 23.1 | 26 | 3.7 | 100.0 |
| Norway | 10 | 2.2 | 100.0 | 0 | 0.0 | 0.0 | 0 | 0.0 | 0.0 | 10 | 1.4 | 100.0 |
| Spain | 25 | 5.6 | 75.8 | 6 | 2.7 | 18.2 | 2 | 6.3 | 6.1 | 33 | 4.7 | 100.0 |
| Sweden | 56 | 12.4 | 69.1 | 23 | 10.4 | 28.4 | 2 | 6.3 | 2.5 | 81 | 11.5 | 100.0 |
| *Total* | 450 | 100.0 | 63.9 | 222 | 100.0 | 31.5 | 32 | 100.0 | 4.5 | 704 | 100.0 | 100.0 |
| **Parent firm industry** | | | | | | | | | | | | |
| Manuf. of basic pharm. products | 40 | 8.9 | 54.1 | 29 | 13.1 | 39.2 | 5 | 15.6 | 6.8 | 74 | 10.5 | 100.0 |
| Manuf. of pharm. preparations | 74 | 16.4 | 62.7 | 33 | 14.9 | 28.0 | 11 | 34.4 | 9.3 | 118 | 16.8 | 100.0 |
| R&D services | 297 | 66.0 | 66.7 | 137 | 61.7 | 30.8 | 11 | 34.4 | 2.5 | 445 | 63.2 | 100.0 |
| Management services | 39 | 8.7 | 58.2 | 23 | 10.4 | 34.3 | 5 | 15.6 | 7.5 | 67 | 9.5 | 100.0 |
| *Total* | 450 | 100.0 | 63.9 | 222 | 100.0 | 31.5 | 32 | 100.0 | 4.5 | 704 | 100.0 | 100.0 |
| **Multinational firm** | | | | | | | | | | | | |
| No | 418 | 92.9 | 69.2 | 170 | 76.6 | 28.1 | 16 | 50.0 | 2.6 | 604 | 85.8 | 100.0 |
| Yes | 32 | 7.1 | 32.0 | 52 | 23.4 | 52.0 | 16 | 50.0 | 16.0 | 100 | 14.2 | 100.0 |
| *Total* | 450 | 100.0 | 63.9 | 222 | 100.0 | 31.5 | 32 | 100.0 | 4.5 | 704 | 100.0 | 100.0 |

Source: Authors' calculation using matched data from Amadeus, Icarus, PATSTAT and Derwent Innovation Index.

Table 3.1 splits firms according to how they organise geographically their drug discovery activity (as measured by the location of the inventors listed in their drug patents over the period 2001-2005) in three categories: home only, home and abroad, and abroad only. The first panel shows the breakdown by country of the parent firm and the total. The last row shows that most firms (63.9%) do not engage in the use of foreign inventors for their drug discovery activities; 31.5% have inventors at home and abroad; and only 4.5% have inventors only abroad. There is variation in terms of the country of the parent firm: firms from smaller countries such as Belgium, Denmark, Finland and the Netherlands are more likely to engage in the use foreign inventors than firms from other countries. The second panel shows the variation across the parent firm's industry and suggests that there is less variation across industries. If anything parent firms operating in manufacturing of basic pharmaceutical products and in management services are more likely to use foreign inventors. When looking at multinational status, most domestic firms only use domestic inventors (69.2%), whereas a minority of multinational firms (32%) operate only domestically in terms of their inventors.[14]

**Fact 1:** 26% of EU firms active in drug discovery activity are engaged globally for the production of knowledge as measured by the use of foreign inventors. These firms co-exist with firms that operate only domestically in all home countries, industries and firm types.

Table 3.2 show some basic characteristics of firms using foreign inventors as compared to those that use domestic inventors, further split by multinational status. Column 1 shows that nearly 60% of all European patenting firms active in drug discovery operate only domestically, 24% firms are domestic but collaborate with foreign inventors for their drug discovery activity, 2.3% are domestic but have all their inventors abroad, suggesting that they may outsource their research to foreign entities. The rest are multinational firms. 4.5% of all firms are multinational in terms of their manufacturing activity but operate domestically in terms of their research activity. Multinational firms that have global networks of inventors at home and abroad represent only 7.4% of all firms but account for the majority of the activity in terms of patents, drug patents, inventors, home inventors, and inventors abroad, as shown in the subsequent columns. They are followed by the domestic firms that use global networks of inventors for their research activities. This is consistent with the widely known fact that innovative activity is highly concentrated in a small number of large multinational firms (see, for instance, Griliches (1990) and Criscuolo et al. (2010)). Furthermore, these numbers provide evidence of the huge differences that exist between firms that use foreign inventors and those that do not.

[14] Furman et al. (2005) document that big pharmaceutical firms do research in a given period in more than one location, with a maximum of 8 locations per multinational firm. Firms research efforts usually rely on in-house laboratories, though collaborative agreements between researchers from different organisations are relatively usual. Research activities towards drug discovery are usually geographically separable from drug development, manufacturing facilities, and even sales and marketing activities. Domestic firms that have inventors abroad represent collaborations.

Table 3.2: *Users of foreign inventors for drug discovery activity, EU firms, 2001-2005*

| Location of drug inventors and MNE status | (1) Firms % | (2) Patents % | (3) Drug Patents % | (4) Inventors % | (5) Inventors at Home % | (6) Inventors Abroad % | (7) Drug Inventors % | (8) Drug Inventors at Home % | (9) Drug Inventors Abroad % |
|---|---|---|---|---|---|---|---|---|---|
| Domestic & Inventors at Home | 59.4 | 9.4 | 12.3 | 7.2 | 11.8 | 0.0 | 9.3 | 15.2 | 0.0 |
| Domestic & Inventors at H&A | 24.1 | 14.3 | 18.2 | 14.3 | 18.6 | 7.5 | 17.9 | 23.3 | 9.6 |
| Domestic & Inventors Abroad | 2.3 | 0.3 | 0.4 | 0.1 | 0.0 | 0.4 | 0.2 | 0.0 | 0.5 |
| MNE & Inventors at Home | 4.5 | 1.5 | 1.7 | 1.1 | 1.8 | 0.1 | 1.4 | 2.3 | 0.0 |
| MNE & Inventors at H&A | 7.4 | 67.6 | 60.0 | 70.9 | 67.8 | 75.8 | 64.4 | 59.2 | 72.5 |
| MNE & Inventors Abroad | 2.3 | 6.9 | 7.4 | 6.3 | 0.1 | 16.3 | 6.8 | 0.0 | 17.4 |
| *Total* | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |

Notes: Number of observation is 704.

Source: Author's calculation using matched data from Amadeus, Icarus, PATSTAT and Derwent Innovation Index.

Table 3.3: *Users of foreign inventors for drug discovery activity, intensive margin, 2001-2005*

| | % Inventors Abroad | |
|---|---|---|
| | (1) | (2) |
| | Drug | Non-Drug |
| **Country of parent firm** | | |
| Belgium | 34.0 | 47.8 |
| Denmark | 33.1 | 40.9 |
| Finland | 10.7 | 10.5 |
| France | 35.8 | 16.1 |
| Germany | 34.5 | 28.4 |
| Great Britain | 53.2 | 48.4 |
| Italy | 35.3 | 48.5 |
| Netherlands | 82.5 | 84.9 |
| Spain | 9.8 | 11.4 |
| Sweden | 32.6 | 48.1 |
| *Total* | 43.6 | 39.6 |
| **Parent firm industry** | | |
| Manuf. of basic pharm. products | 43.4 | 39.7 |
| Manuf. of pharm. preparations | 48.0 | 46.4 |
| R&D services | 28.9 | 28.5 |
| Management services | 49.6 | 40.0 |
| *Total* | 43.6 | 39.6 |
| **Multinational firm** | | |
| No | 21.4 | 17.7 |
| Yes | 47.7 | 42.7 |
| *Total* | 43.6 | 39.6 |

Notes: Number of observations is 254, those that have at least one inventor abroad.
Source: Authors' calculation using matched data from Amadeus, Icarus, PATSTAT and Derwent Innovation Index.

Table 3.3 shows the proportion of inventors abroad as a share of total inventors for the 254 firms out of a total of 704 that use foreign inventors. The first column shows this ratio for drug inventors, and the second column for non-drug inventors for comparison. On average, foreign inventors represent 43.6% of all drug inventors. There is substantial variation across firms from different countries and by multinational status. There is less variation across industries, with R&D services being less internationalised relative to other industries even for firms that use at least one inventor abroad. This is probably due to the smaller number of multinational firms in these industry as mentioned before.

I next investigate the differences between firms that use foreign inventors and those that do not, interacted with multinational status. Trade theory has found that more productive firms are more likely to engage globally, and their market share increases as a result of trade liberalization resulting in these firms expanding their size. I look at whether firms are different in terms of size as measure by number of patents and number of drug patents, a measure of the quality of their patents, proxied by the proportion of triadic drug patents, and the type of knowledge firms generate measured by the proportion of basic drug patents.[15] Table 3.4 shows the results of descriptive regressions that regress each of these variables on dummy variables for each of these categories: i) Domestic and Inventors at Home and Abroad; ii) Domestic and all Inventors Abroad; iii)MNE and all Inventors at Home; iv) MNE and Inventors at Home and Abroad; and v) MNE and all

[15]I do not observe total employment, value added or productivity unfortunately.

Table 3.4: *Regressions of firm level variables on location of drug inventors and MNE status, 1996-2005*

| | (1) Number of patents | (2) Number of drug patents | (3) % of triadic drug patents | (4) % of basic drug patent |
|---|---|---|---|---|
| ***baseline domestic firm with all inventors at home*** | | | | |
| Domestic and | 6.62 | 5.90 | -0.00 | 0.00 |
| Inventors at H&A | (8.41) | (4.74) | (0.03) | (0.02) |
| Domestic and | 1.35 | 0.03 | -0.05 | 0.07 |
| Inventors Abroad | (21.65) | (12.20) | (0.07) | (0.06) |
| MNE and | 0.76 | -1.47 | -0.04 | -0.02 |
| Inventors at Home | (16.91) | (9.53) | (0.05) | (0.04) |
| MNE & | 156.93*** | 98.54*** | 0.09* | -0.03 |
| Inventors at H&A | (13.46) | (7.58) | (0.04) | (0.03) |
| MNE & | 28.01 | 21.92 | 0.25*** | -0.06 |
| Inventors Abroad | (23.28) | (13.12) | (0.07) | (0.06) |
| Observations | 1,318 | 1,318 | 1,317 | 1,317 |
| $R^2$ | 0.1 | 0.1 | 0.0 | 0.0 |

Notes: Standard errors in parentheses * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. All regression include parent country, parent firm industry, and period fixed effects.
Source: Author's calculation using matched data from Amadeus, Icarus, PATSTAT and Derwent Innovation Index.

Inventors Abroad; the excluded category is Domestic and all Inventors at Home. All regressions include parent country fixed effects, period fixed effects and parent firm industry fixed effects. The results show that only MNE with inventors at home and abroad are larger than purely domestic firms and than MNE firms with all inventors at home, and that MNE firms with inventors abroad have a higher proportion of triadic patents, particularly those with all drug inventors abroad. There is no difference in the type of knowledge embedded in drug patents across firms, as indicated in column 4.

**Fact 2:** Using foreign inventors is not associated with a premia in terms of size (as measured by the number of patents) and value of patents, but being a multinational firm and using foreign inventors is associated with a size premium relative to all domestic firms (with and without foreign inventors) and multinational firms that do not use foreign inventors.

## 3.2 Internationalisation patterns of users of foreign inventors for drug discovery activity

This subsection focuses on those firms that do use foreign inventors and examines i) variation in the number of foreign inventors and the number of foreign locations; ii) the extent of concentration of activity (measured by inventors, foreign inventors and drug patents) across and within firms; iii) the extensive and intensive margin of usage of foreign inventors; and iv) a description of the most prevalent foreign locations and foreign location characteristics.

### 3.2.1 Variation in number of foreign inventors and number of foreign locations

Table 3.5 shows a strong variance and skewness in the distribution of number of foreign locations, proportion of foreign inventors and number of inventors per foreign location. For example, on average firms are present on 2 foreign locations (column 3), but the mean is two times larger than the median and the 99th percentile is 19 times larger than the 1st percentile. MNE firms are present in more locations than domestic firms unsurprisingly (columns 1 and 2).

**Fact 3:** There is substantial variation across users of foreign inventors in the number of foreign locations they are present, the number of foreign inventors, the share of foreign inventors and the number of foreign inventors per location.

### 3.2.2 Concentration of activity across and within firms

Table 3.6 examines the extent to which activity is concentrated among few firms that use inventors from many locations. Firms that are present in at least 20 locations, only 2 firms, represent less than 1% of the firms (column 2) but account for around 20% of all foreign inventors, of all inventors and of drug patents. This is consistent with the substantial variation shown in table 3.5. Furthermore, this suggests that firm-level size is correlated not only with using inventors abroad (conditional on being a multinational) but also with firm-level patterns of internationalisation of inventors.

**Fact 4:** Foreign inventors are concentrated among the few firms that operate in a large number of foreign countries.

Table 3.5: *Foreign location patterns of users of foreign inventors for drug discovery activity, 2001-2005*

| | Number of foreign locations MNE | | | Number of foreign inventors MNE | | | Ratio of foreign inventors to all inventors % MNE | | | Number of inventors per foreign location MNE | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Yes | No | Total | Yes | No | Total | Yes | No | Total | Yes | No | Total |
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | (11) | (12) |
| Mean | 5 | 2 | 2 | 175 | 7 | 52 | 53 | 33 | 39 | 77 | 5 | 24 |
| Percentiles | | | | | | | | | | | | |
| 1st | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 2 | 1 | 1 | 1 |
| 25th | 1 | 1 | 1 | 8 | 1 | 2 | 23 | 11 | 13 | 4 | 1 | 1 |
| 50th | 3 | 1 | 1 | 22 | 3 | 4 | 43 | 25 | 30 | 12 | 2 | 3 |
| 75th | 5 | 2 | 3 | 52 | 6 | 14 | 97 | 50 | 53 | 28 | 4 | 8 |
| 99th | 23 | 7 | 19 | 2506 | 67 | 1705 | 100 | 100 | 100 | 1303 | 48 | 707 |

*Notes:* Number of observations (firms) is 254, those that have at least one drug inventor abroad. *Source:* Authors' calculation using matched data from Amadeus, Icarus, PATSTAT and Derwent Innovation Index.

Table 3.6: *Concentration of activity among firms present in at least 1, 2, 3, 5, 10, 20 foreign locations, 2001-2005*

| Number of foreign locations | Number of firms (1) | % Firms (2) | Share of inventors abroad (%) (3) | Share of inventors (%) (4) | Share of Drug Patents (%) (6) |
|---|---|---|---|---|---|
| At least 1 | 254 | 100.0 | 100.0 | 100.0 | 100.0 |
| At least 2 | 122 | 48.0 | 96.4 | 92.0 | 91.1 |
| At least 3 | 74 | 29.1 | 93.3 | 85.7 | 84.7 |
| At least 5 | 29 | 11.4 | 84.0 | 75.1 | 73.1 |
| At least 10 | 8 | 3.5 | 77.2 | 65.5 | 62.2 |
| At least 20 | 2 | 0.8 | 21.7 | 18.3 | 22.34 |

*Notes:* Number of observations (firms) is 254, those that have at least one drug inventor abroad. Inventors are those listed in drug patents. *Source:* Authors' calculation using matched data from Amadeus, Icarus, PATSTAT and Derwent Innovation Index.

Table 3.7: *Concentration of foreign inventors in principal locations, 2001-2005*

| Foreign Location Ranking | Share of foreign location (All firms) % (1) | Share of foreign location (loc=1) % (2) | Share of foreign location (loc=2) % (3) | Share of foreign location (loc=5) % (4) |
|---|---|---|---|---|
| 1 | 81.4 | 100 | 68.0 | 53.8 |
| 2 | 26.0 | . | 32.0 | 21.0 |
| 3 | 13.3 | . | . | 12.0 |
| 4 | 7.0 | . | . | 7.9 |
| 5 | 4.8 | . | . | 5.3 |
| Herfindhal | 76.4 | 100 | 61.3 | 39.4 |
| Number of firms | 254 | 132 | 48 | 11 |

*Source:* Authors' calculation using matched data from Amadeus, Icarus, PATSTAT and Derwent Innovation Index.

Table 3.7 shows that foreign inventors are also concentrated within firms, since for most firms a large proportion of inventors is concentrated in the most important location. Column 1 shows the average share of foreign inventors concentrated in the principal location across all firms, in the second most important location, etc. A Herfindhal index provides a standard measure of concentration. On average the largest location accounts for 81.4% of a firm's foreign inventors. But for more than half the firms, the principal location accounts for 100% since they are present in only one location (as shown in table 3.6). Column 2 shows a similar analysis for those present in only one location and by definition the principal location account for 100% of all foreign inventors. Column 3 shows the distribution of inventors for firms present in two locations and it still shows that the principal location accounts for 68% of foreign inventors. Column 4 focuses on firms present in 5 locations and the principal location accounts for over half of foreign inventors. Table 3.8 shows the top combinations for firms present in one location and for firms present in two locations, the proportion of firms (out of all firms in that category) that are present in a specific combination, and the average account for each location across firms belonging to that combination. The table suggests that there is also heterogeneity in the locations as well.

**Fact 5:** Foreign inventors are concentrated within firms since the top location accounts for at least 80% of a firm's foreign inventors on average.

### 3.2.3 Extensive and intensive margins of foreign inventors usage

I next decompose the variation in firm-level and aggregate usage of foreign inventors into the extensive and intensive margins. First, I consider the firm-level number of inventors of firm $n$ in period $p$, which can be written as follows:

$$log(I_{np}) = log(C_{np}) + log(\frac{I_{np}}{C_{np}}) \tag{3.1}$$

where $I_{np}$ denotes the total number of foreign inventors, $C_{np}$ denotes the number of locations where the firm $n$ has inventors in period $p$ (i.e. the extensive margin), and $\frac{I_{np}}{C_{np}}$ is the average number of inventors per country (i.e. the intensive margin). The reported OLS coefficients tells us how much each margin contributes

Table 3.8: *Most common combinations of locations for firms present in 1 and 2 locations, 2001-2005*

| Locations = 1 | | | Locations = 2 | | |
|---|---|---|---|---|---|
| Top country Combinations | % Firms | Share of Location (%) | Top country Combinations | % Firms | Share of Location (%) |
| US | 28.8 | 100.0 | USA, Switzerland | 8.3 | 58.3, 41.7 |
| Germany | 10.6 | 100.0 | France, Switzerland | 4.2 | 62.5, 37.5 |
| Switzerland | 7.6 | 100.0 | France, Germany | 4.2 | 50.0, 50.0 |
| Italy | 4.5 | 100.0 | Sweden, Italy | 4.2 | 50.0, 50.0 |
| Netherlands | 4.5 | 100.0 | USA, Sweden | 4.2 | 80.0, 20.0 |
| France | 4.5 | 100.0 | Japan, Germany | 4.2 | 60.0, 40.0 |
| No. Combinations | 34 | | 38 | | |

*Notes:* Table shows information about the most common locations among the groups of firms underlying Table 3.7 *Source:* Authors' calculation using matched data from Amadeus, Icarus, PATSTAT and Derwent Innovation Index.

to the total variation in the number of inventors at the firm-level. Columns 1 to 3 of Table 3.9 show that the intensive margin (first row, column 3) accounts for almost two-thirds of the overall variation across firms. This can be partly explained by the large proportion of firms that are present in only one foreign location and by definition the contribution of the intensive margin is 100% for these firms. Furthermore, the different margins are correlated with firm-level characteristics. The number of foreign inventors is positively associated with the size of the firm (as measure by the number of patents, row 2) and the value of their patent portfolio (row 3); and the largest coefficient is the one on the intensive margin, particularly for the size measure.

**Fact 6:** Variation in the usage of foreign inventors across firms is driven by variations in the intensive margin (the number of inventors per foreign location). Larger firms and those with a higher proportion of triadic patents are present in more countries and have more inventors per foreign country (the intensive margin). The intensive margin explains a higher share of the correlation between these variables and the number of foreign inventors.

Next I consider the country-level use of foreign inventors. I construct the total number of inventors in foreign country $c$ for each home country $h$ in period $p$, which can be written as follows:

$$log(I_{hcp}) = log(F_{hcp}) + log(\frac{I_{hcp}}{F_{hcp}}) \tag{3.2}$$

where $I_{hcp}$ denotes the total number of foreign inventors, $F_{hcp}$ denotes the number of firms from home country $h$ that has inventors in foreign location $c$ in period $p$, and $\frac{I_{hcp}}{F_{hcp}}$ is the average number of inventors per firm. Columns 4 to 6 of Table 3.9 show the result of decomposing the variance of total foreign inventors at the country level in the extensive and intensive margins. The intensive margin is also more important in accounting for the variation across countries. I also examine if the margins are correlated with standard gravity variables and found that usage of foreign inventors is negatively associated with bilateral distance and positively associated with the GDP of the foreign location. This is further explored in the next section.

**Fact 7:** Variation in the usage of foreign inventors across foreign countries is also driven by variations in the intensive margin (the number of inventors per firms present in a foreign country), although the extensive margin is also important. Distance is negatively correlated with the number of inventors in a foreign country, and the intensive margin accounts for a higher share of this correlation. GDP is positively associated with the number of inventors, and this correlation is accounted equally by the extensive and intensive margins.

Table 3.9: *Extensive and intensive margin of usage of foreign inventors. 1996-2005*

| | Firm-level use of foreign inventors | | | Country-level use of foreign inventors | | |
|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) |
| | Log(No. of Foreign Inventors) | Log(No. of Foreign Countries) | Log(No. of Inventors per Country) | Log(No. of Foreign Inventors) | Log(No. of Firms) | Log(No. of Inventors per Firm) |
| (1) Log(No. of foreign inventors) | 1.00** | 0.37** | 0.63** | 1.00** | 0.36** | 0.64** |
| | (0.00) | (0.01) | (0.01) | (0.00) | (0.02) | (0.02) |
| $R^2$ | 1.0 | 0.7 | 0.9 | 1.0 | 0.6 | 0.8 |
| (2) Log(Number of Patents) | 0.79** | 0.35** | 0.44** | | | |
| | (0.05) | (0.02) | (0.04) | | | |
| $R^2$ | 0.6 | 0.6 | 0.4 | | | |
| (3) Log(Proportion of triadic patents) | 0.05** | 0.02** | 0.03** | | | |
| | (0.01) | (0.00) | (0.00) | | | |
| $R^2$ | 0.2 | 0.1 | 0.2 | | | |
| (4) Log(Distance) | | | | -0.34** | -0.14** | -0.21** |
| | | | | (0.06) | (0.03) | (0.06) |
| $R^2$ | | | | 0.1 | 0.1 | 0.1 |
| (5) Log(GDP) | | | | 0.51** | 0.25** | 0.27** |
| | | | | (0.07) | (0.03) | (0.04) |
| $R^2$ | | | | 0.3 | 0.3 | 0.2 |
| Observations | 476 | 476 | 476 | 384 | 384 | 384 |

Notes: All columns show results from OLS regressions. Clustered standard errors in parentheses + $p < 0.10$, * $p < 0.05$, ** $p < 0.01$.

Standard errors in columns 1 to 3 are clustered at the firm level; standard errors in columns 4 to 6 are clustered at the home country level.

All regressions include two periods: 1996-2000 and 2001-2005; a period dummy and home country fixed effects. Regressions in columns 1 to 3 also include firm industry fixed effects.

Source: Author's calculation using matched data from Amadeus, Icarus, PATSTAT, Derwent Innovation Index, GeoDist, and IMF WEO database 2011.

Table 3.10: *Distribution of foreign inventors across host countries, aggregate figures, 1996-2005*

| Host country | Country of parent firm (1) % | (2) % | (3) % | (4) % | (5) % | (6) % | (7) % | (8) % | (9) % | (10) % | (11) % | Total % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (1) Great Britain | 0.0 | 0.7 | 1.1 | 0.1 | 0.3 | 0.3 | 0.1 | 0.3 | 0.0 | 0.0 | 0.0 | 3.0 |
| (2) France | 1.5 | 0.0 | 0.9 | 0.3 | 0.1 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 2.9 |
| (3) Germany | 0.8 | 5.6 | 0.0 | 0.2 | 9.4 | 0.1 | 0.0 | 0.5 | 0.0 | 0.1 | 0.0 | 16.7 |
| (4) Italy | 1.4 | 1.1 | 0.3 | 0.0 | 0.3 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 3.3 |
| (5) Netherlands | 0.2 | 0.1 | 0.3 | 0.0 | 0.0 | 0.1 | 0.1 | 0.3 | 0.0 | 0.0 | 0.0 | 1.0 |
| (6) Sweden | 6.4 | 0.1 | 0.2 | 0.0 | 0.1 | 0.0 | 0.0 | 0.2 | 0.1 | 0.0 | 0.0 | 7.1 |
| (7) Belgium | 2.2 | 0.1 | 0.1 | 0.0 | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 2.6 |
| (8) Denmark | 0.1 | 0.0 | 0.1 | 0.0 | 0.1 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.5 |
| (9) Finland | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.3 |
| (10) Spain | 0.3 | 0.1 | 0.2 | 0.6 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.3 |
| (11) Norway | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | 0.2 | 0.0 | 0.0 | 0.0 | 0.3 |
| (12) Switzerland | 0.3 | 0.1 | 1.0 | 0.2 | 1.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 2.8 |
| (13) Japan | 0.4 | 0.3 | 1.8 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 2.7 |
| (14) USA | 24.2 | 4.0 | 12.1 | 0.8 | 2.8 | 0.6 | 0.1 | 1.0 | 0.1 | 0.1 | 0.0 | 45.8 |
| (15) India | 0.2 | 0.2 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.5 |
| (16) China | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 |
| (17) Asian Tigers | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 |
| (18) EU 15 | 0.1 | 0.1 | 1.8 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 2.2 |
| (19) New EU | 0.1 | 1.5 | 0.3 | 0.0 | 0.1 | 0.3 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | 2.4 |
| (20) Others | 2.4 | 0.2 | 1.2 | 0.1 | 0.2 | 0.1 | 0.0 | 0.1 | 0.1 | 0.1 | 0.0 | 4.5 |
| Total | 40.8 | 14.2 | 21.8 | 2.5 | 14.8 | 1.9 | 0.3 | 2.8 | 0.4 | 0.5 | 0.0 | 100.0 |

Notes: All firms that have at least one inventor abroad. Country groups are as follow: (17) Asian Tigers, i.e. Taiwan, Singapur, South Korea and Hong Kong (18) EU 15 are the remaining countries belonging to the original European Union, i.e. Austria, Greece, Ireland, and Luxembourg. (19) New EU are the countries annexed more recently, i.e. Cyprus, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Slovakia, and Slovenia.

Source: Author's calculation using matched data from Amadeus, Icarus, PATSTAT and Derwent Innovation Index.

### 3.2.4 Foreign location characteristics

In this section I show the distribution of foreign inventors across the most relevant countries. The columns in Table 3.10 show the country of the parent firm and how the foreign inventors are geographically distributed for each home country, so the diagonal is zero since home inventors are excluded from the table. The last column shows the distribution for all foreign inventors in the sample. The most important single location is the US, accounting for almost 46% of the total, followed by Germany with almost 17%, followed by Sweden with 7%. Italy, Great Britain, France, Switzerland, Japan and Belgium follow with around 3% each. In total, these 9 countries account for almost 85% of all foreign inventors. Other European countries account for almost another 5%. Emerging countries account for a very small share: India accounts for 0.5%, China and the four Asian Tigers account for 0.1% each. This indicates they do not seem important host locations for EU firms' drug discovery activity, as measured by the inventors listed in patents filed at the EPO. This is consistent with other evidence presented for US multinationals on the location of inventors on US biopharmaceutical patents filed at the USPTO discussed in Cockburn and Slaughter (2010). The results for MNEs in my sample show a very similar picture.

**Fact 8:** EU pharmaceutical firms locate the majority of their foreign inventors engaged in drug discovery activity in developed countries, with the US accounting for almost half of all foreign inventors.

Finally, I investigate the correlation between the distribution of inventors at the firm level across 40 countries and host country and bilateral economic and geographic distance variables. These are estimated using negative binomial regressions:

$$E(Inventors_{nhcp}) = exp(\alpha_1 ARChem_{cp} + \alpha_2 AROther_{cp} + \alpha_3 IPR_{cp} + \alpha_4 GDP_{cp} + \alpha_5 GDPcap_{cp} + \beta_1 CON_{hc} + \beta_2 COMLAN_{hc} + \beta_3 DIST_{hc} + \gamma_p) \quad (3.3)$$

where the dependent variable is a count of inventors a firm $n$, from country $h$ has in host country $c$ in period $p$. The right-hand side variables are those described in section 2: $ARChem_{cp}$ is a count of academic publications in the chemical and pharmaceutical field in host country $c$ and period $p$; $AROther_{cp}$ is a count of other academic publications in exact sciences; $IPR_{cp}$ is the patent right index; $GDP_{cp}$ is market size proxied by gross domestic product in PPP dollars; $GDPcap_{cp}$ is GDP per capita; $CON_{hc}$ is a dummy variable that indicates if the home country $h$ and the host country $c$ share a geographical border; $COMLAN_{hc}$ is a dummy variable that indicates if countries share the first common language; and $DIST_{hc}$ is a distance variable in kilometres. $\gamma_p$ is a period fixed effect. The coefficients reported are incidence rate ratios, a coefficient higher than 1 means a positive correlation and a coefficient less than 1 means a negative correlation.

Table 3.11 shows the results of these regressions for all firms (columns 1 to 3) and for MNEs (columns 4 to 7). Columns 2 and 5 show results also including home country fixed effects to capture unobserved (time invariant) heterogeneity that could relate to the location pattern of foreign inventors, beyond observed economic and geographic distance variables. For example, if a home country is stronger in academic research in a way that affects the relative benefits of foreign locations. Similarly, columns 3 and 6 show results including host country fixed effects, to capture their unobserved time-invariant characteristics. Finally, column 7 includes firm fixed effects to capture firm unobserved heterogeneity, so the correlation between the location of inventors and host country and bilateral characteristics are identified from variation within firms.[16]

The results for all firms and MNEs in columns 1 and 4 are very similar. The number of inventors is substantially higher in host countries with stronger IPR protection and with larger GDP, that are contiguous to the firms' home country and that share a common language; and lower in host countries that are geographically more distant from firms' home country. For example, an area with 1 extra point in the IPR index is associated with 1.31 or 131% more inventors. Surprisingly, the variables on academic research are not significant, although they have been shown to be important for foreign pharmaceutical firms as discussed

[16] There is not sufficient variation for non-MNE with inventors abroad, so I cannot include them in this exercise.

in Abramovsky et al. (2007) and Abramovsky and Simpson (2011) and in Belderbos et al. (2011). Having said that, the sign of the coefficient on academic research in pharmaceuticals and chemistry is positive, as in other studies. Controlling for home country fixed effects yields similar results, except for the fact that sharing a common language is not longer significant for MNEs (column 5), and this could be because it is related to other unobserved characteristic now capture by the fixed effects. Including host countries fixed effects makes all the host country time varying characteristics insignificant, but not the bilateral variables, which remain similar relative to columns 1 and 4. This suggests that there are important unobserved host country variables that can be associated with the location of inventors across countries. Interestingly, when including firm fixed effects for MNEs, all variables are statistically significantly correlated with the number of inventors in a given country, except for sharing a common language, and broadly with the expected sign. The only exception is academic research in chemical/pharma, which is negatively associated with the count of inventors across countries within a firm, conditional on the other variables. But the number of inventors is positively correlated with the number of other academic publication in exact sciences. A priori, given the evidence from other studies, firms should be more likely to locate their inventors in countries with stronger research base in the relevant field (i.e. Chem/Pharma).

**Fact 9:** Economic and geographic distance variables are associated with the number of inventors in a similar fashion to patterns found in gravity models explaining good and service trade. IPR protection seems to be strongly positively associated with the number of inventors firms use in foreign countries.

Table 3.11: *Correlation between firm's number of foreign inventors and host-home country characteristics. 1996-2005*

| Number of foreign inventors | (1) All | (2) All | (3) All | (4) MNE | (5) MNE | (6) MNE | (7) MNE |
|---|---|---|---|---|---|---|---|
| *Host country characteristics* | | | | | | | |
| Academic publications | 1.06 | 0.99 | 1.18 | 1.10 | 0.97 | 1.17 | 0.89* |
| Chem/Pharma | (0.04) | (0.04) | (0.16) | (0.07) | (0.05) | (0.23) | (0.04) |
| All other | 0.97 | 1.02 | 0.91 | 0.95 | 1.03 | 0.93 | 1.09** |
| academic publications | (0.02) | (0.02) | (0.09) | (0.04) | (0.04) | (0.13) | (0.03) |
| IPR Protection | 2.31** | 2.32** | 0.71 | 1.96** | 1.88** | 0.53 | 2.14** |
| | (0.32) | (0.32) | (0.34) | (0.40) | (0.37) | (0.36) | (0.40) |
| GDP PPP t-1 | 1.00** | 1.00** | 1.00 | 1.00+ | 1.00* | 1.00 | 1.00** |
| | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) |
| GDP PPP per capita t-1 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00+ | 1.00 | 1.00** |
| | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) |
| *Host-home countries characteristics* | | | | | | | |
| Contiguous | 1.80** | 1.87** | 1.84** | 1.79+ | 2.62** | 1.78 | 2.47** |
| | (0.37) | (0.41) | (0.43) | (0.56) | (0.84) | (0.65) | (0.69) |
| Common language | 2.42** | 1.81** | 1.76** | 3.05** | 1.25 | 2.29* | 1.35 |
| | (0.46) | (0.37) | (0.37) | (0.91) | (0.40) | (0.75) | (0.40) |
| Distance | 0.99** | 0.99** | 0.99** | 0.99** | 0.99** | 0.99 | 0.99** |
| | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) | (0.00) |
| *Fixed effects* | | | | | | | |
| Period | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Home country | No | Yes | No | No | Yes | No | No |
| Host country | No | No | Yes | No | No | Yes | No |
| Firm | No | No | No | No | No | No | Yes |
| Observations | 19,080 | 19,080 | 19,080 | 5,560 | 5,560 | 5,560 | 5,560 |
| Pseudo $R^2$ | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.2 |

Notes: All columns are estimated using a negative binomial model to account for overdispersion, the coefficient displayed are incidence-rate ratios (IRR). Standard errors in parentheses, + $p < 0.10$, * $p < 0.05$, ** $p < 0.01$.

All columns include period fixed effects. Columns 2 and 5 include home country fixed effects.

Columns 3 and 6 include inventor country fixed effects. Column 7 includes firm fixed effects.

Source: Author's calculation using matched data from Amadeus, Icarus, PATSTAT, Derwent Innovation Index, GeoDist, IMF WEO database 2011 and Belderbos and Leten (2009)

# 4 Conclusion

In this paper I have provided a set of novel facts about EU pharmaceutical firms engaged in the use of foreign inventors for the drug discovery activity, using a rich dataset that matched firms accounts with patents and inventors information, for the period 1996-2005. The main results are that firm-level heterogeneity is a key feature in the internationalisation of inventors and this is similar to patterns from data analysing good and service traders and MNEs. Furthermore, host country distance characteristics are associated with the number of inventors in a similar fashion to patterns found in gravity models explaining good and service trade.

The facts presented in this paper show that these are key aspects to consider when modelling the aggregate trends in the internationalisation of inventors and explaining adjustment mechanisms through which the decrease in the barriers to globalisation can impact aggregate patterns. The fact that both the extensive and intensive margins are important to explain the variation in the number of inventors across firms but also across countries suggests that fixed costs and variable costs should be considered in such a model. Future avenues for research could include the development of a full model that incorporates these features and are able to explain firm-level global engagement of research activities and the general equilibirum effects of reductions in the cost of globalisation of these activities on employment, wages and innovation efforts at the country level.

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