Creation and Diffusion of Knowledge in the Multinational Firm*

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Abstract

This study documents new stylized facts on where and how knowledge creation and diffusion take place in multinational firms and shows that differences in time zones between headquarters and subsidiaries matter for knowledge flows beyond the effects of distance. The data show that (i) knowledge creation, as measured by patents, is increasingly conducted in cross-border collaborative teams of inventors within multinationals, (ii) a large share of patenting activity takes place in foreign affiliates, and (iii) inventors have become more mobile over the last three decades. An econometric analysis shows that a higher overlap in business hours is associated with increased cross-border collaboration, more within-firm citations, and greater inventor mobility.

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1 Introduction

Knowledge creation and diffusion are the pillars of modern growth theory. Multinational enterprises (MNEs) play a central role in both the creation and diffusion of knowledge across international borders. According to UNCTAD (2005), a conservative estimate is that MNEs account for close to half of all global R&D expenditures, and at least two-thirds of business R&D expenditures.[1]

Despite the importance of R&D efforts undertaken by MNEs, there is little micro evidence on this subject. Where do MNEs create knowledge? Is knowledge creation within a multinational firm becoming more concentrated in a few geographic locations, or is there more collaboration taking place across borders? What are the impediments to knowledge diffusion inside the boundaries of the firm?

Due to their very nature, knowledge creation and diffusion are difficult to measure. We use data on patents and collaboration in inventor teams to capture the incidence of knowledge creation, and employ information on patent citations and inventor mobility to capture knowledge diffusion. We construct a novel, cross-country database of MNEs, inventor teams, and their patenting activity over the period 1980-2010. The database provides detailed information about MNEs' headquarters (HQ) and foreign establishments, inventor teams matched with MNE headquarters and subsidiaries as assignees (owners) on each patent application, as well as inventor characteristics such as geographic location and gender. We follow Kerr and Kerr (2018) in defining "global collaborative patents". These are innovations that involve at least one inventor located in the country in which a multinational firm is headquartered and at least one inventor located in another country.

We present a set of new stylized facts. First, we show that knowledge creation is increasingly conducted in global collaborative teams of inventors working together within the same multinational firm. However, there is a lot of variation across investor home countries in this respect. Second, we find that such collaborative patents are of higher quality, as measured by the number of forward citations they receive, than patents filed by teams of inventors located only in the affiliate country. Third, we document that a large share of patenting activity takes place outside of multinationals' HQ countries, by inventors located in foreign affiliates. Fourth, we find that inventors have become more mobile over 1980-2010 but that female inventors are less mobile across borders than male inventors.

We then conduct an econometric analysis to examine barriers to knowledge diffusion

[1] The European Commission estimates that, in 2007, foreign-owned firms accounted for 15% of all business R&D in the United States; 20-25% in France, Germany, and Spain; 30%-50% in Canada, Hungary, Portugal, the Slovak Republic, Sweden, and the United Kingdom (UK); and more than 50% in Austria, Belgium, the Czech Republic, Malta, and Ireland (Dachs et al., 2012).

defined as cross-border collaborations, citations patterns, and inventor mobility within the multinational firm. Our analysis produces three main sets of findings.

First, we find that a greater overlap in business hours between HQ and affiliates leads to a higher incidence of inventor collaboration. For instance, an increase in business hour overlap by seven hours is associated with a 33% increase in the probability of a patent involving international collaboration for inventors located at foreign affiliates. In other words, an inventor working for a Polish subsidiary of a German multinational is 33% more likely than an inventor located in its Japanese subsidiary to collaborate on a patent with colleagues at the firm's HQ. In contrast, a longer distance between a multinational's HQ and its foreign affiliate reduces this probability. The increase in distance from that between Germany and Poland to that from Germany to Japan is associated with a 70% decline in the probability of observing a collaborative patent. These findings are in line with the view that communication and monitoring costs are a major impediment to cross-border collaboration in patenting.

Second, we test for the presence of knowledge diffusion within the multinational firm boundaries using data on citation patterns. Again, we find that the overlap in business hours as well as the distance between HQ and a foreign affiliate matter. A greater overlap in business hours and a shorter distance, independently of each other, increase the probability that patents filed by a multinational's foreign affiliate cite earlier patents filed by the same multinational's HQ. The magnitudes of these effects are quite substantial. An affiliate of a German multinational located in Poland is 28% more likely to cite a patent obtained by the firm's German HQ than the affiliate located in Japan due to the difference in business hour overlap and almost 4 times more likely to do so due to the difference in distance.

Third, we document that inventor mobility within a multinational firm can be facilitated by a greater overlap in business hours between HQ and affiliates, while the distance does not deter mobility. These results hold whether we study the mobility of inventors from HQ countries to affiliate countries or the other way around. They suggest that the ability to communicate in real time and repeated interactions, rather than the willingness to travel, are precursors to inventors' mobility between different establishments of the same firm. We further test whether inventor characteristics affect mobility and find that women are roughly half as mobile between HQ and an affiliate as men are. To the extent that inventor mobility contributes to collaborative patenting and knowledge diffusion, barriers to women inventors' mobility are also barriers to international technology diffusion.

Why should time zones matter for repeated interaction beyond the role of physical distance? Although much of physical production can be fragmented into individual parts and carried out relatively independently, innovative activity involves knowledge exchange that is both tacit and strategic to firms. Sociological studies suggest that work practices in multinational organisations that involve knowledge work have evolved to demand greater hours, commitment, and flexibility from their employees.[2] In economics, Chauvin et al. (2020) show that temporal distance stemming from time zone differences reduce synchronous and impromptu communication from first-best levels within a multinational organisation, presenting costly frictions especially for the multinational's knowledge-intensive work.

Time zones have been shown to be a barrier to women sharing in the benefits of activities by firms engaged in international trade (Bøler et al., 2018). When inventor teams and interactions are key to creating knowledge, barriers before women's ability to collaborate and move between establishments become crucial. We find that women tend to collaborate at similar rates, but they are much less mobile across international borders.

We contribute to several strands of literature. First, we contribute evidence to the literature on where and how knowledge work is conducted within the multinational firm. Canonical models of foreign direct investment (FDI) posit a distance-concentration trade-off, which focus on trade in goods and do not take into account knowledge transfer (Helpman et al., 2004). Recent studies differ on how R&D and knowledge production are incorporated into models of FDI. Bilir and Morales (2020) model knowledge creation as concentrated in the headquarter country and exploited abroad. In Keller and Yeaple (2013), a distance-knowledge trade-off emerges because it is more costly to transfer knowledge by direct communication than by trading intermediates. Similarly, Gumpert (2018) models how communication costs limit the ability of a firm's establishments to access knowledge at the headquarters.

Our findings support the existence of substantial knowledge transfer costs, both due to time zone differences and physical distance. They also show that multinationals increasingly conduct their R&D operations outside their home countries and in collaborative teams of inventors located in multiple countries. As such, the evidence is reminiscent of a vertical model of FDI as in Antràs et al. (2006), who study the formation of cross-country teams in production. It is also in line with a theory of the multinational firm as an organization that specializes in the creation and transfer of knowledge across borders (Kogut and Zander, 1993).

Second, we contribute to the body of evidence documenting the importance of communication costs and time zone differences on multinational firm organization. Stein and Daude (2007) find that differences in time zones negatively affect FDI, while Oldenski (2012) finds that activities requiring complex within firm communication are more likely to occur at multinational's headquarters. Closest to our study is Bahar (2020), who presents evidence of a trade-off between distance to the headquarters and knowledge intensity of the affiliates'

[2] For instance, Kvande (2009) discusses evidence from multinational law and computing firms that require employees to adjust working hours to collaborate with international business partners.

industry.[3]

Third, we add to the literature on cross-border collaboration in knowledge work and inventor mobility. Kerr and Kerr (2018) find, in a sample of publicly listed companies from the United States (US), that global collaborative patents are frequently observed when a firm enters a new foreign region for innovative work, especially where intellectual property protection is weak. They also find that collaborative patents are higher quality than patents produced by inventor teams located only in the US, and employment of ethnic inventors at home is related to cross-border collaboration.[4] Catalini et al. (2020) show that travel costs constitute an important friction to collaboration between inventors, especially for high-quality scientists.

Recent research suggests that ideas are getting harder to find (Bloom et al., 2020). Patents increasingly involve large research teams and evidence shows that interactions with better inventors are strongly correlated with subsequent productivity (Akcigit et al., 2018).[5] This increases the importance of collaboration across borders and ability of large teams of inventors to work together, often facilitated by within-firm mobility. Our work sheds new light on the determinants of cross-border collaboration and inventor mobility.

Fourth, our paper adds to the literature on FDI and the geographic diffusion of knowledge and technology (Keller, 2004). Keller (2002) finds that productivity effects of R&D are declining in distance, while Bilir and Morales (2020) show that parent and affiliate R&D are complementary. Singh (2007) uses patent citation data to document local knowledge flows both from foreign multinationals to host country firms and vice versa, which appear to be facilitated by personnel flows between firms. Our findings on citation patterns and inventor mobility between multinationals' headquarters and subsidiaries provide direct evidence on how they help diffuse technology between countries.

The remainder of this paper is structured as follows. We describe our data and present stylised facts in Section 2. Section 4 contains our results on the determinants of global collaborative patenting activity. Section 5 documents the citation patterns between a multi-

[3] One proposed reason for the negative relationship between distance (both physical and cultural) and FDI is the difficulty of a parent firm to monitor the activities of its affiliates abroad (Blonigen et al., 2020). Monitoring costs can be especially high in the context of innovative activity, where parent firms have an incentive to protect the leakage of proprietary technology. Our results suggest that business hour overlap may contribute to the difficulty of monitoring.

[4] Related, Foley and Kerr (2013) find that increases in the share of a US multinational's innovation performed by inventors of a particular ethnicity at home are associated with increases in the share of that firm's affiliate activity in countries related to that ethnicity.

[5] Akcigit et al. (2018) introduce an endogenous growth model with knowledge diffusion in which inventors learn from each other via collaboration. They quantify the importance of interactions for growth by studying the effects of reducing interaction costs, such as IT or infrastructure, on inventors' learning and knowledge accumulation.

national's affiliates and its headquarters. Section 6 presents our results on inventor mobility within the multinational firm. Concluding remarks appear in Section 7.

2 Data

This section describes the main dataset that we use for the regression analysis. Further details can be found in Appendix A.

2.1 Patents

The main patent dataset underlying our analysis comes from USPTO's (United States Patent and Trademark Office) PatentsView project. PatensView covers the universe of US patents. Crucially, it contains inventor identifiers resulting from a disambiguation exercise. In addition, the data come with information on inventor location (at the city level) and gender.[6] We can thus track inventors across time and space and look at how patterns differ by gender.

We combine the USPTO data with EPO's PATSTAT using publication numbers. We use the Spring 2015 edition. PATSTAT is an effort to collect data on patent filings from all over the world. Importantly, this provides us with patent filings at EPO and JPO, two important patent offices other than the USPTO. We focus on patent families[7] that include a granted patent at all three of these patent offices. We also refer to these as triadic patent families below. These patent families capture the most important inventions and the definition ensures that they are relevant at a global level.[8] PATSTAT also contains information on family-to-family citations which we will use below and technology classes.

2.2 Patent Ownership

A firm can register legal ownership of a patent in a subsidiary that is located in a country different to the firm's headquarters, different to the location where the underlying technology was created, and different to the location where the intellectual property will be applied (Griffith et al., 2014). It is therefore crucial that we accurately identify the firm that is

[6]The information on gender is inferred from inventor names and varies in coverage and reliability by cultural origin. In particular, coverage is worse for Asian countries.

[7]A patent family is a collection of patents concerning the same invention in potentially multiple patent offices around the world.

[8]Note that EPO uses two different definitions of patent families: the simple (DOCDB) and the extended (INPADOC) definition. We use the extended definition here which groups together all applications that have at least one priority in common. In what follows, we use the terms "patent" and "invention" interchangeably, both of which refer to the relevant patent family.

the ultimate owner of a patent and exactly where the invention was created. This requires assigning patents to firms.

To do so, we use the Orbis Intellectual Property (IP) database, provided by Bureau van Dijk. Orbis IP sources its patents data from Lexis Nexis and maps the assignee (or patent owner) names indicated on the patent to Orbis firm identifiers based on a textual matching algorithm and manual checks (see Appendix A for details). These identifiers differentiate between the different establishments (or subsidiaries) of a firm and thus allows us to group patents from the same assignee together. In addition, they allow us to leverage other data collected by Orbis (also provided by Bureau van Dijk), such as financial information, industry classification, and geographic location.

2.3 Firm Ownership Links

We use Bureau van Dijk's Orbis database to obtain data on ownership links. Patents can be assigned to any subsidiary of a firm. As much of R&D is done by multinational firms, it is crucial to be able to map patents assigned to a foreign affiliate back to the ultimate owner. We rely on Orbis's definition of the global ultimate owner (GUO). We define a firm as a multinational enterprise if it has establishments in at least two countries. After we map each patent to a firm, we calculate the number of patents filed by a firm in each country based on the geographic location of its inventors. We define the country that comes on top according to this calculation as a multinational firm's HQ country.

The ownership links were extracted in September 2020 and they reflect the state of the world at that point in time. As we combine the data on ownership links with historical patent data, we may attribute some patents and inventors to a firm that at the time of the patent filing were not part of it, but that the firm subsequently acquired. We would then be confounding an effect that operates through acquisition with an effect operating in a fixed network of establishments. In order to reduce this potential confounding effect, we only use cross-sectional variation from 2000 to 2010 in our regression analysis.

2.4 Sample Coverage

We report figures on the coverage of our dataset in Appendix A. Our matched firm-patent dataset accounts for just over 80% of all triadic patents granted over the period 1980-2010. When we include information on inventors' geographic location and gender, our coverage drops just below 75% when using simple averages (Figure A.1) but remains around 78% when weighted by citations (Figure A.2).

Inventor team size, measured as the number of inventors listed on a patent, has steadily increased from 3.2 in 1980 to 4.5 in 2010 on average (Figure A.3). A larger team size may mechanically lead to greater incidence of collaboration, so we will control for this in our econometric setup. The share of woman inventors has steadily increased from 2.5% in 1980 to 10% in 2010 (Figure A.4), although participation of women on inventor teams varies across countries (Figure A.5).

2.5 Establishment Definition

We define establishments based on patent data. In particular, from the inventors' location of residence we have the country and time zone they are located in[9]. The patent ownership information allows us to assign inventors to firms. Then, an establishment consists of all inventors working for that firm while located in a particular country and time zone. This implies that in countries located in one time zone will have at most one establishment of a given firm, while multiple time zones in the same country can lead to multiple establishments.

2.6 Variable Definitions

We define the following variables that are used in the analysis below.

- Technology Class: Patents are grouped into technology classes by patent offices. We use the International Patent Classification (IPC). Whenever we refer to technology below, we use IPC subclasses, defined by the first four digits of the technology classification. Note that one patent can belong to multiple subclasses.

- Business Hour Overlap: We first define the time zone based on where the inventor is located. Then, we take the the difference in time zone between the HQ location and the foreign affiliate location. The maximum difference is 12 hours. Then we define business hour overlap as 8 hours minus the time zone difference, setting negative values to 0, so that our overlap variable ranges from 0 to 8 hours.

- Distance: Establishment locations are defined as the average latitude and longitude in that time zone and country. For regressions at the inventor location, we use the location of residence of the inventor. The distance is the geodesic (or straight-line) distance between the two locations.[10]

- Both English-speaking: We define a control for whether both countries are English-speaking.

[9] We use the R package lutz to infer the time zone from inventor locations.
[10] We use the R Package geodist.

- Similarity: When we compare patent activity in different establishments of the firm, we construct a similarity measure. For establishments i and j and technology k, we define:

$$similarity_{ij} = 1 - \frac{1}{\sum_k n_{ik} + n_{jk}} \sum_k (n_{ik} + n_{jk}) |s_{ik} - s_{jk}|$$

where n_{ik} is the number of patents of technology k filed in establishment i[11] and $s_{ik} = \frac{n_{ik}}{\sum_{k'} n_{ik'}}$

- Inventor Moves: Below we analyze inventor mobility. To do so, we exploit the panel structure of the patent data, i.e. the permanent inventor identifiers provided by USPTO that allow us to track inventors across different patent filings. We define an inventor as a mover from country A to country B if we observe her patenting when residing in country A first and in country B at a later point in time, as measured by the first filing date of the patent family.

3 Stylized Facts

We use triadic patent family grants from 1980-2010 to document the facts listed below.

1. **The share of cross-border collaboration in patenting has doubled from 4% in 1980 to 8% in 2010** (see Figure 1).

   However, these numbers mask a large degree of heterogeneity in the probability of engaging in international research teams both in the cross-section and across time. Figure 2 shows that inventors located in European countries frequently collaborate with each other. For instance, around 40% of patents filed by inventors located in the United Kingdom (UK) and Switzerland in 2010 had co-inventors located in other countries, double the figure observed in 1980. The share of global collaborative patents tripled in the US from 5% to 15% over the same time period. Notably, patents filed by Japanese inventor teams, which account for a large share of corporate patents in our dataset, rarely involved a co-inventor from another country over the past three decades.

2. **Global collaborative patents are of higher quality than patents filed by teams of inventors located only in the affiliate country.**

[11] Note that this is a simplification for illustration purposes. As we aggregate technologies up to the IPC subclass, we end up with technology shares for each patent, so that n_{ik} is the sum of the individual patent shares for patent class k of all patents with an inventor located in i.

We run a simple least squares regression of patent quality on a variable that indicates global collaborative patents in a sample of patents filed by inventors located in the affiliate country. Patent quality is typically captured by the number of citations that a patent receives. We control for varying combinations of filing year, inventor, GUO, and country-by-technology fixed effects, which capture potential unobserved factors affecting patent quality, and inventor team size. Table 1 shows that global collaborative patents consistently receive a higher number of forward citations regardless of the set of fixed effects we include. According to our most conservative estimate in column (4), such patents receive on average 18% more citations than patents filed by teams of inventors located only in the affiliate country. As expected, team size is also correlated positively with patent quality.

3. **A large share of patenting activity takes place outside of multinationals' HQ countries, by inventors located in their foreign affiliates.**

   Tables 2 and 3 show the top 10 countries by HQ location in our sample by the number of patent families and number of inventors, respectively. The top innovative country in the sample, Japan, is the least collaborative: fewer than 10% of patents filed by Japanese MNEs and their inventors are located outside of Japan. In contrast, around 35% of all inventions filed by US multinationals involve at least one inventor from a foreign affiliate, and 1 in every 5 inventors is located at an affiliate outside the US. The share of patenting outside HQ countries and the incidence of HQ-affiliate collaboration are even larger for European multinationals. For German MNEs, 25% of patents involve global collaboration and 1 in every 4 inventors is located abroad. Notably, MNEs from the UK and Switzerland have very high levels of patenting outside their home countries. More than half of UK MNEs' inventors are located abroad, and 4 in 5 inventors working for Swiss MNEs are located abroad.

4. **Inventors have become more mobile across international borders.**

   They are almost four times as likely to move across international borders in 2010 than they were in 1980 (see Figure 3). Inventor mobility varies by the nationality of MNEs. Figures 4 and 5 show inventor mobility by origin and destination country, respectively. More than 1 in 10 inventors working for UK and Swiss multinationals have filed patents both in the HQ country and at a foreign affiliate. For US and other European multinationals, inventor mobility had reached 5% as of 2010, while for Japanese MNEs inventor mobility has traditionally been minimal. The fact that mobility by origin and destination countries are similar suggests that inventors move in both directions between HQ and affiliate countries.

Inventor mobility is a key ingredient in knowledge diffusion within multinationals. However, mobility may well depend on individual inventor characteristics; for instance, women's willingness to commute is less than men (Le Barbanchon et al., 2021). Our data show that woman inventors have indeed been less mobile for most of our sample period (Figure 6). However, they engage more in global collaborative patents than men (Figure 7).

These stylized facts corroborate earlier observations on the internationalization of R&D during the period between 1980 and early 2000s. According to UNCTAD (2005), the share of R&D conducted by majority-owned foreign affiliates of multinationals from the United States in total firm R&D rose from 11% in 1994 to 13% in 2002. Similarly, German multinationals set up more foreign R&D units in the 1990s than they had done in the preceding 50 years, and the share of foreign to total R&D at Swedish MNEs shot up from 22% to 43% between 1995 and 2003 (UNCTAD, 2005).

The facts we document on our dataset are also in line with findings by the World Intellectual Property Organization. According to WIPO (2019), only 9% of patents filed by US or Western European companies had foreign inventors in the 1970s and 1980s; by the 2010s, this share had risen to 38% for the US and 27% for Western Europe.

Figure 8 foreshadows our results in the next section. It shows the correlation between the probability of global collaboration and overlap in business hours between a multinational's HQ and its foreign affiliate, which is strongly positive. This relationship can of course be driven by variables that are correlated with business hour overlap, such as distance, and other factors. The next section attempts to isolate the effect of business hour overlap from confounding effects.

4 Determinants of International Collaboration

We start by examining determinants of international collaboration among inventors at the level of the inventor-patent combination. In other words, we ask whether a patent obtained by an inventor located outside of the firm's home country involved another inventor located at the HQ.

We estimate the following econometric specification:

$$Collaboration_{pjifc} = \alpha_0 Overlap_{ifc} + \beta_0 Distance_{ifc} + \delta_{cj} + \gamma_f + \eta_i + \varepsilon_{pjifc} \tag{1}$$

where $Collaboration_{pjifc}$ takes on the value of one if patent p belonging to technology class j obtained by inventor i working for firm f's affiliate located in country(-time zone) c included a co-inventor located at firm f's HQ, and zero otherwise.[12] $Overlap_{ifc}$ captures the overlap in business hours between the location of inventor i working in affiliate country c and the location of firm f's HQ. $Distance_{ifc}$ captures the distance between the two. The equation also includes country-technology class fixed effects (δ_{cj}), firm fixed effects (γ_f) and inventor fixed effects (η_i). Country-technology fixed effects capture the supply, sophistication and cost of scientists in a given country, quality of infrastructure that might be relevant to a particular branch of technology, and any other country-specific factors that may affect its capacity to innovate in a particular technology class. Firm fixed effect account, among other things, for the propensity of a given multinational to engage in R&D in general as well as its propensity to do so abroad. Inventor fixed effects capture the productivity of a given inventor, their gender and other inventor-specific unobservables. We estimate a linear probability model and cluster standard errors at the firm level.

Our sample includes all patents granted during the period 2000-2010 involving at least one inventor located outside the HQ country, i.e. we exclude patents obtained by single inventors or inventor teams located entirely at the HQ.[13]

Alternatively, we examine the same question at the affiliate level by estimating the following equation:

$$Collaboration_{jcf} = \alpha_1 Overlap_{fc} + \beta_1 Distance_{fc} + \delta_{cj} + \gamma_f + \varepsilon_{jcf} \qquad (2)$$

where $Collaboration_{jfc}$ captures collaboration between inventors working in firm f's affiliate country c and inventors located at firm f's HQ on patents granted in technology class j.[14] We use two definitions of collaboration: (i) a dummy taking on the value of one if at least one patent among those filed by firm f's affiliate in country c in technology class j involved collaboration with inventors at the HQ; (ii) the share of such collaborative patents among all patents filed by firm f's affiliate in country c in technology class j.

$Overlap_{fc}$ captures the overlap in business hours between the time zone of affiliate in country c and the location of firm f's HQ. $Distance_{fc}$ captures the distance between the two. The equation also includes country-technology class fixed effects (δ_{cj}) and firm fixed effects (γ_f). Standard errors are clustered at the firm level.

[12]Note that a firm f may have multiple affiliates located in different time zones in a country. To keep notation simple, we refrain from specifying a time zone subscript. In what follows, c refers to a country-time zone, which ensures that we calculate the business hour overlap accurately. Since most countries in the sample have a single time zone, we refer to country-time zone pairs simply as "country".

[13]Note that if a single patent involves two inventors from the same affiliate, it will enter the sample twice.

[14]Again, note that a firm may have multiple affiliates located in different time zones in a country. In this scenario, they will enter the sample as separate observations, as c refers to country-time zone pairs. We do not specify a subscript for affiliates to keep notation simple. If a firm has multiple affiliates in the same country-time zone pair, we pool observations from these affiliates.

As argued earlier, we hypothesize that international collaborations are deterred by a longer distance between the affiliate ($\beta<0$) and the HQ but are facilitated by a greater overlap in business hours ($\alpha>0$). A longer distance increases the costs of travel and the amount of time that needs to be spent traveling and thus deters face to face interactions. In contrast, a greater overlap in business hours facilitates communication between affiliates and HQs. The results from estimating equation (1) are presented in Table 4. We start with a simple specification including just the business hour overlap, subsequently adding distance and the fixed effects. In an augmented specification in the last column, we additionally control for the size of the inventor team on a given patent, a dummy for the firm's home and host country being both English speaker and we allow for a differential effect of business hour overlap and distance on female inventors.

The estimates confirm our hypotheses. In all specifications, we find a positive coefficient on the business hour overlap with its magnitude ranging from 0.0325 to 0.1078. The estimate is statistically significant at the one percent level, except for column (2) where it is significant at the 5 percent level. Similarly, we find the expected negative effect of distance (ranging from -0.0652 to -0.0755), which is statistically significant at the one percent level in all specifications. Not surprisingly, we find that international collaboration is facilitated by both the home and host country of the multinational being English-speaking. We find no differential effect of variables of interest on female inventors. Reassuringly, our results are robust to controlling for team size which mechanically drives the propensity to collaborate.

The estimated magnitudes are economically meaningful. Taking the coefficient in column (5), an increase in business hour overlap by seven hours, equivalent to comparing an affiliate of a German multinational in Poland to its affiliate in Japan, is associated with a 33% increase in the likelihood of a patent involving international collaboration.[15] In contrast, the increase in distance from that between Poland and Germany to that from Japan to Germany is associated with a 70% decline in the likelihood of the patent being collaborative.[16]

In Table 5, we present the results of estimating subsidiary-level equation (2) using a linear probability model with the dependent variable defined as a dummy for the existence of any collaboration between a given subsidiary and the firm's HQ. Again, we find support for our hypotheses. In all specifications, we find a positive and highly significant effect of business hour overlap on the likelihood of international collaboration in patenting between subsidiaries and HQs. As before, all specifications show a negative and highly significant effect of distance on such collaborations. International collaboration is also facilitated by

[15] The overlap in business hours between Germany and Japan is 1 whereas it is 8 between Germany and Poland. The average of the dependent variable is 0.235. We thus have $(\log(9) - \log(2))\frac{0.051}{0.235} \approx 0.33$

[16] The distance between Berlin and Tokyo is 9515.03km and 998.02km between Berlin and Warsaw. We thus have $(\log(9515.03) - \log(998.02)) * \frac{-0.0732}{0.235} \approx -0.70$

both the home and host country being English speaking.

In Table 6, we focus on the intensive margin of international collaboration with the dependent variable now capturing the share of all patents filed a given a given subsidiary that involve inventors from HQs. The left hand side panel of the table focuses only on non-zero share, while the right hand side panel also includes cases of no international collaboration. In all eight specifications, the coefficient on the business hour overlap is positive and statistically significant, thus lending support to our hypothesis. An anticipated, we find a negative coefficient on distance, significant in all but two specifications.

Turning back to our previous example, a foreign affiliate of a German multinational in Poland has 3 percentage points (or 22%) more of its international collaborations with inventors located in Germany than an affiliate located in Japan. Including affiliates that do not collaborate internationally, the 7-hour difference in business hours overlap corresponds to a 1.3 percentage points (or 15.5%) increase in the share of patents that are collaborations with headquarters. The shorter distance between Poland and Germany is associated with a 2.4 percentage points (or 29%) higher share of collaborations with headquarters.

One may be wondering whether affiliates located closer to HQ in terms of physical distance and time zones are more likely to have a similar profile of patent portfolios. There are a few reasons why this may be the case. First, if MNEs set up affiliates with a view towards potential collaboration between their HQ and foreign affiliates, then one is more likely to observe inventors producing similar portfolios of patents at the affiliates to those produced in HQ. Second, inventors working at different affiliates of an MNE may still share knowledge with each other, even if they do not formally collaborate on a patent. Such informal knowledge sharing is more likely to occur if inventors located at the affiliates work in technological areas that are close to the work conducted by inventors located in HQ.

We investigate this question by estimating the following model:

$$Similarity_{fc} = \mu Overlap_{fc} + \kappa Distance_{fc} + \delta_c + \gamma_f + \varepsilon_{fc} \tag{3}$$

where $Similarity_{fc}$ is a continuous variable capturing the similarity of the patent portfolio between firm f's HQ and its subsidiary located in country c in the period from 2000 to 2010 (see the previous section for a precise definition). $Overlap_{fc}$ and $Distance_{fc}$ are defined as above. The specification includes fixed effects for the affiliate country c and for the firm f. Standard errors are clustered at the firm level.

The results, presented in Table 7, give some indication that a greater overlap in business hours is associated with more similar patent portfolios. The coefficients of interest are positive and statistically significant at the one percent level in the two most stringent specifications which include fixed effects. The distance, however, does not seem to matter as its coefficient does not reach conventional significance levels in any of the specifications. Neither does language similarity seem to play a role. These results suggest that communication costs, rather than physical distance, play a more important role in determining knowledge sharing co-inventorship within the multinational firm.

5 Knowledge Diffusion from HQ to Subsidiaries: Citation Analysis

In this section, we focus knowledge diffusion from HQ to foreign subsidiaries by examining determinants of patent citations. More specifically, we ask whether the business hour overlap and the distance between a foreign subsidiary and the firm's HQ affect the likelihood of a patent involving an inventor located in a subsidiary citing earlier patents filed by the firm's HQs.

We first examine this question at the inventor-patent level by estimating the following model:

$$Citations_{pjifc} = \alpha_3 Overlap_{ifc} + \beta_3 Distance_{ifc} + \delta_{cj} + \gamma_f + \eta_i + \varepsilon_{pjifc} \tag{4}$$

where $Citations_{pjifc}$ takes on the value of one if patent p belonging to technology class j obtained by inventor i working for firm f's affiliate located in country c cited an earlier patent filed by firm f's HQ, and zero otherwise. $Overlap_{ifc}$ captures the overlap in business hours between the location of inventor i working in affiliate country c and the location of firm f's HQ. $Distance_{ifc}$ captures the distance between the two. The equation also includes country-technology class fixed effects (δ_{cj}), firm fixed effects (γ_f) and inventor fixed effects (η_i). Country-technology fixed effects capture the supply, sophistication and cost of scientists in a given country, including their knowledge of foreign patents in a particular technology class. Firm fixed effect account, among other things, for the propensity of a given multinational to engage in R&D in general as well as its propensity to do so abroad. Inventor fixed effect capture the productivity of a given inventor, their foreign experience, gender and other inventor-specific unobservables. We estimate a linear probability model and cluster standard errors at the firm level.

Our sample includes all citing patents granted during the period 2000-2010 involving at least one inventor located outside the HQ country, i.e. we exclude patent obtained by single inventors or inventor teams located entirely at the HQ.[17]. For cited patents we include

[17]If a single patent involves two inventors from the same affiliate, it will enter the sample twice.

patents filed between 1980 and 2010. Importantly, we exclude multi-establishment patents (i.e. HQ-affiliate patents) here in order to avoid capturing a mechanical effect arising through global collaboration.

We also investigate the same question from the perspective of a foreign affiliate:

$$Citations_{jcf} = \alpha_4 Overlap_{fc} + \beta_4 Distance_{fc} + \delta_{cj} + \gamma_f + \varepsilon_{jcf} \tag{5}$$

where $Citations_{jfc}$ is an indicator variable taking on the value of one if any patent p belonging to technology class j obtained by firm f's affiliate located in country c cited an earlier patent filed by firm f's HQ, and zero otherwise. $Overlap_{fc}$ captures the overlap in business hours between the time zone of affiliate in country c and the location of firm f's HQ. $Distance_{fc}$ captures the distance between the two. The equation also includes country-technology class fixed effects (δ_{cj}) and firm fixed effects (γ_f). Standard errors are clustered at the firm level.

We are interested in understanding whether a greater business hour overlap facilitates knowledge diffusion from HQ to subsidiaries, as reflected in inventors at subsidiaries citing patents obtained earlier by their colleagues at HQ (α>0). We also hypothesize that a larger distance between the affiliate and the HQ deters knowledge diffusion from HQ to subsidiaries (β<0).

The results from estimating equation (4) are presented in Table 8. We begin with a simple specification including just the business hour overlap, subsequently adding distance and fixed effects. In an augmented specification in the last column, we also include an indicator variable for the firm's home and host country being both English speaking and allow for a differential effect of business hour overlap and distance on female inventors.

We do not find much support for our first hypothesis. Although all coefficients on the business hour overlap bear a positive sign, they reach a conventional level of statistical significance only in one specification. In contrast, the data lend strong support for our second hypothesis. The estimated effect of distance is negative is statistically significant at the one percent level in columns (3)-(5), though not in the less stringent specification without any fixed effects in column (2). The additional control variable do not appear to be statistically significant.

The picture changes when we examine the question of interest from the perspective of a foreign subsidiary. As evident from Table 9, now both hypotheses find support in the data. We find a positive and statistically significant coefficient on business hour overlap in three of four specifications, and a negative and statistically significant coefficient on distance in two of three specifications. Both variables are statistically significant in the specifications including fixed effects and additional controls.

The magnitudes point to the effect being economically meaningful. Again comparing a German-owned affiliate in Poland with one located in Japan, we find that the difference in business hour overlap is associated with the one in Poland to be 28% more likely to cite a patent from headquarters.[18] The effect of distance is even stronger. The longer distance from Germany to Japan compared to Poland is associated with a 374% decrease in the probability of citing a patent filed by German headquarters.[19]

6 Knowledge Diffusion within a Multinational Firm: Analysis of Inventor Mobility

In this section, we focus on knowledge diffusion taking place within multinational firms in the form of inventor mobility. More specifically, we consider inventors moving from HQ to foreign subsidiaries and vice versa, and we examine whether the business hour overlap and the distance between a foreign subsidiary and the firm's HQ affect the likelihood of such moves taking place.

We investigate this question at the establishment level by estimating the following model:

$$Move_{fc} = \alpha_5 Overlap_{fc} + \beta_5 Distance_{fc} + \delta_c + \gamma_f + \varepsilon_{fc} \tag{6}$$

where $Move_{if}$ is an indicator variable taking on the value of one if at least one inventor moved from HQ of firm f to its foreign subsidiary in country c or vice versa during the period 1980-2010.[20]

$Overlap_{ifc}$ and $Distance_{ifc}$ are defined as before. The specification includes fixed effects for the affiliate country c and for the firm f. They capture the push and pull effect that may be relevant to the decision to change location.[21] We estimate a linear probability model and cluster standard errors at the firm level.

We are interested in understanding whether a greater business hour overlap facilitates inventor moves and whether a longer distance between HQ to a subsidiary deters inventor moves. Thus, we expect to observe $\alpha{>}0$ and $\beta{<}0$.

The results from estimating a linear probability model at the inventor level are displayed in Table 10. The results are separated by the direction of the move, i.e. from HQ to a

[18]The mean of the dependent variable is 0.13. Hence, we get $(\log(9) - \log(2))\frac{0.0244}{0.13} \approx 0.28$

[19]The mean of the dependent variable is 0.13. Hence, we get $(\log(9519.3) - \log(998.02))\frac{-0.2158}{0.13} \approx 3.74$

[20]To be consistent with previous sections we run this specification where the filing year of the first patent in the new location is between 2000 and 2010.

[21]An inventor may be patenting in multiple technology classes, which is why we do not control for country-technology-class fixed effect.

foreign affiliate and vice versa. As in previous section, we begin with a simple specification including just the business hour overlap, subsequently adding distance and fixed effects. In an augmented specification in the last column, we also include an indicator variable for the firm's home and host country being both English-speaking and allow for a differential effect of business hour overlap and distance on female inventors.

Our results lend strong support to the first hypothesis (α>0). The coefficients of interest bear the expected signs and are statistically significant. The results of the augmented specification suggest that a one-standard-deviation increase (around 3 hours) in business hour overlap is associated with a 77% (or 17 percentage point) increase in the likelihood of an inventor moving from the HQ to a foreign subsidiary[22] and a 93% (or 15 percentage point) of a move in the opposite direction. We do not find evidence for the second hypothesis (β<0). Inventor mobility is constrained by time zone difference, but not by geographical distance.

So far, we have only studied establishment-level factors determining mobility. To further investigate the role of inventor characteristics in global inventor mobility, we look at how the probability of moving between HQ and subsidiaries differs by gender. We run the following specification at the inventor level

$$Move_{ifct} = \eta Woman_i + \theta Tenure_{ift} + \delta_c + +\gamma_f + \varepsilon_{ifct} \tag{7}$$

where $Move_{ifct}$ equals one if an inventor i moves between HQ of firm f and a foreign subsidiary in country c in a given period t. $Woman_i$ equals one if the inventor is a woman and $Tenure_{ift}$ captures the inventor's tenure at firm f. We measure this by the number of patents that the inventor has filed working for firm f, either unweighted or weighted by citations received.

We are interested in η, i.e. whether an inventor's gender affects the propensity of moving after controlling for tenure. Table **??** shows the results from estimating this equation. After controlling for country and firm fixed effects, the coefficient on our variable of interest is negative and statistically significant at the 1%-level. Women are less likely to move, including when controlling for previous patenting activity and time fixed effects.

The coefficient is large in magnitude. After controlling for fixed effects, women are around 0.5 percentage points less likely to move in a given period, compared to a baseline probability of moving of around 1%. Put differently, being a woman is associated with roughly halving the probability of a move between HQ and an affiliate.

This result comes with a caveat, due to the nature of inventor disambiguation. The algorithms for disambiguation are in part based on inventor names. If an inventor changes

[22] The standard deviation of business hour overlap is 2.99 and the mean of the dependent variable is 0.22. Thus, we obtain $\log(1+2.99)\frac{0.1227}{0.22} \approx 0.77$

names, her later publications are less likely to be matched to her work prior to the change. In general, women tend to be more likely to change names than men. If changing names is correlated with moving, we may systematically underestimate the probability of moving for women.

To alleviate concerns about a bias in disambiguation, we run our specification with inventors that have published more than three patents previously (compared to a sample average of around 4.5). The coefficient remains almost unchanged and statistically significant. The fraction of inventors changing names after having published three patents is unlikely to be large enough to offset the effect that we find.

7 Conclusion

Multinational companies account for the vast majority of business expenditure on R&D and innovative activity. We construct a new, cross-country database of multinationals and their patenting activity to document new stylised facts about the role that multinationals play in knowledge creation and diffusion across borders. Our findings provide new evidence that communication costs – as measured by difference in business hour overlap – significantly affect cross-border collaboration in patenting, within-firm patent citations, and inventor mobility. They also uncover the mechanisms that lie behind the knowledge-distance trade-off. We find that while time zone differences between headquarters and subsidiaries are important to explain inventor mobility, geographical distance is not.

A few caveats are in order to interpret our findings.

First, patents as a measure of knowledge creation are not without drawbacks. A patent legally grants a firm the exclusive rights to use or license a new invention over a specified time period (typically, 20 years), in return for publicly disclosing the invention. This creates room for a strategic decision by firms, which may choose not to patent an invention or at least delay its publication. However, patents provide an objective and easily measurable metric for the creation of new technologies. Most importantly, they allow us to observe exactly who contributed to the invention and their geographic locations. Alternative measures, such as R&D, do not reveal where and how teams of researchers collaborate.

Second, multinationals may be making a joint decision in acquiring foreign establishments with an eye for collaboration with HQ teams. If business hour overlap is a significant consideration in this decision, then our results may suffer from endogeneity. In ongoing work, we tackle this and other sources of potential confounders in our empirical approach.

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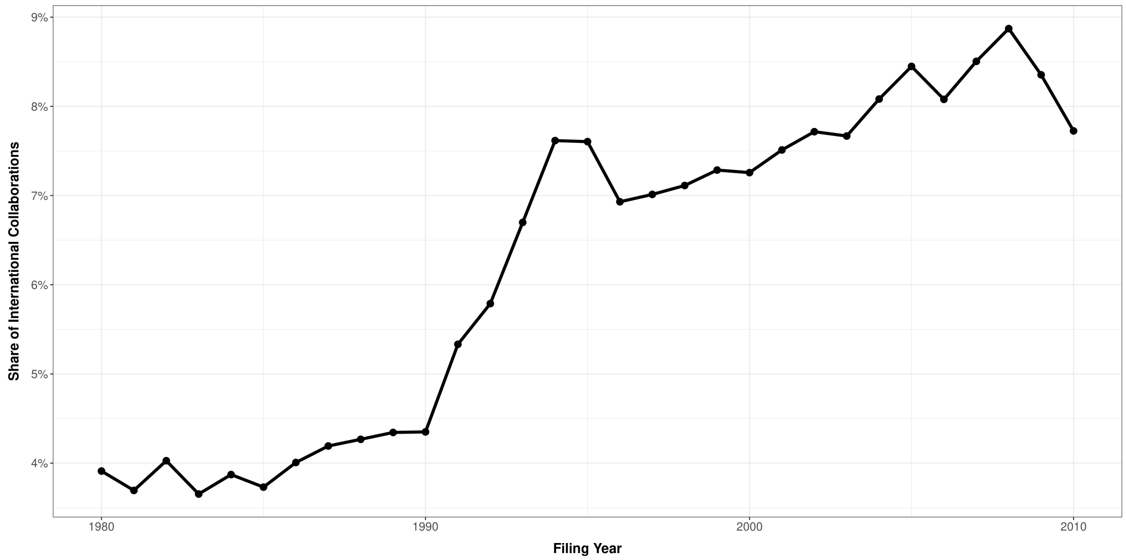
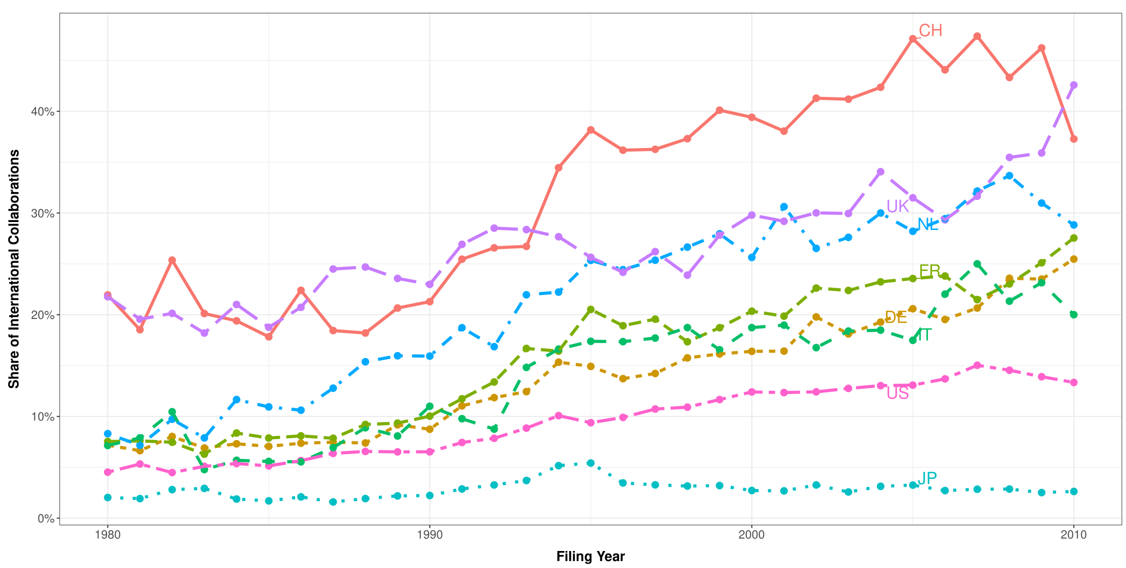
Figures and Tables

Figure 1: Global collaborative patents



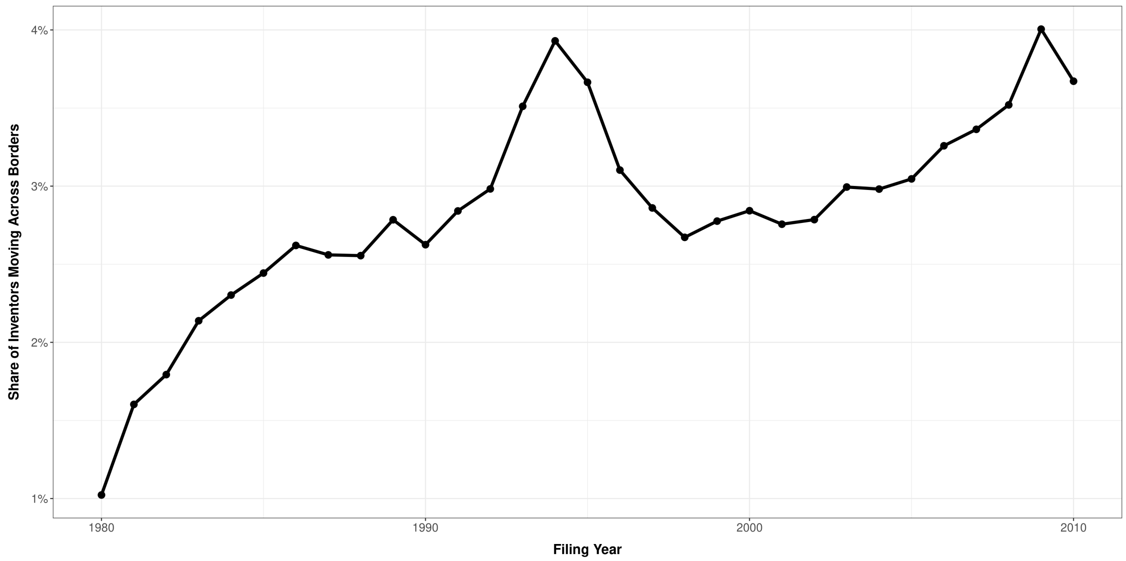
Notes: This figure shows the share of global collaborative patents in all patents.

Figure 2: Global collaborative patents by origin country



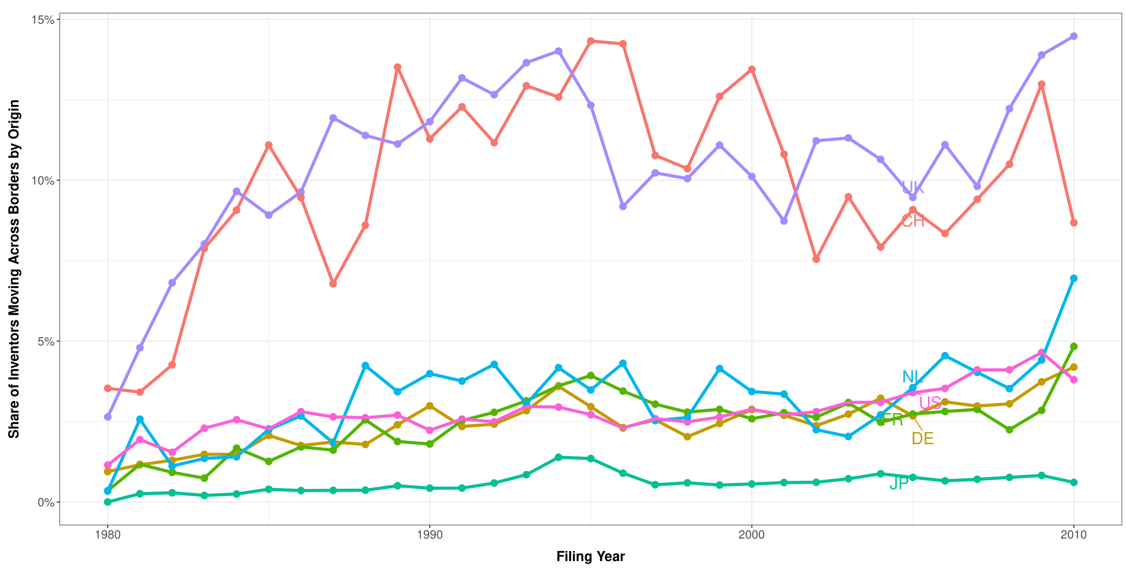
Notes: This figure shows the share of global collaborative patents in all patents filed by origin country of inventors.

Figure 3: Inventor mobility



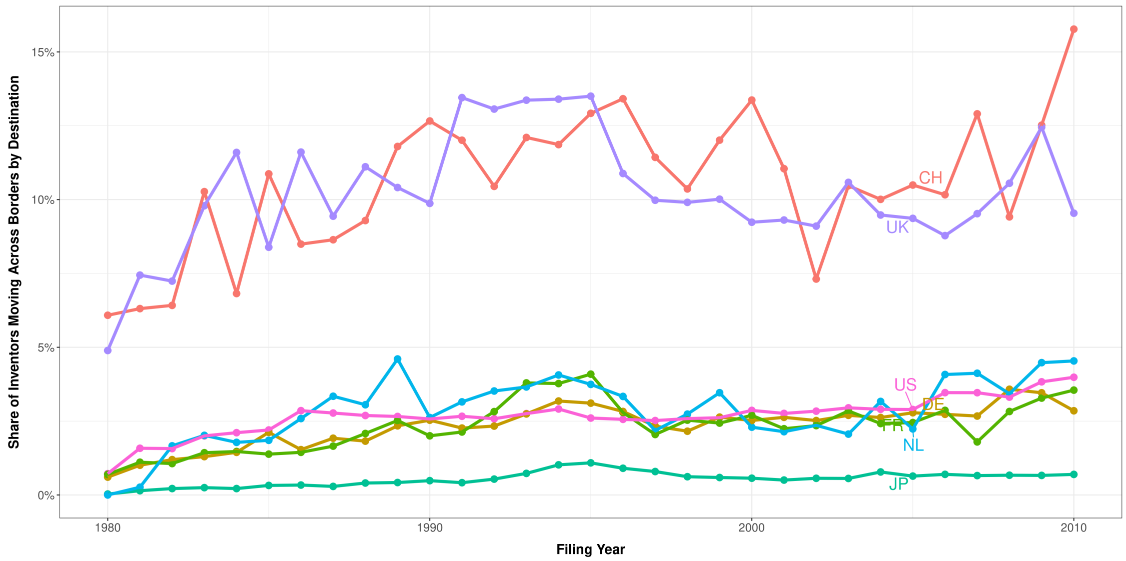
Notes: This figure shows inventor mobility as measured by all inventors that are observed at least once previously and reside in a country in this filing year different than a country in their previous filing.

Figure 4: Inventor mobility by origin country



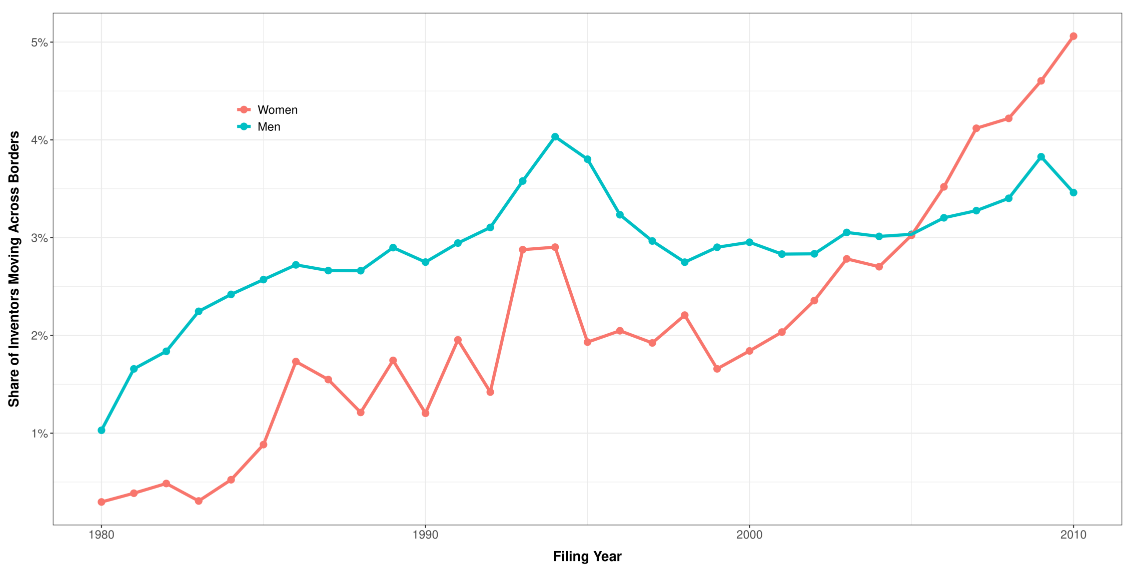
Notes: This figure shows inventor mobility by the origin country of inventors, where the origin country is defined as the country observed in an inventor's previous filing.

Figure 5: Inventor mobility by destination country



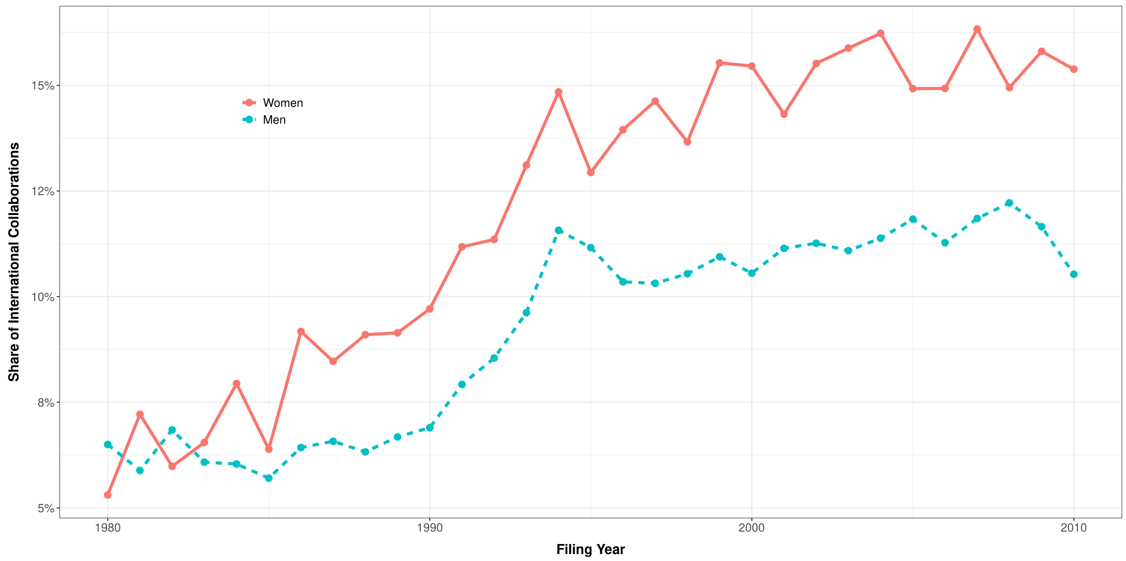
Notes: This figure shows inventor mobility by the destination country of inventors, where the destination country is defined as the country that an inventor is located in in the current filing.

Figure 6: Inventor mobility by gender



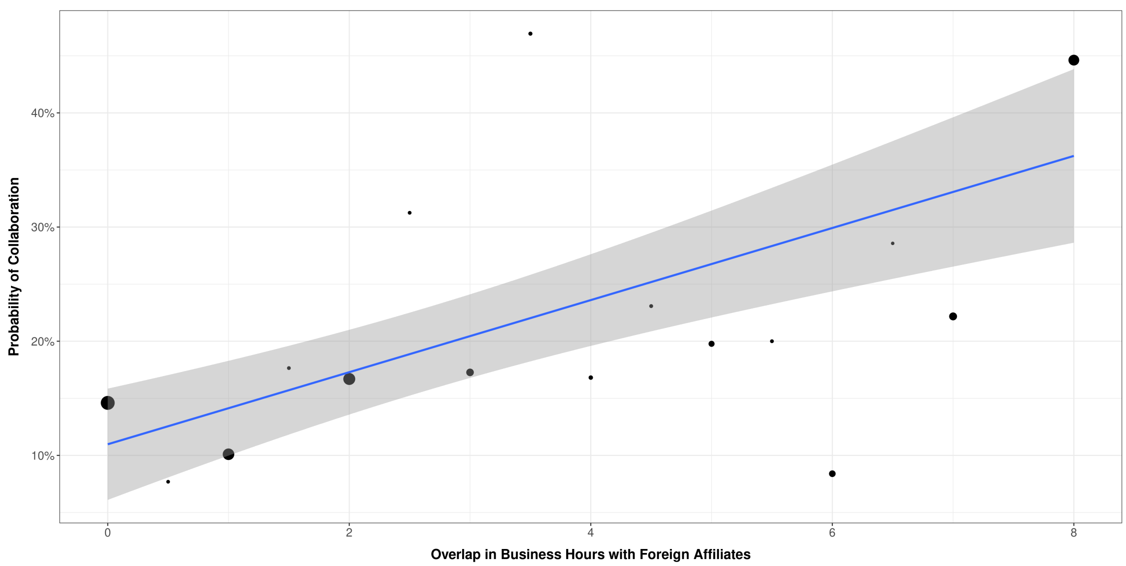
Notes: This figure shows inventor mobility by inventor gender.

Figure 7: Global collaborative patents by gender



Notes: This figure shows the share of global collaborative patents in all patents filed by gender of inventor.

Figure 8: Global collaborative patents and business hour overlap



Notes: This figure shows the share of global collaborative patents in all patents at the establishment level against business hour overlap between the foreign establishment of an MNE and its headquarters.

Table 1: Patent quality of global collaborative patents

Dependent Variable:	log(1+Citations)			
Model:	(1)	(2)	(3)	(4)
Variables				
Collaboration with HQ country	0.9411***	0.4357***	0.4023***	0.1784***
	(0.1278)	(0.0549)	(0.0532)	(0.0409)
log(Inventors)				0.5520***
				(0.0387)
Fixed-Effects				
Filing Year	Yes	Yes	Yes	Yes
Inventor	No	Yes	Yes	Yes
GUO	No	No	Yes	Yes
Country x Technology	No	No	Yes	Yes
Fit statistics				
Observations	589,609	589,609	589,609	589,609
R^2	0.25045	0.92168	0.93152	0.93957
Within R^2	0.10895	0.03472	0.02971	0.14375

One-way (GUO) standard-errors in parentheses.
*Signif Codes: ***: 0.01, **: 0.05, *: 0.1*

Notes: This table presents results of an OLS regression of patent quality on an indicator variable that equals 1 for global collaborative patents, and 0 otherwise. The dependent variable is the (log) number of forward citations a patent receives.

Table 2: Patent Families and Collaboration Patterns by Country

HQ Country	Patent families	HQ inventors (in %)	Affiliate inventors (in %)	HQ-affiliate collaboration (in %)
JP	111606	90.75	4.24	5.01
US	75528	64.41	14.41	21.18
DE	38738	64.56	10.58	24.86
FR	18330	52.17	23.05	24.78
UK	8653	34.59	30.20	35.21
CH	6390	16.07	49.20	34.73
NL	5880	11.36	52.02	36.62
SE	5800	49.72	23.14	27.14
KR	5203	78.47	8.38	13.15
IT	4909	60.87	11.96	27.17

Notes: This table shows the number of patent families filed by MNEs over the period 2000-2010 and the geographic breakdown of their inventors by headquarter country. Column (3) shows the share of patents by inventor teams located in HQ. Column (4) shows the share of patents by inventor teams located in affiliates. Column (5) shows the share of patents by collaborative inventor teams.

Table 3: Location of Inventors by Country

HQ Country	Inventors	HQ inventors (in %)	Affiliate inventors (in %)
JP	296603	91.47	8.53
US	255277	79.48	20.52
DE	98278	73.98	26.02
FR	39714	57.85	42.15
UK	27794	46.33	53.67
CH	17812	20.93	79.07
KR	15467	83.06	16.94
NL	14643	22.64	77.36
SE	13641	59.09	40.91
IT	9752	64.05	35.95

Notes: This table shows the number of inventors on patents filed by MNEs over the period 2000-2010 and their geographic breakdown by MNEs' headquarter country. Column (3) shows the share of inventors located in HQ. Column (4) shows the share of inventors located in affiliates.

Table 4: Collaboration at the inventor-patent level

Dependent Variable:	Collaboration				
Model:	(1)	(2)	(3)	(4)	(5)
Variables					
log(1+hours overlap)	0.1072***	0.0516**	0.0341***	0.0532***	0.0510***
	(0.0124)	(0.0220)	(0.0118)	(0.0156)	(0.0158)
log(distance)		-0.0512***	-0.0702***	-0.0736***	-0.0732***
		(0.0181)	(0.0107)	(0.0173)	(0.0178)
log(Inventors)					0.1102***
					(0.0116)
Both EN-speaking					0.0721***
					(0.0265)
log(1+hours overlap) x Woman					0.0199
					(0.0163)
log(distance) x Woman					0.0078
					(0.0122)
Fixed-Effects					
Country x Technology	No	No	Yes	Yes	Yes
GUO	No	No	Yes	Yes	Yes
Inventor	No	No	No	Yes	Yes
Fit statistics					
Observations	607,304	607,304	607,304	607,304	607,304
R^2	0.04121	0.04689	0.47931	0.72588	0.73059
Within R^2	–	–	0.02308	0.01998	0.03682

One-way (GUO) standard-errors in parentheses.
*Signif Codes: ***: 0.01, **: 0.05, *: 0.1*

Notes: This table presents results of Equation (1). The dependent variable, *Collaboration (0/1)*, equals 1 if a patent team includes inventors from both HQ and affiliate countries, and 0 otherwise.

Table 5: Collaboration at the establishment level

Dependent Variable:	Collaboration			
Model:	(1)	(2)	(3)	(4)
Variables				
log(1+hours overlap)	0.1047***	0.0268**	0.0359***	0.0352***
	(0.0095)	(0.0132)	(0.0129)	(0.0130)
log(distance)		-0.0715***	-0.0655***	-0.0606***
		(0.0079)	(0.0094)	(0.0095)
Both EN-speaking				0.0688***
				(0.0229)
Fixed-Effects				
Country x Technology	No	No	Yes	Yes
GUO	No	No	Yes	Yes
Fit statistics				
Observations	84,028	84,028	84,028	84,028
R^2	0.03594	0.0456	0.52778	0.52823
Within R^2	–	–	0.02324	0.02417

One-way (GUO) standard-errors in parentheses.
*Signif Codes: ***: 0.01, **: 0.05, *: 0.1*

Notes: This table presents results of Equation (2). The dependent variable, *Collaboration (0/1)*, equals 1 if at least one patent filed by inventors located in an "establishment" (affiliate country-time zone) involves an inventor from HQ country-time zone, and 0 otherwise.

Table 6: Share of global collaborative patents at the establishment level

Dependent Variable:	Share of Collaborations with HQ							
	No Zeros	No Zeros	No Zeros	No Zeros	With Zeros	With Zeros	With Zeros	With Zeros
Model:	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Variables								
log(1+hours overlap)	0.0617***	0.0203***	0.0215***	0.0213***	0.0374***	0.0128***	0.0085**	0.0085**
	(0.0041)	(0.0063)	(0.0062)	(0.0062)	(0.0029)	(0.0042)	(0.0037)	(0.0037)
log(distance)		-0.0377***	-0.0102*	-0.0081		-0.0225***	-0.0112***	-0.0107***
		(0.0047)	(0.0053)	(0.0056)		(0.0031)	(0.0035)	(0.0036)
Both EN-speaking				0.0249*				0.0073
				(0.0130)				(0.0078)
Fixed-Effects								
Country x Technology	No	No	Yes	Yes	No	No	Yes	Yes
GUO	No	No	Yes	Yes	No	No	Yes	Yes
Fit statistics								
Observations	47,621	47,621	47,621	47,621	84,028	84,028	84,028	84,028
R^2	0.04422	0.05434	0.61576	0.61593	0.02431	0.02941	0.518	0.51802
Within R^2	–	–	0.00865	0.00907	–	–	0.00456	0.00462

One-way (GUO) standard-errors in parentheses.
*Signif Codes: ***: 0.01, **: 0.05, *: 0.1*

Notes: This table presents results of Equation (2). The dependent variable, *Share of collaborative patents*, measures the share of patents filed by inventors located in an "establishment" (affiliate country-time zone) that involves an inventor from HQ country-time zone in total patents by inventors located in the "establishment".

Table 7: Similarity of patent portfolios

Dependent Variable:	Similarity			
Model:	(1)	(2)	(3)	(4)
Variables				
log(1+hours overlap)	0.0038	-0.0027	0.0340***	0.0341***
	(0.0047)	(0.0071)	(0.0079)	(0.0080)
log(distance)		-0.0063	0.0085	0.0084
		(0.0058)	(0.0067)	(0.0067)
Both EN-Speaking				-0.0025
				(0.0096)
Fixed-Effects				
Host Country	No	No	Yes	Yes
GUO	No	No	Yes	Yes
Fit statistics				
Observations	5,221	5,221	5,221	5,221
R^2	0.00025	0.00058	0.59567	0.59568
Within R^2	–	–	0.0125	0.01251

One-way (GUO) standard-errors in parentheses.
*Signif Codes: ***: 0.01, **: 0.05, *: 0.1*

Notes: This table presents results of Equation (3). The dependent variable, *Similarity*, measures the similarity of patent portfolios between a headquarter and affiliate location (see text for further details).

Table 8: Citations at the inventor-patent level

Dependent Variable:	Citation Count > 0				
Model:	(1)	(2)	(3)	(4)	(5)
Variables					
log(1+hours overlap)	0.0067	0.0062	0.0225**	0.0263	0.0236
	(0.0086)	(0.0087)	(0.0089)	(0.0195)	(0.0195)
log(distance)		-0.0009	-0.1439***	-0.1377***	-0.1395***
		(0.0142)	(0.0415)	(0.0512)	(0.0512)
Both EN-speaking					0.0746
					(0.0632)
log(1+hours overlap) x Woman					0.0224
					(0.0151)
log(distance) x Woman					0.0110
					(0.0210)
Fixed-Effects					
Citing GUO	No	No	Yes	Yes	Yes
Country x Technology	No	No	Yes	Yes	Yes
Inventor	No	No	No	Yes	Yes
Fit statistics					
Observations	241,436	241,436	241,436	241,436	241,436
R^2	0.00035	0.00035	0.28995	0.63465	0.63472
Within R^2	–	–	0.01127	0.02052	0.02071

One-way (Citing GUO) standard-errors in parentheses.
*Signif Codes: ***: 0.01, **: 0.05, *: 0.1*

Notes: This table presents results of Equation (4). The dependent variable, *Citation Count > 0*, indicates whether a patent filed at a foreign affiliate cites at least one patent previously filed by inventors at HQ.

Table 9: Citations at the establishment level

Dependent Variable:	Citation Count > 0			
Model:	(1)	(2)	(3)	(4)
Variables				
log(1+hours overlap)	0.0169**	0.0115	0.0249***	0.0253***
	(0.0078)	(0.0076)	(0.0096)	(0.0096)
log(distance)		-0.0103	-0.2166***	-0.2158***
		(0.0142)	(0.0546)	(0.0545)
Both EN-speaking				-0.0107
				(0.0272)
Fixed-Effects				
Citing GUO	No	No	Yes	Yes
Country x Technology	No	No	Yes	Yes
Fit statistics				
Observations	28,735	28,735	28,735	28,735
R^2	0.00168	0.00197	0.38796	0.38797
Within R^2	–	–	0.01984	0.01986

One-way (Citing GUO) standard-errors in parentheses.
*Signif Codes: ***: 0.01, **: 0.05, *: 0.1*

Notes: This table presents results of Equation (5). The dependent variable, *Citation Count > 0*, indicates whether a patent filed at a foreign affiliate cites at least one patent previously filed by inventors at HQ.

Table 10: Inventor mobility at the establishment level, 1980-2010

Dependent Variables:	Move from HQ to Affiliate			Move from Affiliate to HQ		
Model:	(1)	(2)	(3)	(4)	(5)	(6)
Variables						
log(1+hours overlap)	0.0265**	0.1357***	0.1227***	0.0423***	0.1226***	0.1079***
	(0.0123)	(0.0286)	(0.0272)	(0.0161)	(0.0285)	(0.0283)
log(distance)		-0.1260	-0.1419		0.0135	-0.0044
		(0.0876)	(0.0888)		(0.0655)	(0.0658)
Both EN-Speaking			0.1500*			0.1697
			(0.0898)			(0.1078)
Fixed-Effects						
GUO	No	Yes	Yes	No	Yes	Yes
Host Country	No	Yes	Yes	No	Yes	Yes
Fit statistics						
Observations	12,611	12,611	12,611	12,611	12,611	12,611
R^2	0.00032	0.1989	0.19925	0.00105	0.18127	0.18185
Within R^2	–	0.00493	0.00537	–	0.00398	0.00469

One-way (GUO) standard-errors in parentheses.
*Signif Codes: ***: 0.01, **: 0.05, *: 0.1*

Notes: This table presents results of Equation (6) from OLS estimation using moves where the year of patenting at destination is between 1980 and 2010.

Online Appendix for

Creation and Diffusion of Knowledge in the Global Firm

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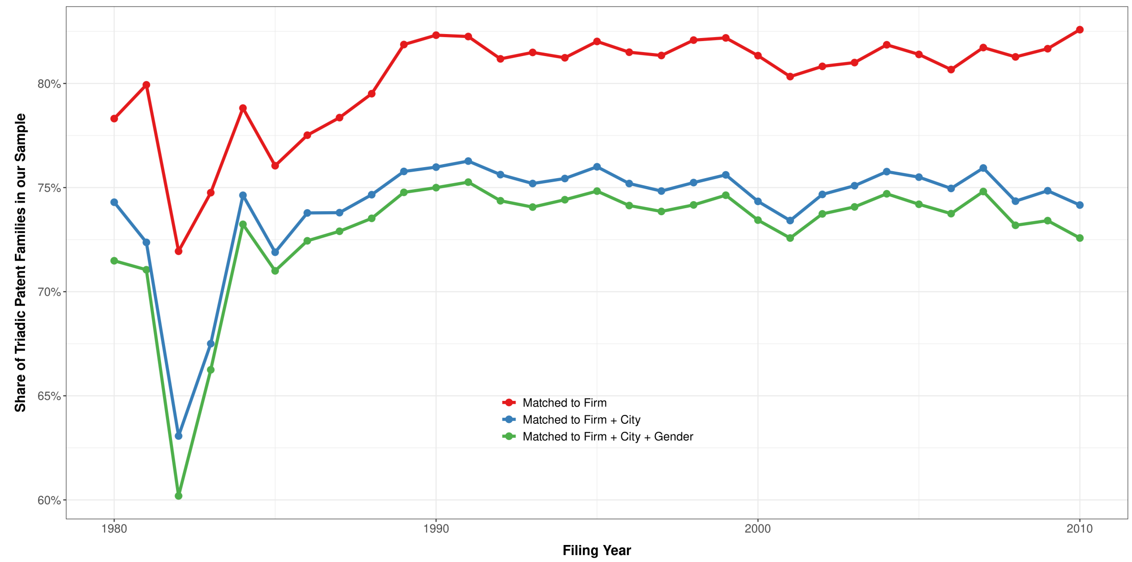
Appendix A

A.1 Data description

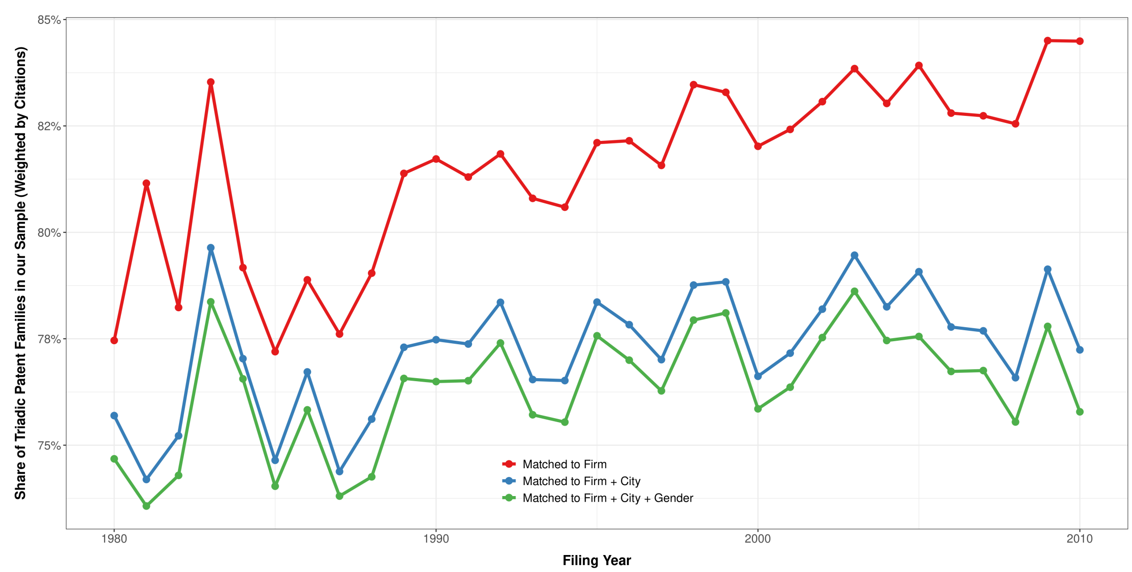
We provide details on our data in this Appendix section.

Figure A.1: Coverage of our dataset - 1



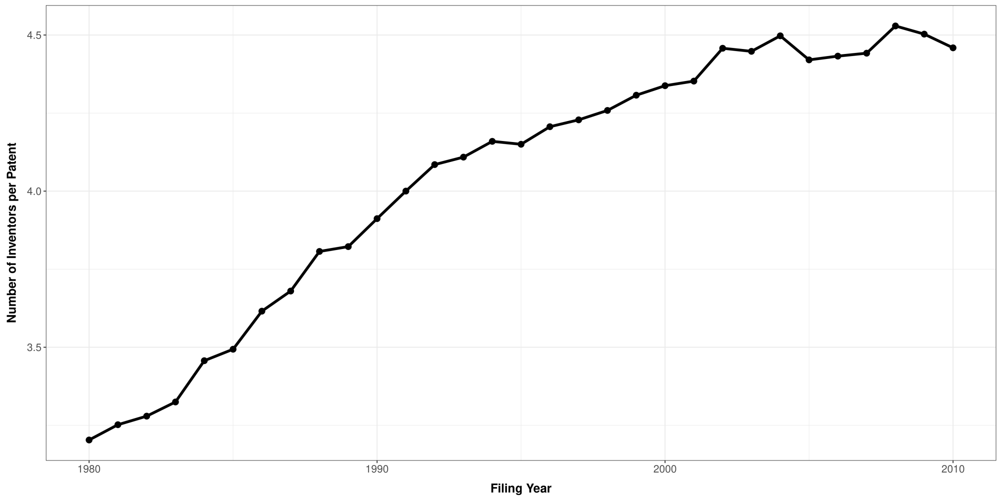
Notes: This figure shows the coverage of our dataset against the universe of triadic patents.

Figure A.2: Coverage of our dataset - 2



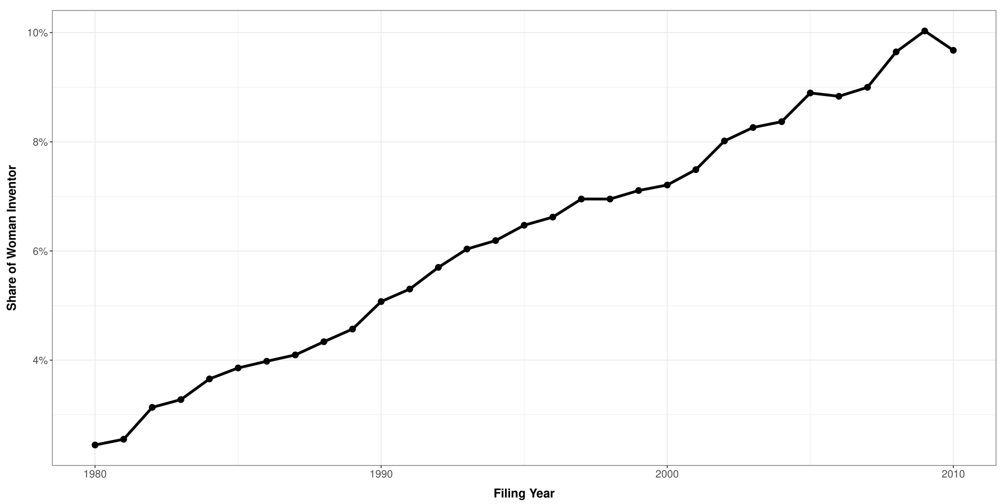
Notes: This figure shows the coverage of our dataset against the universe of triadic patents when weighted by citations.

Figure A.3: Inventor team size



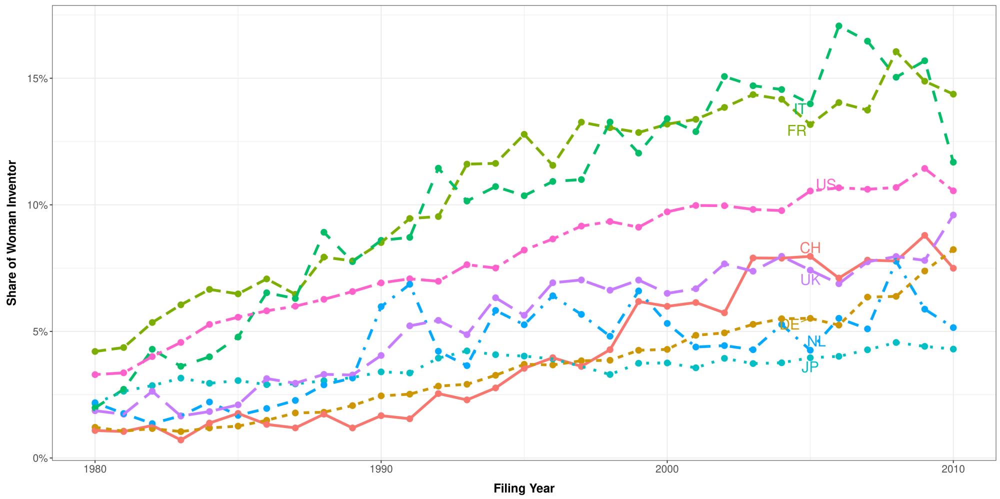
Notes: This figure shows the average number of inventors on patents by filing year.

Figure A.4: Woman inventors



Notes: This figure shows the share of woman inventors in all inventor-patent combinations.

Figure A.5: Woman inventors by country



Notes: This figure shows share of woman inventors in all inventor-patent combinations by country.

A.2 Additional results

Table A.1: Inventor mobility at the establishment level, 2000-2010

Dependent Variables:	Move from HQ to Affiliate			Move from Affiliate to HQ		
Model:	(1)	(2)	(3)	(4)	(5)	(6)
Variables						
log(1+hours overlap)	0.0020	0.0480***	0.0452***	0.0097	0.0562***	0.0570***
	(0.0072)	(0.0138)	(0.0143)	(0.0086)	(0.0151)	(0.0146)
log(distance)		-0.0257	-0.0291		0.0337	0.0347
		(0.0387)	(0.0389)		(0.0380)	(0.0379)
Both EN-Speaking			0.0324			-0.0098
			(0.0402)			(0.0614)
Fixed-Effects						
GUO	No	Yes	Yes	No	Yes	Yes
Host Country	No	Yes	Yes	No	Yes	Yes
Fit statistics						
Observations	12,611	12,611	12,611	12,611	12,611	12,611
R^2	1e-05	0.21991	0.21996	0.00017	0.17767	0.17768
Within R^2	–	0.00185	0.00192	–	0.00241	0.00242

One-way (GUO) standard-errors in parentheses.
*Signif Codes: ***: 0.01, **: 0.05, *: 0.1*

Notes: This table presents results of Equation (6) from OLS estimation using moves where the year of patenting at destination is between 2000 and 2010.