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Fast Friends: The Impact of Short-Term Visits on Firms' Invention Outcomes*

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Abstract

We examine how employees' short-term visits between Research and Development (R&D) centers across different countries can enhance a firm's invention outcomes through enhancing intra-organizational knowledge flows and mutual trust between scientists. We utilize the staggered introduction of the US visa waiver program (VWP) to 41 countries in 1988–2023, which substantially increased short-term visits to the United States. Following the introduction of the VWP, global pharmaceutical companies with R&D centers in VWP countries showed a significant increase in invention quantity and scope compared to those without R&D centers in VWP countries. Notably, we find that the benefits of short-term visits are greater when there is an intermediate knowledge distance between firms' R&D centers in the United States and VWP countries. If R&D centers have similar knowledge bases, efficient knowledge flows can occur even without visits. For centers with very different knowledge bases, short-term visits do not provide enough time for sufficient knowledge flows. Benefits of short-term visits are also magnified when the cultural distance is greater between their R&D centers. Our findings highlight that even short-term face-to-face interactions can enhance the sharing of tacit knowledge and subsequent invention, thereby offering important managerial and policy implications.

Keywords: Technology and Innovation Management, Geography of Innovation, International Management, Knowledge-based View (Knowledge Sharing or Knowledge Management)

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1. Introduction

For large established firms, research and development (R&D) is a global undertaking (Cheng & Bolon, 1993; Monteiro & Birkinshaw, 2017; Nobel & Birkinshaw, 1998). Such firms have R&D centers in multiple countries addressing a range of scientific and technological problems. A challenge for these large firms is to ensure the "whole" is greater than "the sum of the parts." With multiple R&D centers in distant locations, how can firms ensure that these centers do not invent in isolation, thereby losing the benefits of the recombination of rich intra-organizational knowledge between centers? (Fleming, 2001; Monteiro, Arvidsson, & Birkinshaw, 2008; Szulanski, 1996) To ensure R&D centers collaborate effectively, firms can utilize a variety of approaches, such as information technology (Hoegl, Weinkauf, & Gemuenden, 2004) or inter-center R&D teams (Gassmann & Von Zedtwitz, 2003). As invention involves sharing highly tacit knowledge, enabling a greater number of rich face-to-face interactions between researchers in different centers will be a key way that firms can enhance their knowledge recombination.

The migration of scientists from an R&D center in one country to a center in another, geographically distant country can facilitate such face-to-face interactions (Inkpen, 2008; Inkpen & Dinur, 1998). This migration can be through either short-term, temporary travel typically spanning less than three months, or long-term, intrafirm transfers from an R&D center in one country to a center in another country for an extended period (usually > 1 year) (Criscuolo, 2005). Multiple studies (e.g., Choudhury & Kim, 2019; Hunt & Gauthier-Loiselle, 2010; Krol, 2021) have examined the impact of long-term migration on innovation outcomes at different levels (e.g., individual, firm, and country). However, less attention has been paid to the easier way of enhancing intra-organizational knowledge flows, namely how short-term travel between centers in different countries affects firms' innovation outcomes and the mechanisms through which such visits can shape firms' invention efforts (Choudhury, 2017; Inkpen, 2008).

In this paper, we seek to understand the relationship between short-term visits across units within multinational firms and the invention outcomes of those firms. Specifically, we ask the question *"How does an increased ease in short-term visits of employees between countries in which a firm has major R&D centers and the associated increase in short-term travel impact the recombination of a firm's existing knowledge and* *its invention outcomes?"* We argue that an increase in short-term travel by scientists from an R&D center in one country to a center in a different country enables richer face-to-face interactions associated with colocation. This can help reduce *search costs* associated with finding pertinent knowledge and collaborators and can increase *mutual trust* and understanding between inventors in geographically dispersed R&D centers. Both mechanisms can enable firms to benefit from short-term visits between their R&D centers by increasing the quantity of inventions and by creating broader inventions that draw from a more diverse set of knowledge.

Moreover, the distances between R&D centers vary and "distance" can take several forms: geographic distance, knowledge distance, or cultural distance (Bahar, Choudhury, Kim, & Koo, 2023). We argue that the benefits of an increase in short-term travel between R&D centers are magnified when there is an intermediate level of knowledge distance and greater cultural distance between firms' R&D centers that are located in different countries. When the knowledge distance between R&D centers is small, both parties will have shared tacit knowledge that can flow effectively and be recombined in the absence of short-term visits using media such as email and phone conversations. However, if the knowledge distance between the R&D centers is too great, short-term visits are unlikely to enable effective knowledge flows; for recombination to occur, scientists from both centers, which have very different tacit knowledge bases, will need more time to develop a shared understanding of the invention problem they face. With respect to cultural distance, we argue that the incremental benefits of increased trust and mutual understanding between scientists resulting from short-term visits will be greater when these scientists have different cultural backgrounds and a lower baseline level of trust.

To investigate our theoretical predictions empirically, we take advantage of a change in US visa requirements for short-term entry that significantly eased short-term travel between the United States and a select group of countries. The Visa Waiver Program (VWP) enables individuals from pertinent countries to enter the United States for up to 90 days without needing to apply for a visa. The first country to participate in the VWP was the United Kingdom in 1988. As of 2023, citizens of 40 other countries could enter the United States for a short-term visit without the need for a visa. We examine the impact of the introduction of the VWP on the invention outcomes of large multinational pharmaceutical firms with R&D centers in multiple countries, including the United States.

We find that, following the introduction of the VWP, firms with major R&D centers in affected countries saw an increase of 23% in invention quantity (patent filings) and of 11% in invention scope (average number of technology classes) relative to firms with major R&D centers in non-VWP countries. Consistent with our theoretical arguments, we also observe that the marginal benefits of an increased ease in short-term visits between R&D centers are greater when there is an intermediate knowledge distance between the two centers and when cultural distances are greater. In fact, we observe that firms in the highest tercile for knowledge distance between their pertinent R&D centers gain no invention benefits from an increased ease in short-term visits following the VWP. Post-hoc analyses provide additional insights: knowledge flows in both directions (with a higher influx toward the US center); the benefits of short-term visits are greater for new collaborations than for existing ones and greater for the US center than they are for the non-US center; and co-inventions with inventors from both R&D centers (US and non-US) increase following an easing in the ability to undertake short-term travel between these centers.

This study contributes to three different literature streams. First, we extend existing theory regarding intra-organizational knowledge flows and invention by firms' R&D units by illustrating that even short-term face-to-face exposure between individuals from different R&D locations can facilitate the sharing of highly tacit knowledge. Notably, the effect is most pronounced when there is an intermediate knowledge distance between the pertinent R&D centers. If the knowledge distance between the R&D centers is very large, then short-term visits are less effective and potentially longer-term migration may be more effective in ensuring effective knowledge flows and recombination. Second, we contribute to the literature on organization design by illustrating an important way through which firms can enhance intra-organizational cooperation and coordination across their various international R&D units. Third, we contribute to the broader discussion on international migration and its impact on invention. We extend this discussion by highlighting that many of the benefits of accessing talented labor from other countries can be achieved even through short-term visits, reducing search costs for pertinent knowledge and collaborators, and enhancing mutual trust.

2. Theory and Hypotheses

2.1. The benefits of long-term migration and short-term visits for firms' invention outcomes

Multinational firms often have R&D laboratories located around the world (Choudhury, 2017; DeSanctis, Glass, & Ensing, 2002; Monteiro et al., 2008). Having such a dispersed footprint enables firms to access a global scientific talent pool (Nobel & Birkinshaw, 1998), to tap into a broader body of knowledge (Lahiri, 2010; Pearce, 1994), and to adapt their products to local needs (Von Zedtwitz & Gassmann, 2002). For example, in 2022 Johnson and Johnson illustrated on its website the point that the best science can come from anywhere:

> "*We seek the best science and technology, no matter where it is, to solve the greatest healthcare unmet needs of our time. Through our four regional Innovation Centers, located across the globe, we support and invest in highly differentiated early-stage innovations that extend and improve lives everywhere.*"[1]

Firms face a variety of challenges in realizing the benefits associated with their global network of R&D centers. These challenges include: difficulties in communication between laboratories due to large traveling distances and time zone differences (Choudhury & Kim, 2019; Jensen & Szulanski, 2004; Lahiri, 2010; Szulanski & Jensen, 2006); duplication of effort across laboratories (Argyres & Silverman, 2004); and harmful internal competition between laboratories that can adversely impact knowledge flows (Birkinshaw, 2001; Birkinshaw & Lingblad, 2005).

Firms attempt to mitigate some of these challenges through both longer-term migration and short-term visits of scientists from one R&D center to a center in another country (Choudhury, 2022). We distinguish between longer-term migration and short-term visits using the European Union (EU) definition of a short-term visitor as a person who moves to a country other than that of their usual residence for a period of up to 90 days.[2] In contrast, long-term migrants are those who move for a period of at least a year.[3]

There is extensive literature examining the longer-term migration of inventors between countries

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[1] https://jnjinnovation.com/innovation-centers. Accessed 25 Mar. 2022.

[2] https://home-affairs.ec.europa.eu/policies/schengen-borders-and-visa/visa-policy/entry-and-stay-schengen-area_en.

[3] https://home-affairs.ec.europa.eu/networks/european-migration-network-emn/emn-asylum-and-migration-glossary/glossary/long-term-migration_en.

and its impact on firms' invention outcomes. These studies have illustrated that geographic mobility can enhance a firm's invention outcomes through the two broad mechanisms on which our hypotheses are developed (Choudhury, 2022).

First, long-term intrafirm migration of inventors between countries facilitates effective intra-organizational knowledge flows and recombination (e.g., Froese, Stoermer, Reiche, & Klar, 2021; Haas, 2006; Marino, Mudambi, Perri, & Scalera, 2020; Stadler, Helfat, & Verona, 2021). Chang, Gong, and Peng (2012) describe how expatriate transfers to overseas subsidiaries help to transfer knowledge to improve subsidiary performance; this effective knowledge transfer is contingent on migrants' abilities and motivations to transfer knowledge as well as the subsidiaries' absorptive capacity. Catalini (2018) illustrates how the colocation of both migrant and domestic scientists is associated with reduced search costs, costs of finding suitable collaborators, and execution costs, the costs of running projects. Within the context of a Fortune 500 company, Choudhury (2016) finds that local Indian subsidiary inventors file more patents with return migrant managers who have previously worked in a firm's US headquarters and provides strong evidence that long-term return migration enables robust transfer of intra-organizational and cross-border knowledge. Froese et al. (2021) illustrate the importance of long-term migrants' roles in overseas units in facilitating effective intra-organizational knowledge transfer.

Beyond the simple transfer of knowledge, long-term migration from one R&D center to a center in another country enables the effective recombination of a firm's knowledge. For example, Haas (2006) illustrates how teams of local and migrant inventors can leverage both internal and external knowledge to deliver better project outcomes. Relatedly, Singh (2008) describes the challenges associated with invention across R&D centers in different geographic locations, however when cross-regional knowledge is integrated, inventions of value are created.

Second, long-term intrafirm migration of inventors between countries enables firms to create more tightly knit inventor networks with greater levels of trust, which can improve the likelihood of successful invention projects (e.g., Agrawal, Cockburn, & McHale, 2006; Hernandez & Kulchina, 2020). As Edström and Galbraith (1977: 14) state, "*[I]nternational transfers can thus serve an important role in the socialization* *of managers.*" In this way managers can increase their international networks within organizations and enhance their working relationships with individuals in those networks. Madsen, Mosakowski, and Zaheer (2003) suggest that long-term migration can help to engender greater trust by enabling consistent ways of working across an organization. Distinct from the knowledge transfer mechanism, Choudhury and Kim (2019) illustrate how migrants from another country can help a firm unlock new overseas knowledge through greater trust in knowledge from a different cultural context. Baruffaldi and Landoni (2012) illustrate how long-term migrant inventors maintain social ties with their home country, which enables firms to access unique pockets of knowledge in those countries.

Long-term migration of individuals within firms, however, can come with significant costs (Choudhury, 2022; Criscuolo, 2005). These include personal costs as inventors' families as well as individual inventors must move, transfer costs of relocating a family across borders, and regulatory challenges such as accessing requisite visas, to name a few. Short-term travel of inventors from one R&D location to another provides a possible solution to these problems (Criscuolo, 2005). Less attention has been paid to the impact of short-term visits on firms' invention outcomes, but recent studies hint that—with respect to enhancing firms' invention outcomes—similar mechanisms are at play with briefer visits as with longer-term geographic mobility.

Hovhannisyan and Keller (2015) have shown that short-term visits are associated with increased invention at the country level with respect to the country visited; a 10% increase in business travel is associated with a 0.2% increase in patenting. Choudhury (2017) illustrates that even temporary relocation of employees can have longer-term impacts on firms' innovation and describes the two mechanisms—tacit knowledge sharing and recombination—as well as access to new resources through which short-term visits can facilitate firms' innovation. Chai and Freeman (2019) and Boudreau et al. (2017) examine how short-term visits can reduce the search costs associated with finding new research collaborators; this also occurs with longer-term migration, which can provide access to a broader knowledge base. In a qualitative set of case studies, Criscuolo (2005) illustrates that short-term visits within firms are associated with a transfer of knowledge that is narrower in scope and helpful in overcoming cultural differences between distant R&D

centers. Through examination of direct flights between cities in different countries, Bahar et al. (2023) illustrate that greater ease of travel is associated with enhanced knowledge diffusion and invention outcomes within firms, especially when two R&D centers are more distant from each other and have greater knowledge stocks. In Table 1 we highlight the key similarities and differences between short-term visits and longer-term migration with respect to the impact on firms' invention outcomes.

--- Insert Table 1 About Here ---

These studies of short-term visits have provided keen insights into their impact in the context of a single company, at an overall country level, within academic communities, and across a small number of firms qualitatively. However, we do not have large-scale multi-firm evidence that easier short-term cross-border visits by scientists across centers within the same firm can impact firms' invention outcomes. Further, with a few exceptions (e.g., Chai & Freeman, 2019) , we do not have a comprehensive understanding of the mechanisms through which short-term visits can impact firms' invention outcomes. This is an important domain to understand as firms continuously seek to develop more global R&D footprints for access to a broader array of knowledge that will enhance these outcomes.

2.2. Hypothesis development: Increased short-term visits and their effect on invention quantity and scope

In developing our hypotheses, we draw from multiple interviews with R&D managers from leading pharmaceutical companies that have R&D centers in the United States, Europe, and Asia (our empirical context) and from existing studies. The insights from these interviews pertain to the mechanisms through which short-term visits can impact a firm's invention outcomes. We highlight these insights using relevant quotes from these interviews to outline the theoretical mechanisms leading to our respective hypotheses. We focus on firms' invention outcomes as opposed to their broader innovation outcomes. This is because invention, defined as the upstream stage of innovation focused on idea creation (Garud, Tuertscher, & Van de Ven, 2013), is the stage of innovation that is most dependent on intra-organizational knowledge flows.

An increase in the ease of short-term visits between countries provides more and richer face-to-face interactions associated with the colocation at a single site of a firm's scientists from R&D centers in different countries. Easier access to short-term visits enables extended periods of interaction that are not generally possible when using communication media such as phone calls, video calls, or email. Drawing on prior studies focused on longer-term migration and short-term visits, we suggest that an increased ease in short-term visits can enhance the effectiveness of interactions between a firm's scientists from separate R&D centers through face-to-face exchanges. Such benefits of temporary colocation can enhance firms' invention outcomes at the overall firm level via two primary mechanisms.

First, short-term visits can reduce search costs in terms of inventors' abilities to find and access suitable individuals who have the requisite knowledge to address critical invention problems; this can facilitate more effective intra-organizational knowledge flows and recombination of a firm's knowledge (Boudreau et al., 2017; Chai & Freeman, 2019). Short-term visits and the associated face-to-face meetings enable both the transmitters and recipients of knowledge to iteratively clarify their understanding of the relevant knowledge through pertinent questioning and rephrasing of knowledge statements. This is especially important for firms' invention activities that leverage a significant amount of tacit knowledge that may be difficult to communicate through less rich communication media (Grant, 1996). Further, in a technical setting, observing and interacting with experimental processes is far more powerful in transmitting knowledge than simply receiving a document or observing the experiment from a distance. The recipient of the knowledge can view the experimental activity in real time, ask pertinent questions, and provide relevant suggestions. Statements from our interviews with R&D managers illustrate this point:

> *"I could see the process in real time, and it enabled me to ask more insightful questions. Without the visit I would have been stuck asking very basic questions that could be easily answered by observation. I came back with a notebook full of notes and ideas."*

> *"The team can learn new techniques that cannot be learned via books. Sitting down on and off for several weeks* [during the visit] *is a gradual process – in order to learn such new skills."*

Second, an increased ease in short-term travel can help develop trust between scientists working in different laboratories. Face-to-face meetings associated with short-term visits are likely to facilitate greater familiarity between individuals which, in turn, helps to reduce conflict (Hinds & Bailey, 2003). These meetings may even engender friendships among inventors (Festinger, Schachter, & Back, 1950).

Both factors are likely to facilitate greater trust between the visitors and those in the host laboratory; such trust will extend beyond the period of the visit (Hinds & Bailey, 2003). This was also highlighted in our interviews with R&D managers:

> *"The trip enabled me to uncover a group of different people with highly relevant skills that I was able to build a personal relationship with so that they would respond to my calls and emails."*

Other scientists highlighted that:

> *"These short-term visits help both scientific parties to develop respect for each other in their future interactions."*
>
> *"Because you know the other scientist now* [after the visit] *and have a relationship, any collaboration that you do electronically is much more effective. It is impossible to start a good collaboration with somebody that you have never met."*

Greater trust can enable more effective sharing of knowledge between scientists, both during the actual short-term visit and afterward as the relationship continues to develop and can allay concerns about sharing knowledge. As highlighted by the work of Szulanski (1996), the provider of knowledge may fear a loss of ownership of the knowledge and of the privilege this provides, whereas the recipient of the knowledge may be reluctant to use this knowledge because of such issues as the "not invented here" syndrome (Katz & Allen, 1982). The greater trust engendered between scientists through short-term visits is likely to help to overcome any reduced motivation or incentives to share tacit knowledge. Further, such trust will help to clarify who has contributed most effectively to a firm's invention efforts thereby facilitating the provision of rewards. Thus an elevated level of trust is likely to facilitate greater cooperation between scientists across different laboratories, which will facilitate firms' invention efforts (Puranam, Alexy, & Reitzig, 2014).

We argue that the enhanced flows of intra-organizational knowledge and trust, which are engendered between scientists associated with short-term visits, will strengthen two specific invention-related outcomes. First, invention quantity is likely to increase following an increase in short-term visits. This is because firms will be able to recombine their knowledge and execute invention projects more efficiently due to increased intra-organizational knowledge flows and trust. Thus:

Hypothesis 1*: An increased ease in short-term travel between a firm's R&D centers located in different* *countries will be associated with an increase in the quantity of inventions that firm produces.*

Second, we also consider an essential metric of invention quality: the scope of inventions. Invention involves the recombination of existing knowledge in novel ways. The scope of an invention serves as a prominent measurement for gauging the extent of a firm's knowledge recombination across different technology domains (Verhoeven, Bakker, & Veugelers, 2016). In the wake of increased intra-organizational knowledge flows, firms will be better able to leverage the full extent of knowledge embedded within each R&D center. This expanded access to diverse knowledge resources has the potential to elevate the novelty and value of the inventions produced. Further, the scope of inventions lies at the core of the enhanced knowledge flow and recombination mechanism detailed earlier (Fleming, 2001). Scope also provides an indication of an invention's value (Squicciarini, Dernis, & Criscuolo, 2013: 10). Hence, emphasizing the recombination-driven nature of inventions, we argue that an increased ease in short-term travel between R&D centers is likely to lead to a greater scope of inventions produced by a firm.

Hypothesis 2*: An increased ease in short-term travel between a firm's R&D centers located in different countries will be associated with an increase in that firm's mean invention scope.*

Firms' R&D centers vary in a wide variety of attributes, and pairs of R&D centers differ to a greater or lesser extent across these attributes. The differences in attributes can be seen as akin to creating varied "distances" between R&D centers such that the centers are closer together when the attributes have similar magnitudes or are farther apart when their magnitudes are very different. Drawing on work on gravity models, we suggest that greater "distance" between relevant pairs of R&D centers creates larger challenges in achieving successful invention outcomes (Bahar et al., 2023). For example, inter-center collaboration is more challenging when two centers are farther apart geographically and are in different time zones.

In building our theory, we focus on how the two mechanisms discussed earlier—reduced search costs that enhance knowledge flows and increased trust—can magnify the benefits of short-term visits by helping to overcome the challenges of greater distances between R&D centers. First, we examine the knowledge distance between the two R&D centers; namely, is there a high degree of knowledge overlap between the centers (close) or do they focus on very different types of knowledge (more distant). We argue that the enhanced knowledge flows and knowledge recombination associated with short-term visits will help close this gap. Second, we examine the cultural distance between the two R&D centers. We suggest that the enhanced trust that develops between scientists following short-term visits will help reduce such cultural distances. Thus, in the following two subsections 2.3 and 2.4, we examine the moderating effect of both knowledge and cultural distance on the relationships outlined in Hypotheses 1 and 2.

2.3. Moderating impact of knowledge distance

We define knowledge distance as the difference in the content of the knowledge utilized in each pertinent R&D center. For example, in our empirical context, one R&D center may focus on oncology and another on dermatology; this knowledge distance is greater than that between two centers that both focus on endocrinology and diabetes conditions. Empirically, we measure knowledge distance as the degree of knowledge overlap between the two centers; a high degree of overlap signifies a lesser distance, and a low degree signifies a greater distance. At one extreme, if the degree of overlap between the knowledge stock of the two associated R&D centers is high and the knowledge distance low, neither center will be able to provide much additional benefit to the other; both centers will have a rich understanding of the tasks the other is undertaking and will be able to communicate effectively using media such as email and phone (Puranam, Raveendran, & Knudsen, 2012). In this case, the knowledge transfer and recombination benefits of an increased ease in short-term travel will be muted.

As the knowledge distance between two R&D centers increases and knowledge overlap declines, each center is more likely to possess non-redundant knowledge that can benefit the other center, with each center able to learn from the other (Lane, Ganguli, Gaule, Guinan, & Lakhani, 2021). Because such knowledge is generally highly tacit, significant challenges may arise in using media such as email, video calls, or phone calls to transfer and recombine these different knowledge bases. Hence, as knowledge distance increases, short-term visits can encourage more effective recombination of new pieces of knowledge. This in turn will enable the creation of more new inventions of increased scope as previously unconnected pieces of knowledge are brought together from across the firm (Boudreau et al., 2017).

However, when the knowledge distance is great and the degree of overlapping knowledge is low, sharing knowledge between two R&D centers becomes increasingly difficult because each lacks sufficient absorptive capacity to take advantage of the other's unique knowledge set (Cohen & Levinthal, 1990). In this case, increased short-term travel between a firm's R&D centers and the associated knowledge transfer and recombination benefits are likely to be less effective in facilitating invention projects. The gap in knowledge is likely to be so great that the short duration of a trip provides insufficient time to ensure effective knowledge transfer and combination. This is when longer-term migration is likely to have a greater impact by providing adequate time for both sets of scientists to develop an understanding of each other's science domains (Criscuolo, 2005).

Together, these arguments suggest that the benefits of an increased ease in short-term travel between a firm's R&D centers will be greater when the knowledge distance between centers is intermediate (as compared to knowledge distance that is low or high) as the knowledge recombination benefits will be greatest in this case. The requirement of an intermediate level of knowledge distance to obtain invention benefits from short visits was also highlighted in our interview with an R&D group leader:

> *"It is important that these short-term visitors come with a slightly different skill set to what my research group has, so that we can learn from them, and they can learn from us …. I've tried collaborating with scientists in very different domains to mine but these efforts have not really been that productive and not got off the ground."*

Hence, we argue that:

> ***Hypothesis 3a****: The positive association between an increased ease in short-term travel between a firm's R&D centers located in different countries and a firm's invention quantity is more positive when there is an intermediate knowledge distance (as compared to a low or high knowledge distance) between the R&D centers.*

> ***Hypothesis 3b****: The positive association between an increased ease in short-term travel between a firm's R&D centers located in different countries and a firm's mean invention scope is more positive when there is an intermediate knowledge distance (as compared to a low or high knowledge distance) between the R&D centers.*

2.4. Moderating impact of cultural distance

The cultural distance between R&D centers may also vary. Scientists in R&D centers located in countries with very different cultures may struggle to understand each other and to develop an understanding of the technical aspects of the problem3 (Keller & Loewenstein, 2011). One driver of cultural distance is the absence of a common spoken language, such as English, shared by scientists in the two R&D centers; this is our primary empirical measure. We argue that the benefits of increased trust between R&D centers associated with an increased ease of short-term visits will be greater when the cultural distance between the two R&D centers is greater.[4]

First, a greater cultural distance can lead to scientists in one laboratory to simply dismiss another's knowledge as less valid because the primary language in which the knowledge is documented differs from the language of the potential recipient. Choudhury and Kim (2019) describe a case where Chinese and Indian herbal medicine is underappreciated by non-native speakers of Mandarin and Sanskrit. Scientists unfamiliar with the source languages documenting such medicines may not fully appreciate the logical evidence presented to support such medications to treat certain conditions. This situation will be exacerbated when, for example, scientists in one laboratory receive poorly translated documentation or documentation in the original language transmitted by email from the other laboratory. Discounting knowledge, primarily because it is documented in a different language, is likely to reduce trust between scientists in the two laboratories. Short-term visits and the ability to meet collaborators face to face can build greater trust between scientists who speak different languages. Face-to-face visits may be less necessary when the same language is spoken, and greater trust can be built through information-limited media such as phone and email.

Second, the transfer of tacit knowledge is dependent on both parties having a shared understanding of the problems they are addressing (Grant, 1996). When communicating using channels such as email or phone, misunderstandings associated with greater cultural distances are likely to further reduce mutual

[4] For knowledge distance, we consider the curvilinear relationship. In the case of large knowledge distances, short-term visits do not allow the requisite time for effective knowledge recombination as scientists with very different knowledge bases will struggle to gain a common understanding of the problem that they are trying to address. To be effective, bridging knowledge distance may require a significant incubation period due to the non-linear nature of invention. For cultural distance, a linear (dichotomous) relationship is considered. Even when scientists come from R&D centers with a large cultural distance between them, they will experience an increase in trust and mutual understanding following a short-term visit because cultural distance can be bridged relatively quickly through immediate exposure. This increased trust is also likely to persist after the short-term visit. Further, through developing our hypothesis as a linear (positive) moderating impact of cultural distance, we make our theory consistent with our primary empirical analysis in which we use an inherently binary variable relating to whether the two R&D centers share a common spoken language.

trust. Rich contextual non-verbal cues may be missed, preventing scientists in the two centers from developing greater mutual trust. When together in person, scientists can build trust using a combination of written and spoken communication. For example, one R&D scientist commented that using multiple modes of communication in person was beneficial:

> *"We [a UK lab] had a Chinese person in our [English-speaking] research team for a while. Their English was not great. I often had to resort to writing things down for them to communicate."*

Thus, the simple acts of one scientist observing another and using multiple channels of in-person communication can advance collaboration and mutual respect.

Finally, there is substantial variance in the expression of specific issues; these are likely to differ across languages (Oldroyd, Morris, & Dotson, 2019). Even within English, Americans use words that are different from those used, for example, in the UK and Australia. The words "wrench" and "faucet" may mean nothing to a British scientist needing to create a liquid supply line, whereas references to "spanner" and "tap" would be quickly understood. Nuances lost when using a specific string of words in one's non-native language are likely to add to miscommunication and reduced trust, even if non-native language speakers possess a good working knowledge of the relevant language (Kramsch, 1998). Also, greater homophily is likely among scientists who span a lower cultural distance, so ties between scientists in different R&D centers may be stronger even when they use less rich communication channels such as email or phone (McPherson, Smith-Lovin, & Cook, 2001). For example, even through a series of short phone conversations, two individuals with the same cultural background can develop a rapport by seamlessly extending their conversation into non-work domains. Creating rapport is much more challenging when the two parties do not share a common language or cultural context and struggle to understand each other. Short-term visits to another country enable scientists to develop a shared context, greater familiarity with one another, and even lasting friendships despite their greater cultural distance (e.g., Hinds & Bailey, 2003). Such visits help a firm to establish deeper relationships between its scientists in different laboratories by engendering greater trust. As one R&D manager commented:

> *"These short-term visits help both scientific parties to develop respect for each other in their future interactions."*

Together these arguments suggest that:

> ***Hypothesis 4a****: The positive association between an increased ease in short-term travel between a firm's R&D centers located in different countries and a firm's invention quantity is more positive when there is greater cultural distance between the R&D centers.*

> ***Hypothesis 4b****: The positive association between an increased ease in short-term travel between a firm's R&D centers located in different countries and a firm's mean invention scope is more positive when there is greater cultural distance between the R&D centers.*

Our overall theoretical framework is illustrated in Figure 1.

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3. Empirical Strategy

3.1. Setting: US Visa Waiver Program for short-term visits

Stringent visa requirements associated with the destination country can present a key restriction with respect to short-term business travel between R&D units within the same firm located in different countries (Czaika & Neumayer, 2017). A short-term visit generally lasts fewer than 90 days. For example, in the EU "*the definition of short stay of non-EU citizens in the Schengen area is 90 days in any 180 days period.*"[2] Overcoming stringent visa requirements often entails significant effort on the parts of the individual seeking to travel and their employer. These efforts may include completing an application and attending an interview at the embassy of the country that they wish to visit, tasks that can often take months to complete (Torpey, 2018). As a result, there is less business travel to the relevant country than there would be in the absence of stringent visa requirements. Reduced travel can lead to decreased trade and foreign direct investment in the visited country (Czaika & Neumayer, 2017). A relaxation of visa requirements to enter a specific country has been shown to be associated with a significant increase in business travel to that country (Hovhannisyan & Keller, 2015).

Waiving visas represents the greatest easing of visa restrictions. A major example of this is the introduction of the US government's Visa Waiver Program (VWP) in 1988. In this study, we utilize the staggered introduction of the VWP to 41 countries from 1988 through 2023. Prior to the introduction of this program, obtaining a visa to visit the United States involved significant time and effort; it could take several months or even years to prepare the required documents, schedule an interview, and receive a visitor visa stamp. The VWP significantly eased access to the United States for short-term visits. Under the VWP, citizens of designated countries can visit the United States for tourism or business for up to 90 days without undertaking all the processes required to obtain a short-term B-1 visa (for business) or B-2 visa (for tourism). Figure 2 illustrates the staggered introduction of the VWP for 41 countries. The United Kingdom and Japan were the first countries included in the program in 1988. VWP designation for a country is arguably not correlated with the country's invention activities. The US Department of Homeland Security's most important criterion for the VWP designation is that a country "*have had a nonimmigrant visitor visa refusal rate of less than 3% for the previous year or a lower average percentage over the previous two fiscal years*" (Kolker & Platzer, 2021; p.2). We illustrate and discuss further below how the VWP increased short-term travel between the United States and pertinent VWP countries (see Online Appendix A for further details).

---- Insert Figure 2 About Here ----

3.2. Research context, data, and sample

We study the global pharmaceutical industry over the period 1976 through 2020. This industry provides a suitable context for our study for three primary reasons. First, novel knowledge recombination and the generation of inventions is the lifeblood of this industry (Petrova, 2014). Second, we can focus on several large global pharmaceutical firms with R&D operations in laboratories in multiple countries that often examine very different aspects of a firm's R&D (DeSanctis et al., 2002; Pisano, 2006). Online Appendix B provides specific examples of firms' major R&D centers across the globe and their respective areas of focus. Third, the use of patent data to measure firms' invention quantity suffers from multiple limitations: not all inventions may get patented (e.g, Levin et al., 1987), patents may not always correspond to products (e.g., Hall, Jaffe, & Trajtenberg, 2001), and patents may be filed for strategic rather than knowledge-capture purposes (e.g., Spender & Grant, 1996). Some of these limitations are mitigated as firms patent a large proportion of their inventions and these patents closely relate to final products (e.g., Dushnitsky & Shaver, 2009; Gunther McGrath & Nerkar, 2004).

Our sample consists of global pharmaceutical companies. We use Compustat North America and Global to obtain information on publicly traded companies in the pharmaceutical industry (SIC codes: 2833–2836). Patents are used to measure both invention quantity and scope and to obtain information on the location of inventors and R&D centers. The July 2021 release of PatentsView provides the universe of granted patents in the United States from 1976 through 2020.

Since we study short-term visits to the United States and their impact on invention activities, we impose a minimal restriction that a pharmaceutical firm's *US unit* must have filed ten or more US patents during the sample period to ensure the firm has sizable US R&D operations. A total of 533 companies met this criterion, giving us a total of 23,985 firm-year observations. Among these, 135 firms were treated; these were firms in which, during the sample period, the largest non-US unit (as defined by the number of patents granted) was in a country designated to the VWP ("VWP unit"). Most firms were treated in 1988 (48 firms; R&D centers in Japan and the United Kingdom) and 1989 (68 firms; R&D centers in France, Germany, Netherlands, Italy, and Sweden). The remaining firms were treated in 1991 (9 firms; multiple European countries and New Zealand), in 1995 (5 firms; Ireland), in 1996 (3 firms; Argentina and Australia), and in 2008 (2 firms; South Korea and multiple Eastern European countries). The remaining 398 firms were not treated during the study period. Table 2 provides descriptive statistics. More detailed descriptive statistics by groups are provided in Online Appendix C.1.

---- Insert Table 2 About Here ----

3.3. Measurement

Outcome variables. The outcomes of interest are *invention quantity* as measured by the logged number of patents registered with the United States Patent and Trademark Office (USPTO) and *invention scope* as measured by the logged average number of technology classes of patents (four-digit Cooperative Patent Classification [CPC]) at the firm-year level. To determine the timing of invention, we look at the initial submission date of patent applications ("date of apply") for granted patents. In additional analyses, we examine *the direction of knowledge flows* (measured by the number of citations by a US unit's patents to patents of the VWP unit and vice versa) and *co-invention* (measured by the number of patents filed jointly by inventors with US and VWP units) at the firm-year level. We also investigate the *long-term migration of inventors* at the country-year level by counting the number of inventors who filed a patent in a VWP unit and later filed another patent in the United States. For example, if an inventor filed a patent in 2008 with a South Korean address and then filed another in 2009 with a US address and US employer, we code this inventor as having migrated to the United States in 2009.

Explanatory variables. The explanatory variables for the two-way fixed effect (TWFE) difference-in-differences model are *Treat* (which takes 1 for firms where the country of the largest non-US unit was included in the VWP) and *Post* (which takes 1 for years after the VWP introduction and 0 otherwise). These variables are used to test all four hypotheses.

To test Hypothesis 3, we split the treated firms into three groups by their degree of knowledge distance as measured by *knowledge overlap* (Shaver, 2019). We measure *knowledge overlap* between the US and VWP units as the proportion of patents in overlapping technology fields at the four-digit CPC level (o) over all patents ($P_o/(P_o + P_{-o}) \in [0,1]$), using the primary and secondary technology classes. The knowledge distance is lower for firms whose centers have more overlapping knowledge. The group with small overlap (or high knowledge distance) consists of treated firms for which the *knowledge overlap* lies in [0, 0.33] (i.e., is less than or equal to 33%); groups with medium and large overlap (medium and low knowledge distance) consist of treated firms with (0.33, 0.66] and (0.66, 1] overlap measures, respectively.

In testing Hypothesis 4, we split our empirical sample based on whether the US and VWP units are in countries with the same spoken language (English). To construct this variable, we checked whether English is a *de jure* or *de facto* official language of the relevant VWP country.

Control variables. We include firm and year-fixed effects to account for unobserved time-invariant firm heterogeneity and any time-variant trends (e.g., macroeconomic shocks) during the period.

3.4. Estimation methods

Utilizing the introduction of the US VWP to 41 countries at different times from 1988 through 2023, we estimate a staggered difference-in-differences model at the firm-year level. The treatment is that the country of a firm's largest non-US unit is included in the VWP. The treatment group ("switchers") consists of firms where the largest (as defined by patents granted) non-US R&D center receives the treatment during the sample period. The control group comprises firms for which their largest non-US laboratory is in a country (1) *never* included in the VWP ("never treated") and (2) *not yet* included in the VWP but eventually included ("not yet treated").

We first estimate the TWFE difference-in-differences models where y_{it} is the outcome of interest for firm *i* at year *t*, D_{it} is the post-treatment period indicator for the treated (i.e., $Treat_i \times Post_{it}$), and α_i and λ_t are the firm and year-fixed effects; the terms $Treat_i$ and $Post_{it}$ are absorbed by the fixed effects:

$$y_{it} = \alpha_i + \lambda_t + D_{it} + \epsilon_{it} \tag{1}$$

Let E_i denote the year when firm i initially received the treatment (VWP); the term $l = t - E_i$ then represents relative periods to the treatment. Our main analyses focus on $l \in [-5, 7]$ for the treated firms.

A concern with the TWFE model is that, under the existence of treatment effect heterogeneity, a *bad* or *forbidden* comparison would bias the estimates; already-treated units should not be used as controls (this is the fourth case in the Bacon Decomposition; Goodman-Bacon (2021)). We address this concern in two ways. First, a large portion of never-treated firms mitigates the issue (Baker, Larcker, & Wang, 2022). In our sample, such firms account for 75% of all observations. Second, we use new estimators that address the problem: Sun and Abraham (2021) ("SA21") and Callaway and Sant'Anna (2021) ("CS21").[5] SA21 uses never-treated units (or the last treated units if never-treated units do not exist) as controls. CS21, our preferred estimator, uses either never-treated units or a combination of never-treated and not-yet-treated units as controls.[6]

For the main hypotheses, we compare the above three estimators.[7] To test the moderation hypotheses, Hypotheses 3 and 4, we undertake split-sample analyses with the CS21 estimator. We use the

[5] Another estimator is de Chaisemartin and D'Haultfœuille (2020). In staggered adoption designs with a binary treatment, where firms do not switch in and out of treatment, this estimator is identical to Callaway and Sant'Anna (2021) with not-yet-treated and never-treated units as controls (de Chaisemartin & D'Haultfœuille, 2023, 2024). For a comparison of the estimation results, refer to Online Appendix C.5.1.

[6] In our sample, most firms (98.5%) were treated within a relatively short time window (i.e., 1988, 1989, 1991, 1995, and 1996), effectively leaving us only two firms, treated in 2008, as *not-yet-treated* units. Both firms had their VWP unit in a single country, South Korea. This makes the sole use of not-yet-treated units as controls undesirable.

[7] We used the latest version of R packages—*did* and *fixest*—as of August 17, 2023. For reproducibility, we set the seed number 2021 (project start year) for random number generations (e.g., bootstrapping and permutation tests).

same control group as the main analysis (i.e., never treated and not yet treated) for all split groups. We also illustrate our theoretical mechanisms through quotes from interviews with five R&D managers from some of the sample firms utilized in the theory development section of this paper. The interviews were conducted via Zoom and lasted about 30 minutes. The focus of these interviews was on understanding the mechanisms through which short-term visits could impact firms' invention outcomes.

4. Results

4.1. Short-term migration and the quantity and scope of invention

Investigating whether the VWP has indeed eased short-term travel and increased the flow of short-term visitors is an important initial step in evaluating our hypotheses. By analyzing immigration statistics from the US Department of Homeland Security, we confirm a substantial increase in the number of short-term visitors to the United States from VWP-designated countries following the onset of the VWP. Figure 3(a) shows the average number of short-term visitors to the United States from VWP-designated countries (a solid red line) that entered the program in 1999 or later, and the total number of short-term visitors from all countries in the continents to which each VWP country belongs (a dashed blue line) around the year of the VWP introduction. The numbers are standardized based on the pre-VWP year average. The number of visitors to the United States from VWP-designated countries increased by about 60% in the five years after the introduction of the VWP, whereas those from all countries in the corresponding continents increased by only about 20%. The example of South Korea in Figure 3(b) shows that short-term Korean visitors to the United States increased threefold in the ten years after the VWP introduction in 2008, and entries under the VWP rapidly replaced visa-based (B-1 and B-2) entries. The increase in visitors to the United States was similar for other VWP-designated countries; see Online Appendixes A.1 and A.2 for details.[8] These

[8] Note that the VWP is a reciprocal agreement; visitor visas are waived for US citizens visiting the non-US country as well as for non-US citizens visiting the United States. We thus check how the VWP changed (1) the number of visitors from VWP countries to the United States and (2) the number of visitors from the United States to VWP countries. In most cases, the difficulties experienced by those visitors from non-US countries visiting the United States is greater than that experienced by US nationals visiting the VWP countries. Hence, it is expected that the effect of easing short-term visits to the United States is greater than that associated with easing visits to VWP countries. Online Appendix A.2 indeed shows that the number of visitors from South Korea and Taiwan to the United States increased by 51% and 68%, respectively, for the three years after the VWP introduction for those two countries. In contrast, visitors from the United States to these two countries increased by only 14% and 22%, respectively over the same period.

illustrations validate the first-stage effect of VWP: that easing short-term travel restrictions was indeed associated with an increase in short-term travel.

---- Insert Figure 3 About Here ----

We then undertake staggered difference-in-difference analyses to test Hypotheses 1 and 2, which examine the relationship between short-term travel and firms' invention quantity and scope. The first four columns of Table 3 show the results of testing Hypothesis 1 in which the dependent variable is the quantity of inventions: TWFE model (column 1); SA21 model with control groups consisting of never-treated firms (column 2); and CS21 model with two different control groups, never treated (column 3) and both never treated and not yet treated (column 4). The estimates for *Treat* × *Post* range from 0.207 to 0.257. These log point differences are equivalent to an increase of 23–29.3% in patenting (or 13.6–17.3 patents) per year per firm on average for the seven years following the treatment. Figure 4(a) graphically illustrates the dynamic effects along with the pre-treatment trend (see Online Appendix C.5.1 for the analyses with different estimation techniques). The number of patent filings appears to increase significantly in the fourth year of the VWP and continues to increase further through the seventh year following the VWP. The estimate for Year 7 is 0.490 (std. error 0.131 and analytic $p<0.01$). This illustrates that it takes some time for the increased ease in short-term visits to translate into tangible outputs as firms may not immediately increase their short-term travel post-VWP, and invention in a domain like pharmaceuticals takes an extended period. The effects by the treatment cohort (VWP introduction year) are provided in Online Appendix C.2.

Turning to Hypothesis 2, Table 3, columns 5–8, show that the invention scope for treated firms increased by 8.7–9.6 log points or 9.1–10.1% after the VWP. The treated firms filed patents in, on average, 5.13 technology classes before the treatment, so the magnitude of the effect is equivalent to broadening an additional 0.47–0.52 technology classes (four-digit CPC) for each patent post-VWP. Yet, the effect on invention scope is not precisely estimated. This is likely because the *Post* indicator pools all post-treatment estimates to create an average treatment effect over seven years, not considering the increasing trends evident in Figure 4(b). Further, the economic magnitude of invention scope is smaller than that of invention quantity and emerges more slowly over a longer period. To check this, the dynamic pattern of the effect is shown in Figure C5 in Online Appendix C.5.2 for an extended timeframe. The yearly estimates for the invention scope are universally smaller in magnitude and become statistically significant in the seventh year (analytic p=0.028), compared to the fourth year (analytic p=0.064) for invention quantity. This suggests that short-term visits have a more pronounced and immediate effect on invention quantity than on scope, representing one important boundary condition of temporary face-to-face interactions.

---- Insert Table 3 and Figure 4 Here ----

4.2. Moderators that affect the short-term migration-invention relationship

4.2.1. Knowledge distance

Hypotheses 3 and 4 examine how the primary relationships outlined in Hypotheses 1 and 2 are moderated by different *distances* between a firm's US and VWP R&D centers, specifically, knowledge (Hypothesis 3) and cultural distance (Hypothesis 4). We suggest that firms whose US and VWP R&D centers have an intermediate knowledge distance (as compared to a low or high distance) and a greater cultural distance will benefit more from an increase in short-term visits.

Table 4, columns 1–3, shows the results for invention quantity from the split-sample analysis testing of Hypothesis 3a. We find that the estimate for the intermediate-distance group (59.3 log point difference) is economically large and statistically significant. The estimate is greater in magnitude and more precisely estimated than that for small- and large-distance groups. This supports Hypothesis 3a in that, for firms with an intermediate knowledge distance between their R&D centers, the relationship between short-term visits and invention quantity is more positive than that of firms whose centers have a low or high knowledge distance. The results of a three-way interaction with the TWFE model are also consistent with this finding (see Online Appendix C.3).[9]

[9] The new estimation techniques, SA21 and CS2, do not support three-way interaction analyses and we were only able to undertake this three-way interaction using TWFE models. Hence, we cannot definitively state that the moderation impact of intermediate knowledge distance is more positive than that of low knowledge distance on the short-term visit-invention quantity/scope relationship. However, we observe that the moderation impact of intermediate knowledge distance is more positive than that associated with high knowledge distance. Thus, the empirical patterns associated with knowledge distance suggest that the effect of eased short-term migration on invention quantity and scope tends to be higher with intermediate knowledge distance between a firm's US and non-US R&D centers.

Interestingly, the effect for the low knowledge distance group (with large knowledge overlap) is economically large (35.3 log point difference). Hence, for firms whose US and VWP R&D centers have very similar knowledge bases, short-term visits are also associated with an increase in invention quantity, but the impact is lower than when the centers are at an intermediate knowledge distance. On the other hand, firms, whose centers have a high knowledge distance (i.e., low level of knowledge overlap) between pertinent R&D centers, do not appear to benefit from the VWP as the point estimate is negative (–6.8 log point difference; we cannot reject the null hypothesis of no effect).

The results for the scope of invention show a similar pattern (Hypothesis 3b). In Table 4, columns 4–6, we show that firms with intermediate and low knowledge distances (i.e., medium and large levels of knowledge overlap) experience an increase in the scope of invention following the VWP; the magnitude is greater for the intermediate-distance group. The results from the three-way interaction with the TWFE model are consistent (see Online Appendix C.3). Notably, the effect on invention scope is negative for the high distance (or small overlap) group (β=–0.160; p<0.01), suggesting the smallest—or even negative—effect on the scope of a firm's inventions occurs when its R&D centers have very different knowledge bases.

4.2.2. Cultural distance

Table 5 illustrates our analyses testing Hypothesis 4. For both the quantity and scope of invention, the effects for firms where different languages are spoken in the US and VWP centers (columns 1a and 2a) are higher than those for centers with the same spoken language (columns 1b and 2b). For firms with R&D centers speaking different languages, invention quantity and scope increase 30% and 14.3%, respectively, and are statistically distinguishable from zero. This is equivalent to 5.1 more patents per year in 0.73 more patent technology classes per patent. For centers with the same language (i.e., English), however, the point estimates are small (7.7% and –2.1%) and are not statistically significant (i.e., we cannot reject the null hypothesis of no effect). In sum, the effect on the quantity and scope of invention is greater for firms with a greater cultural distance between the pertinent R&D centers, supporting our Hypothesis 4. The results from the three-way interaction with the TWFE model are provided in Online Appendix C.3.

---- Insert Table 4 and Table 5 About Here ----

4.3. Robustness checks

We perform several robustness checks. First, we run the Fisher's permutation test (also known as re-randomization tests) to assess whether our findings are driven by spurious correlations or modeling inaccuracies. We randomly reassign the treatment status to all firms while preserving the distribution of treated timing and the number of treated firms each year. We then run the same regressions as those reported in Table 3, columns 4 and 8. To account for the observed gradual increase in effects over time, as depicted in Figure 4, we calculate average estimates for post-VWP years 5, 6, and 7 ($l \in [-5, 7]$). The results of 2,000 iterations are provided in Online Appendix C.4. Our estimates for both invention quantity and invention scope, 0.416 and 0.164, are distinct from the permutation results with empirical p-values 0.0001 and 0.075, respectively.

Second, we utilize a range of different post-treatment time windows for our staggered difference-in-differences analyses (five, seven, ten, and twelve years). To further check the longer-term effects, we extended the time window to include twelve pre- and post-treatment years ($l \in [-12, 12]$) and estimated the yearly coefficients. The results are robust to both approaches (see Online Appendix C.5.2 for details).

Third, to mitigate the concern that multiple treatments at different times for the same firm may confound the results, we restrict our sample to (1) US-based firms (i.e., those with US units filing the greatest number of patents of any international unit) and (2) firms that received the treatment once (i.e., we excluded firms with R&D units in countries where the VWP was introduced in years that were different and non-consecutive from the introduction of the VWP to the country associated with the largest non-US unit). The results are robust to these alternative approaches (see Online Appendix C.6.1 and C.6.2). Further, we reconfigured the firms as a combination of their US unit, VWP unit, and units that received the treatment within one year as the VWP unit (and dropped units that received the treatment at a different time). We obtained consistent results with this narrower definition of firm boundaries (see Online Appendix C.7).

Fourth, we use an alternative measure for invention scope at the firm level (rather than taking the average of patent-level technology classes). Namely, we count the number of different (unique) patent classes (four-digit CPC) of all patents in each firm-year. The estimation with this alternative measure produces large (13.418.5%) and statistically significant results (see Online Appendix C. 8 for details).

Fifth, we create alternative measures for cultural distance (spoken language). We use Education First's English Proficiency Index (EF EPI), which was based on test results of more than two million adults in 112 countries. For each country, the index provides the ranks and assigns one of five categories of English-language proficiency (Very high, High, Moderate, Low, and Very low). We define countries with "Very high proficiency" as English-speaking. The results are robust to this alternative measure (see Online Appendix C.9).

5. Post-hoc Analyses

5.1. Examining how short-term visits impact knowledge flows

Knowledge flow is a dyadic process in which knowledge flows from one party to another. To evaluate whether the visitor, host, or both parties utilize the knowledge available in the other center, we examine the direction of patent citations between the US and VWP R&D centers. In our empirical context, the US center is the host, and scientists from the VWP center (i.e., the largest non-US unit that was in a country entering the VWP) are visiting. To account for the possibility that multiple non-US units are in countries that receive the VWP designation at similar times (±1 year), we consider all such non-US units to be VWP units.

As shown in Table 6, columns 1a–1b, following the introduction of the VWP to the relevant country, R&D units in the United States cite 11% (or 10.26 log points) more patents from the VWP units, while R&D units in the VWP countries cite 5% (or 4.8 log points) more patents from the US units. This suggests that knowledge flows in both directions with a greater flow toward the United States than away from it. Thus, even if visits are made primarily by non-US scientists to the United States (compared to the number of visits US scientists make to centers in other countries), the US units tend to acquire more knowledge from the visitors than vice versa. An alternative explanation of our main findings reported in Section 4.1 is that researchers attended and learned from conferences in the United States (rather than visiting the firm's US R&D units). Our citation analysis provides strong support for the theory that short-term visits between R&D centers (i.e., within the firm) drive increased invention outcomes, but we cannot completely rule out the learning-from-conference effect.

We then investigate whether firms' inventions increased in the technology classes exclusive to one R&D center or in classes overlapping between the two centers. Table 6, columns 2a–2b, shows the results. After the VWP, firms increasingly engaged in technology classes that were previously pursued exclusively by one of the two R&D centers in both centers, suggesting that previously exclusive technology classes diffuse across the centers within the firm. This also provides important evidence that short-term visits indeed facilitated knowledge flows between US and VWP R&D centers.

---- Insert Table 6 About Here ----

5.2. Examining the trust mechanism using an alternative measure of cultural distance

In developing Hypothesis 4, we argue that R&D centers in more culturally distant countries will obtain greater marginal benefits associated with an increase in short-term visits than will centers located in countries that are more culturally similar. We suggest that this occurs because such visits foster more trust between scientists from different, more culturally distant countries (e.g., Jarvenpaa & Leidner, 1999). As another way of measuring cultural distance, we test our arguments using Hofstede's six cultural dimensions (Hofstede, Neuijen, Ohayv, & Sanders, 1990). We calculate the average cultural distance between the United States and the VWP countries across these six dimensions and split our sample around the median value of cultural distance using this measure. Table 7 shows the split-sample results for invention quantity (columns 1a–1b) and invention scope (columns 6a–6b). Consistent with Hypothesis 4, the impact of short-term visits on firms' invention outcomes is greater in magnitude and precisely estimated for firms whose US and VWP units are more culturally distant. In contrast, firms with culturally close R&D units experience no change in invention outcomes as short-term visits increase.

5.3. Do short-term visits facilitate the creation of new collaborations?

The invention benefits associated with short-term visits can simply arise when research teams absorb knowledge from scientists in other centers and create more inventions of greater scope, or when new collaborations emerge between scientists from the two pertinent R&D centers. One way to examine this is to measure the number of patents filed jointly by inventors in US and VWP units before and after the introduction of the VWP. Table 7(a), column 2 shows that co-invention by US and VWP centers increased, on average, 4.4% (or 0.043 log points) post-VWP. Forming a new collaboration takes more time than does simply absorbing new knowledge into existing project teams, so the average effect size is smaller than that of the main effect. Still, the effect size reaches 8.1% (analytic $p<0.05$) in the fifth year of VWP (see Online Appendix C.10). Hence, one way that firms enhance their invention outcomes post-VWP is through the creation of new intra-organizational collaborations that involve scientists from the two centers. This bolsters our argument that the findings are indeed driven by the VWP.

By observing whether the improvement of firms' invention outcomes post-VWP arises from new or existing collaboration ties, we find further evidence that short-term visits spur the creation of new collaborations between scientists within firms (Seo, Kang, & Song, 2020). Table 7 shows that invention quantity (columns 3a and 3b) and scope (columns 7a and 7b) increased for both new and existing teams. The estimates for both quantity and scope, however, are higher for new teams than for existing teams and are more precisely estimated; this is consistent with the marginal benefits of short-term visits being greater for new than for established collaboration ties. Yet, it is difficult, with the CS21 estimator, to conclude whether this difference between new and existing teams is statistically significant.

5.4. Which team benefits more? Single-country versus cross-border teams

Distinct parts of a firm may benefit differentially from an increase in the number of short-term visits. We examine two drivers of heterogeneity in the impact of short-term visits within firms: single country versus multi-country teams and US versus non-US R&D centers. First, we examine whether single country inventor teams or cross-border teams within firms benefit more from the VWP. Table 7, columns 4a–4b, shows the results for invention quantity. Quantity increased in both cases, but the estimate for the single-country teams (log point difference of 20.2) is greater than that for the cross-border teams (log point difference of 11.6). This suggests that, although knowledge may be transferred through a short-term visit, to create inventions at a greater rate the knowledge is better leveraged for the creation of more inventions when the inventors are in the same R&D center. Specifically, to boost invention quantity, continuous proximity is required to take advantage of new knowledge acquired through short-term visits. In contrast, as shown in columns 8a and 8b, we observe that single-country and cross-border teams benefit almost equally from short-term visits with respect to invention scope, with log point differences of 10.4 and 10.0, respectively.

---- Insert Table 7 About Here ----

5.5. Which R&D center benefits more? US centers versus VWP centers

We examine where the primary advantages of short-term visits accrue, namely in US or (non-US) VWP R&D centers. To do so, we evaluate how invention quantity and scope change in the United States as opposed to VWP centers in other countries after introduction of the VWP. After separating US and VWP centers, we run a firm-country-year level analysis. Table 7, columns 5a–5b, shows the results for invention quantity; columns 9a–9b show the results for invention scope. The invention quantity increased for both R&D centers. Interestingly, however, the magnitude of the effect is 44% greater for the US centers than for the VWP centers. We postulate that US centers benefit more from short-term visits because they have greater resources and complementary assets that enable US-based scientists to take advantage of the additional knowledge. Consistent with this reasoning, we find that 90.4% of treated firms in our sample had their primary R&D centers (i.e., those with the greatest number of patents) in the United States.[10] In contrast, the scope effect is 30% smaller for the US centers (and the estimate for the US centers is not statistically significant). This is probably because non-US VWP centers are likely to have focused on fewer technological domains prior to the increase in short-term travel (due to their smaller size on average as measured by patent stock) and are likely to experience a greater marginal increase in patent scope with an increase in short-term visits.

5.6. Do short-term visits facilitate long-term migration?

Finally, the short-term visits of scientists could have longer-term effects by increasing the likelihood that such scientists become long-term immigrants to the United States. For example, after making a few visits

[10] The US centers of treated firms had an average patent stock of 103 and an inventor stock of 67 around the VWP year. In contrast, these firms' largest non-US centers had a patent stock of 12 patents and inventor stock of 10 during the same period.

and learning about US culture, lifestyle, and scientific research environment, scientists could migrate to the United States on a longer-term basis. This implies that an increase in short-term visits could have indirect yet far-reaching and persistent effects that have not been fully captured in our analyses.

We use US patent data to test whether non-US scientists immigrate to the United States after their country is incorporated into the VWP. The results from the staggered difference-in-differences estimation at the country-year level from 1976 through 2020 are illustrated in Online Appendix C.12. The number of long-term migrants (or immigrants) from VWP-incorporated countries to the United States gradually increases after the VWP, compared to the number from the non-VWP countries. This indicates that short-term visits can provide a gateway for the longer-term migration of inventors, which could further enhance knowledge flows.[11]

6. Discussion and Conclusion

In this paper we show that increasing the ease of short-term travel between a firm's R&D centers can unlock invention benefits for multinational firms through magnifying intra-organizational knowledge flows and mutual trust and understanding between an organization's scientists. Empirically we discover that, following the introduction of the VWP in the United States, firms with R&D centers in the United States and in countries where the VWP is newly established, are associated with an increase in both the quantity and scope of their inventions relative to firms with non-US R&D centers in non-VWP countries. We observe a 26% increase in the number of patents and a 10% increase in the scope of patents for treated firms following the pertinent country's entry into the VWP. This is due to increased short-term travel between the United States and the relevant country, which we observe at a country-year level. We also find that the benefits of an increase in short-term travel are greater when there is intermediate knowledge distance and a greater cultural distance between the two R&D centers. When the knowledge distances between R&D centers is small, knowledge can flow effectively and can be recombined in the absence of short-term visits

[11] Note that our findings from year $\in[-5, 8]$ come primarily from short-term visitors. In an analysis of inventors who did not migrate to the United States within five years from introduction of the VWP, we continue to see an increase in firms' invention quantity and scope following the VWP (see Online Appendix C.11). This suggests that non-movers drive the results of this study.

using media such as email and phone conversations because both parties share tacit knowledge. However, if the knowledge distance between the R&D centers is too great, short-term visits are unlikely to enable effective knowledge flows or recombination because scientists from both centers, who have very different tacit knowledge bases, will need more time to develop a shared understanding of the invention problem they face. With respect to cultural distance, the incremental benefits of increased trust and mutual understanding between scientists resulting from short-term visits is greater when these scientists are likely to have a lower baseline level of trust due to their different cultural backgrounds. Further, we find that both centers gain from an increase in short-term migration with the gain being greater for the US center with access to more resources, knowledge flows in both directions (with a greater flow toward the United States), and much of the benefit of short-term visits comes from the creation of new collaborations.

This study specifically contributes to three literature streams. First, we extend existing theory regarding intra-organizational knowledge flows (Argyres, Rios, & Silverman, 2020; Grant, 1996; Tsai, 2001; Tsai & Ghosal, 1998). We illustrate that even short-term in-person exposure can facilitate the recombination of a firm's existing tacit knowledge in new ways. However, as illustrated in Figure 4, we observe that the increase in short-term visits may require some time for the benefits of richer intra-organizational knowledge flows and increased inter-scientist trust to be realized tangibly. This stems from the fact that invention is a lengthy process, and it can take some time for a firm to create an invention in the form of a filed patent starting from an initial project idea that may have been created during a specific visit. Increasing the number of short-term visits is most effective when the pertinent scientists have an intermediate degree of knowledge overlap; if they possess very different knowledge, then short-term visits are less effective and longer-term migration may have greater potential for ensuring effective knowledge flows and recombination. This helps to illustrate that an increase in the ease of short-term visits between a firm's R&D centers and the subsequent increase in short-term visits are likely to provide different benefits than the longer-term migration of scientists who move to other R&D centers for extended periods (i.e., several years). Specifically, longer-term migration may be more effective in enabling radically new combinations of knowledge to develop highly novel inventions that require extended contact between scientists, whereas shorter-term visits facilitate the creation of a higher volume of inventions.

Second, we contribute to the literature on organization design by illustrating an important way in which firms can enhance intra-organizational cooperation and coordination across their various international units. Puranam et al. (2014p. 163) propose that effective organization design provides *"a set of solutions to four universal problems that all organizations confront"*. These four problems relate to the effective division of labor (division and allocation of tasks) and to integration of effort (provision of rewards and information). Short-term visits provide organizations with an opportunity to integrate their efforts across their several dispersed units through reducing search costs and thereby increasing both intra-organizational knowledge flows and levels of trust between scientists in the firm. This hints at a more fluid perspective on organization design in which, although firms' formal structures are well defined, boundaries between units can become blurred as short-term visits by employees from one unit to another provide a formalized linking mechanism (Taylor & Helfat, 2009).

Third, we contribute to the broader discussion on international migration and its impact on invention. Prior studies have focused primarily on invention at a national level and on how patenting activity is enhanced by an increase in immigrant numbers (Hovhannisyan & Keller, 2015; Hunt & Gauthier-Loiselle, 2010). We extend this prior work in two dimensions. First, we show that short-term visits can enhance the invention outcomes of firms in that country as illustrated by the significant gains of US R&D centers following the introduction of the VWP. Thus, increased mobility of highly skilled workers can start to pay dividends even if these workers visit a country for only a short period of time, providing the host country has scientists with whom such highly skilled temporary migrants can work and exchange knowledge. Post-hoc analyses highlight that the main gains from the VWP accrue to inventors who remain in their original specific R&D centers. This implies that the benefits come from short-term visits as opposed to longer-term migration. If longer-term migration were driving our results, then we would expect to see the benefits coming primarily from inventors who move from R&D centers in one country to those in another for extended periods of time. Second, the benefits of short-term visits are even greater if the visitors speak a language that is different from that spoken in the host country or if they come from more culturally distant countries. This hints at the benefits of leveraging greater cultural diversity within a firm's workforce. Firms do not benefit so much from having diverse workers in separate locations as from having these diverse workers interacting with each other, even if only through short-term visits.

These results can have significant policy implications in that firms may be able to extract many of the benefits of their global workforce without having to resort to long-term immigration of their employees from an R&D center in one country to one in another country. Firms may be able to obtain significant invention benefits through maintaining frequent contact between individuals in R&D centers in different geographical locations by using a combination of short-term visits and new technologies such as videoconferencing. Thus, countries may be able to side-step some of the delicate political issues associated with longer-term migration through enabling friction-free short-term travel that can still provide significant benefits with respect to a country's innovation output.

This study has several limitations that can provide avenues for future research. First, with respect to internal validity, we do not have access to data on the movement of scientists between different R&D centers within the firms in our sample. Ideally, we would track the actual short-term visits of scientists between laboratories within a firm and examine how this impacts the firm's invention outcomes. We can show an increase in collaborations on patents within the firm across laboratories and an increase in overall country-level short-term visits between both countries following the introduction of VWP. Thus, we make a major assumption that visits between a US site and a non-US site within the same firm increase following the introduction of the VWP. Future studies could collect data on the travel of scientists between laboratories within the same firm across a variety of different firms.

Second, this study is focused on a single industry, namely the global pharmaceutical industry. The knowledge associated with creating and developing new drug candidates is highly tacit and requires a significant degree of complex experimentation. This sets some important boundary conditions for our study. Future studies could examine invention that can be undertaken using knowledge that is more codified and that requires less formal experimentation. For example, the development of new software code may benefit less from an increased ease in short-term travel between a firm's sites in different countries.

Third, intra-organizational knowledge flows and trust are not mutually exclusive and are likely to be intricately interdependent and, in some cases, may even be sequential. For ease of theoretical exposition, we separate these mechanisms and examine moderators that are likely to have a stronger impact on one mechanism over another. Future work could examine methods that manipulate a single mechanism such as laboratory experiments. Finally, our key dependent variables relate to invention quantity and scope. It may be the case that for other aspects of firms' innovation activities, such as development or commercialization, the impact of short-term visits will be different from their impact on firms' invention outcomes.

Despite these and other limitations, this study serves to illustrate the significant impact of easing visa restrictions and the associated increase in short-term travel on both the quantity and scope of inventions by multinational firms, especially when firms have R&D centers with an intermediate degree of overlapping knowledge and are more culturally distant.

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Figure 1. Theoretical framework

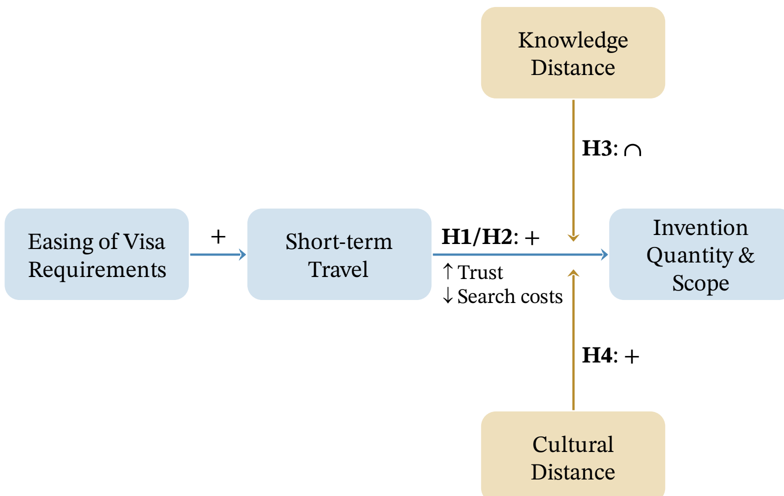
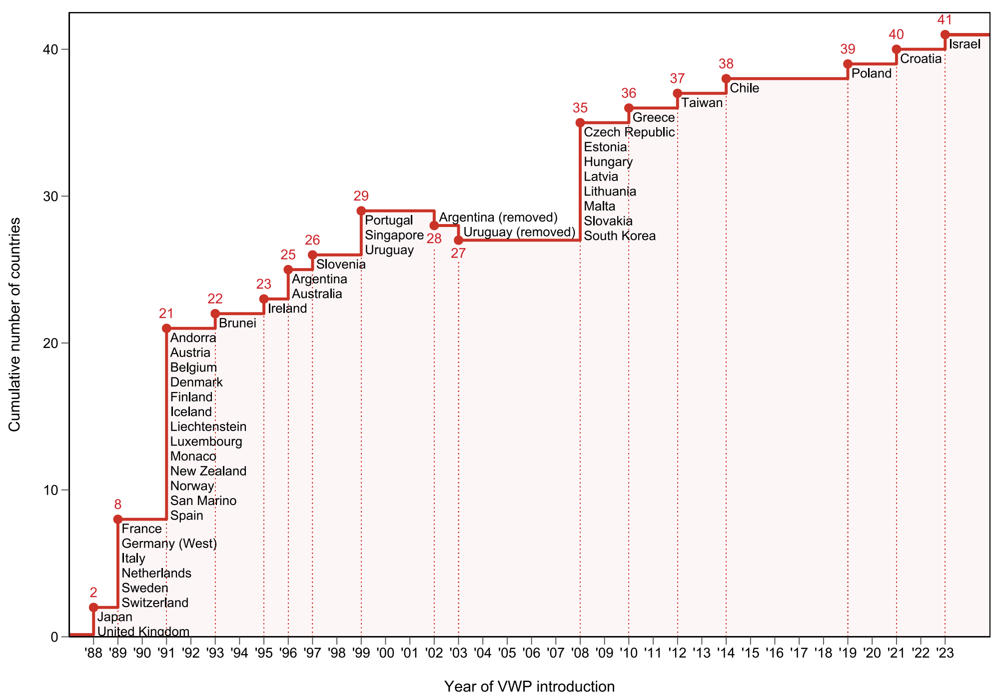


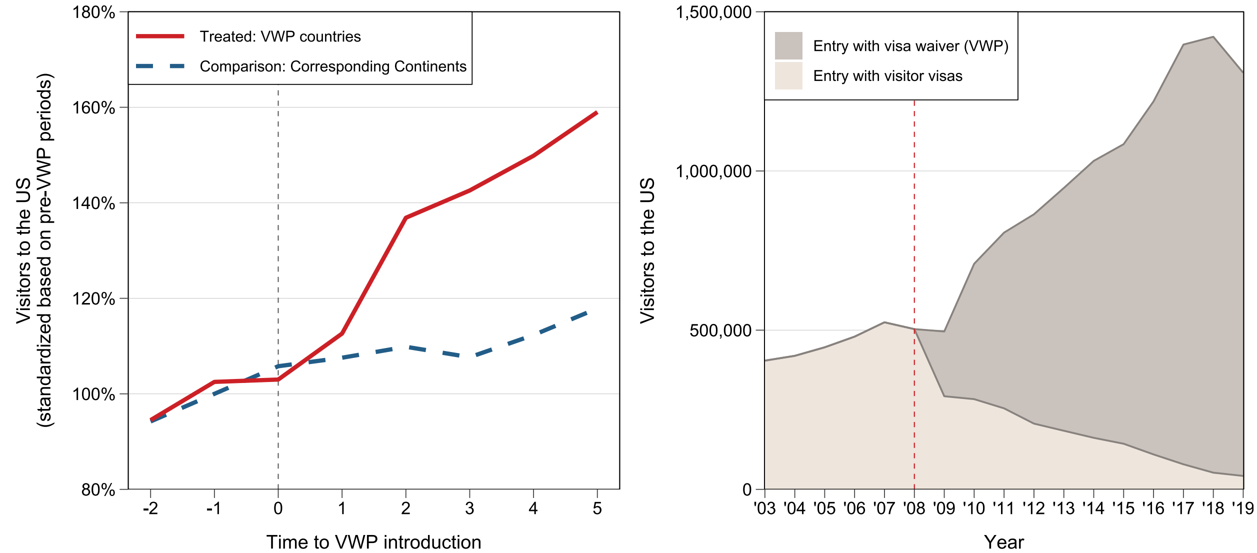
Figure 2. The staggered introduction of the US Visa Waiver Program, 1988–2023



Data. US Department of Homeland Security.

Figure 3. Visa-waiver and short-term visitors to the US

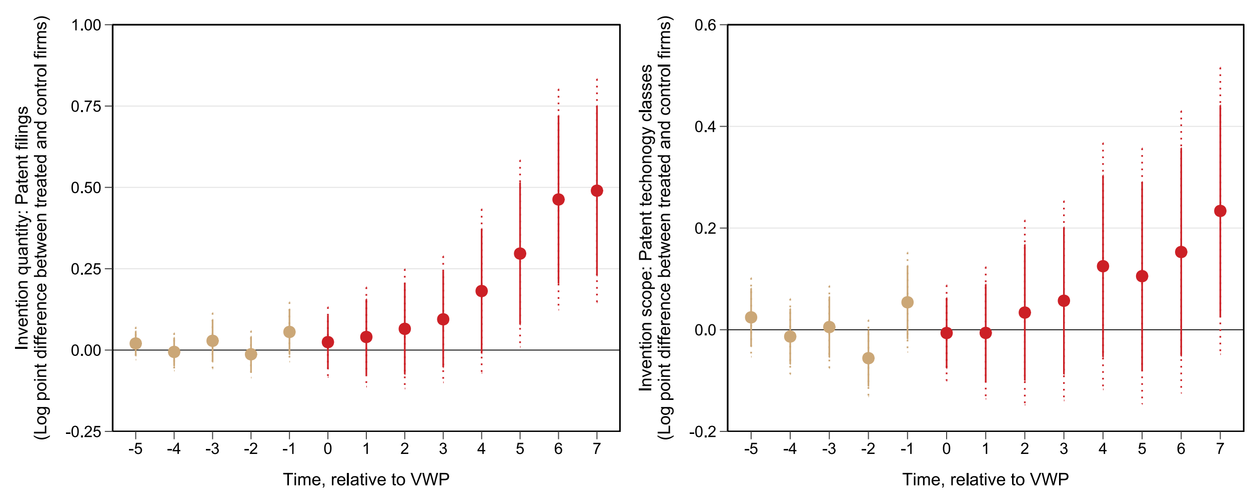
(a). All VWP Countries, aggregated (b). South Korea



Notes. Visitor visas include nonimmigrant visas for a temporary stay in the US: B-1 (business) and B-2 (tourism). *Panel (a)*: The total number of short-term visitors to the US from the countries that received the VWP on and after 1999 (data is only available from 1999; a solid red line) and the total number of short-term visitors from continents each country belongs to (a dashed blue line) around the year of VWP introduction. The numbers are standardized based on the pre-VWP year average. *Panel (b)*: The number of visitors from South Korea, divided by visa-based visitors (light brown) and visa-waiver visitors (dark brown). *Data*. *Yearbook of Immigration Statistics*, US Department of Homeland Security.

Figure 4. The effects of visa waiver on invention outcomes: Event study approach

(a). Invention quantity (b). Invention scope



Notes. The points represent the estimates of *Treat*×*Post* from the staggered difference-in-differences method (Callaway and Sant'Anna, 2021). *T*=0 is the year of VWP introduction. The estimates for pre-treatment periods are colored brown, while the red points represent the estimates for the post-treatment periods. Analytical 95% confidence intervals are reported in solid vertical lines. Bootstrap 95% confidence intervals (10,000 iterations), clustered at the firm level, are provided in dotted vertical lines.

Table 1: Comparison of long-term migration and short-term visits on invention: Summary of key insights from prior studies

	Long-term migration	**Short-term visits**
Impact on invention outcomes	• Increased invention output (Crown, Faggian, & Corcoran, 2020) • Higher value patents (Singh, 2008) • Higher quality patents (Ferrucci & Lissoni, 2019; Kerr & Kerr, 2018)	• Increased invention output (Bahar et al., 2023; Choudhury, 2017) • Increased publication citations (Catalini, Fons-Rosen, & Gaulé, 2020)
Key mechanisms enhancing invention	*Increased knowledge flows* • Increases access to new knowledge for migrant and host country unit through more effective intra-organizational knowledge transfer and sharing (Choudhury & Kim, 2019; Criscuolo, 2005; Szulanski & Jensen, 2006) • Enables broader knowledge recombination within a firm (Choudhury & Kim, 2019; Haas, 2006) *Increased Trust* • Increases socialization of R&D managers in the broader organizational culture and aligns intra-organizational norms that can increase trust between inventors in different locations (Criscuolo, 2005; Edström & Galbraith, 1977; Orlikowski, 2002) *Access to Additional Resources* • Enables access to additional resources in country of host unit or from home country of migrant (Carpenter, Sanders, & Gregersen, 2001; Choudhury, 2022)	*Increased knowledge flows* • Increase cross-border collaboration and reduce search costs in finding new collaborators within a firm in other countries (Boudreau et al., 2017; Catalini et al., 2020; Chai & Freeman, 2019) • Enhance knowledge transfer and diffusion between different parts of organization (Bahar et al., 2023) *Increased Trust* • A greater frequency of face-to-face interactions engenders greater trust between inventors (Catalini et al., 2020) *Access to Additional Resources and Greater Efficiency* • Help inventors to access additional resources within their firms from the relevant country visited (Choudhury, 2017) • Reduce project execution costs within multinational teams, thereby enabling greater productivity (Catalini, 2018)
Limitations	• Employee personal frictions associated with moving counties, e.g., family separation (Criscuolo, 2005) • Employee career concerns pertaining to hindered progression (Yan, Zhu, & Hall, 2002) • Cost to firm associated with moving staff between countries (Criscuolo, 2005) • Employee and firm concerns regarding obtaining requisite work permits (Choudhury, 2022; Yan et al., 2002)	• Potential limits in the complexity of problems that can be examined through shorter visits (Criscuolo, 2005) • Cost to firm of short-term travel (Catalini et al., 2020) • Employee and firm concerns regarding obtaining travel permits for short visits (Catalini et al., 2020; Choudhury, 2022)

Table 2. Descriptive statistics

Variable type	Mean	SD	Min	Max
Outcome variables				
Invention quantity				
– by all inventor(s) in firm	16.97	51.75	0.00	461.00
– by single-country inventor(s)	15.59	47.62	0.00	409.00
– by cross-border inventors	0.97	3.25	0.00	34.00
Invention scope				
– by all inventor(s) in firm	6.48	3.93	1.00	31.21
– by single-country inventor(s)	6.45	4.02	1.00	33.54
– by cross-border inventors	6.66	5.18	1.00	38.75
Long-term migration of non-US inventors to the US*	67.48	217.46	0.00	2,641.00
Moderators				
Knowledge distance	0.43	0.38	0.00	0.98
Cultural distance	0.73	0.44	0.00	1.00
Invention (R&D center-level)				
Patent stock: US center	103.28	361.02	0.00	2,740.00
Patent stock: non-US center	12.04	83.34	0.00	885.00
Inventor stock: US center	66.67	218.83	0.00	1,465.00
Inventor stock: non-US center	10.36	66.86	0.00	693.00

Notes. The descriptive statistics are calculated for the treated firms (i.e., firms that had an R&D center in a country that had been designated as one of the forty countries in the US Visa Waiver Program) at the firm-year level from five years before the VWP introduction through seven years after ($T \in [-5, 7]$), unless otherwise stated. For invention quantity, we imputed zero to a firm-year observation where no patent was filed.

* This country-year level variable is measured by counting the number of inventors who filed a patent in a non-US country and later filed another patent in the US. If an inventor filed a patent in 2008 with a South Korean address and filed another patent in 2009 with a US address and US-based employer, we code that this inventor as having migrated to the US in 2009.

Table 3. The effects of visa waiver on invention outcomes (testing Hypotheses 1 and 2)

	Dependent variables (log point difference):							
	Invention quantity				Invention scope			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Treat × Post	0.257***	0.213***	0.213***	0.207***	0.096	0.093	0.093	0.087
	(0.077)	(0.069)	(0.077)	(0.077)	(0.063)	(0.060)	(0.061)	(0.062)
	[0.106, 0.408]	[0.078, 0.350]	[0.063, 0.363]	[0.057, 0.357]	[−0.027,0.219]	[−0.024, 0.219]	[−0.025, 0.212]	[−0.035, 0.209]
Obs.	19,665	19,665	23,985	23,985	19,665	19,665	23,985	23,985
Firms	533	533	533	533	533	533	533	533
Method	TWFE	SA21	CS21	CS21	TWFE	SA21	CS21	CS21
Control group	All	Never treated	Never treated	Never & Not yet	All	Never treated	Never treated	Never & Not yet
Time	[−5, 7]				[−5, 7]			

Notes. The main estimation was performed in R using the *lfe* (TWFE), *fixest* (SA21), and *did* (CS21) packages. The number of observations differs by the estimation methods. For columns (1), (2), (5), and (6), the observations include relative times, −5 through 7, for the treated group and the entire sample period for the control group (1976–2020). Analytic standard errors, clustered at the firm level, are provided in parentheses; the corresponding 95% confidence intervals are in squared brackets. For columns (3), (4), (7), and (8), the data with the entire sample period is used in the estimation, and the results are aggregated for the time window, [−5, 7]. Analytic standard errors are provided in parentheses. We construct the 95% confidence interval with clustered bootstrapping at the firm level (10,000 iterations). Since the exact p-values are not provided with this approach, we provide the range of p-values. $^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$.

Table 4. The effects of visa waiver on invention outcomes: Knowledge distance (testing Hypothesis 3)

	Dependent variables (log point difference):					
	Invention quantity			Invention scope		
Distance	(1) High	(2) Medium	(3) Low	(4) High	(5) Medium	(6) Low
	Small overlap: [0, 33%]	Med overlap: (33%, 66%]	Large overlap: (66%, 100%)	Small overlap: [0, 33%]	Med overlap: (33%, 66%]	Large overlap: (66%, 100%]
Treat×Post	−0.068	0.593***	0.353**	−0.160***	0.530***	0.178*
	(0.058)	(0.223)	(0.152)	(0.059)	(0.150)	(0.107)
	[−0.180, 0.045]	[0.156, 1.030]	[0.057, 0.650]	[−0.275, −0.045]	[0.236, 0.823]	[−0.031, 0.387]
Observations	20,565	18,945	20,295	20,565	18,945	20,295
Number of firms	457	421	451	457	421	451
Method	CS21 (control: never treated, not yet treated)			CS21 (control: never treated, not yet treated)		
Time window	[−5, 7]			[−5, 7]		

Notes. The estimation was performed in R using the *did* package. The number of treated firms in each category (and thus the number of observations) differs based on the knowledge overlap between US and non-US units. Analytic standard errors are provided in parentheses. We construct the 95% confidence interval with (1) Student's *t*-distribution (conventional) and (2) clustered bootstrapping at the firm level (10,000 iterations). We take a conservative approach and report the wider interval in squared brackets. *$p<0.1$; **$p<0.05$; ***$p<0.01$.

Table 5. The effects of visa waiver on invention outcomes: Cultural distance (testing Hypothesis 4)

	Dependent variables (log point difference):			
	Invention quantity		Invention scope	
Distance	(1a) High	(1b) Low	(2a) High	(2b) Low
	Different language	Same language	Different language	Same language
Treat × Post	0.262***	0.074	0.134*	−0.021
	(0.073)	(0.201)	(0.069)	(0.118)
	[0.118, 0.405]	[−0.319, 0.467]	[−0.002, 0.270]	[−0.253, 0.211]
Obs.	22,365	19,530	22,365	19,530
Firms	497	434	497	434
Method	CS21 (control: never & not yet treated)			
Time	[−5, 7]			

Notes. The estimation was performed in R using the *did* package. The number of observations is different across models because we split the treated group into two subgroups based on the primary spoken language of the VWP unit. Analytic standard errors are provided in parentheses. We construct the 95% confidence interval with (1) Student's *t*-distribution (conventional) and (2) clustered bootstrapping at the firm level (10,000 iterations). We take a conservative approach and report the wider interval in squared brackets. *$p<0.1$; **$p<0.05$; ***$p<0.01$.

Table 6. The effects of visa waiver on knowledge flows between R&D centers

	Dependent variables (log point difference):			
	Backward citations		Overlapping classes	
	US cites VWP (1a)	VWP cites US (1b)	Overlap classes (2a)	Exclusive classes (2b)
Treat × Post	0.102*	0.045*	0.108**	0.194***
	(0.057)	(0.027)	(0.049)	(0.069)
	[−0.009, 0.213]	[−0.008, 0.098]	[0.012, 0.204]	[0.058, 0.330]
Obs.	23,985	23,985	23,985	23,985
Firms	533	533	533	533
Method	CS21 (control: never & not yet treated)			
Time	[−5, 7]			

Notes. The estimation was performed in R using the *did* package. We define overlapping classes as the five most patented four-digit CPC classes where both the US and VWP units of a firm have patented (column 2a). The exclusive (non-overlapping) classes are the remaining patent classes where either the US or VWP unit exclusively patented (column 2b). Analytic standard errors are provided in parentheses. We construct the 95% confidence interval with (1) Student's *t*-distribution (conventional) and (2) clustered bootstrapping at the firm level (10,000 iterations). We take a conservative approach and report the wider interval in squared brackets. *$p<0.1$; **$p<0.05$; ***$p<0.01$.

Table 7. The effects of visa waiver on invention outcomes: Post-hoc analyses

(a). Invention quantity

	Dependent variables (log point differences): invention quantity								
	Cultural distance (Hofstede)		Collaboration patterns: Patents by			Which team benefits more?		Which R&D center benefits more?	
	Distant culture (1a) *High*	Close culture (1b) *Low*	Collaboration between units (2)	New teams (3a)	Continuing teams (3b)	Single-country teams (4a)	Cross-border teams (4b)	US center (5a)	VWP (non-US) center (5b)
Treat ×	0.243***	0.178	0.034	0.190***	0.153**	0.202***	0.116***	0.166**	0.115***
Post	(0.095)	(0.121)	(0.023)	(0.065)	(0.063)	(0.075)	(0.035)	(0.074)	(0.040)
	[0.058, 0.423]	[–0.059, 0.415]	[–0.011, 0.080]	[0.063, 0.317]	[0.030, 0.275]	[0.055, 0.349]	[0.047, 0.185]	[0.022, 0.311]	[0.038, 0.193]
Obs.	20,880	21,015	23,985	23,985	23,985	23,985	23,985	23,985	23,985
Firms	464	467	533	533	533	533	533	533	533
Method	CS21 (control: never treated, not yet treated; time: [–5, 7])								

(b). Invention scope

	Dependent variables (log point differences): invention scope							
	Cultural distance (Hofstede)		Collaboration patterns: Patents by		Which team benefits more?		Which R&D center benefits more?	
	Distant culture (6a) *High*	Close culture (6b) *Low*	New teams (7a)	Continuing teams (7b)	Single-country teams (8a)	Cross-border teams (8b)	US center (9a)	VWP (non-US) center (9b)
Treat ×	0.147*	0.037	0.107*	0.081	0.104*	0.100**	0.083	0.118***
Post	(0.087)	(0.083)	(0.062)	(0.055)	(0.063)	(0.049)	(0.062)	(0.037)
	[–0.023, 0.316]	[–0.125, 0.198]	[–0.015, 0.229]	[–0.027, 0.1904]	[–0.020, 0.228]	[0.003, 0.196]	[–0.039, 0.205]	[0.046, 0.191]
Obs.	20,880	21,015	23,985	23,985	23,985	23,985	23,985	23,985
Firms	464	467	533	533	533	533	533	533
Method	CS21 (control: never treated, not yet treated; time: [–5, 7])							

Notes. The estimation was performed in R using the *did* package. Analytic standard errors are provided in parentheses. We construct the 95% confidence interval with (1) Student's *t*-distribution (conventional) and (2) clustered bootstrapping at the firm level (10,000 iterations). We take a conservative approach and report the wider interval in squared brackets. $^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$.