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Migration and Innovation: Learning from Patent and Inventor Data

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Migration and innovation have gone together since the dawn of human history. It was migration from the Near East that brought farming to the European continent in the Neolithic period (Skoglund et al. 2012). About 10,000 years later, in 1685, it was Huguenot refugees escaping persecution in France after the revocation of the Edict of Nantes that brought to Prussia the most advanced textile technologies (Scoville 1952; Hornung 2014). In the US experience, a well-known episode is that of the scientists of Jewish origins who, fleeing Germany in the 1930s after the Nazi party's rise to power, brought their knowledge in several fields of chemistry and physics (Moser, Voena, and Waldinger 2014).

But migrants contribute to innovation not only when moving jointly from a more to a less advanced economy, as in these and other well-known historical examples. Many of them travel in the opposite direction and on an individual basis, in search of the best place to develop their own new ideas. The case of Katalin Karikó, who

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received the Nobel Prize in Medicine in 2023, is exemplary. After earning her PhD in Biochemistry in Hungary, she moved to the United States in 1989 for a postdoc and started studying the potential applications of mRNA technologies to vaccines. Following a long spell at the University of Pennsylvania, and many difficulties in getting tenure and funding, in 2013 she joined the German start-up BioNTech, where she contributed, as vice-president, to the development of its Covid-19 vaccine (Kollewe 2020; Johnson 2021).

While Karikó left Hungary after completing her PhD studies, many students worldwide move abroad in order to earn an advanced degree, especially in scientific fields or engineering. They take advantage of lower transport costs, the spread of English as both an instruction and working language, and the global search for talent by multinational companies and universities (Kerr 2018). Unlike the experienced Huguenot weavers of the seventeenth century or the German scientists in the twentieth, when they first move they do not bring along any superior knowledge, but like Karikó, may be deciding to pursue a research career and swell the ranks of scientists and inventors in the host countries. In the United States, immigrants are overrepresented relative to natives not only among the most productive researchers and the winners of important scientific prizes (Stephan and Levin 2001; Bernstein et al. 2022), but more generally among the students who, upon graduation, end up filing a patent (Hunt and Gauthier-Loiselle 2010) or otherwise hold jobs in science and technology (Hanson and Slaughter 2017). Absent them, R&D-intensive economies would face serious job shortages. In a small, highly innovative country like Switzerland, more than a quarter of scientists and inventors are foreign-born (Cristelli and Lissoni 2020). Absent the possibility of migrating, many of them would have not undertaken a research career or would have not been as productive as they are.

Technology transfer and self-selection (into science and technology jobs and especially those best matching one's own skills) are thus key factors behind migrants' contribution to innovation. An additional factor is the diversity that migrants bring about. While it is difficult to establish a clear-cut causality link, the correlation between migration-induced diversity and innovation is well-documented at the regional or city levels (Bosetti, Cattaneo, and Verdolini 2015) and, in part, also for firms and teams (Parrotta, Pozzoli, and Pytlikova 2014). Anecdotes are uncountable. While Karikó's Nobel prize cowinner and colleague at the University of Pennsylvania, Drew Weissman, was born and bred in the United States, the BioNTech co-founders who reached out to her from Germany were Uğur Şahin and Özlem Türeci, both from Turkish parents. The CEO of Pfizer, BioNTech's key US partner, is Albert Bourla, born in Thessaloniki (Greece), where he first joined the company after earning a PhD in veterinary science. The CEO of Moderna, another US company with a pioneer Covid-19 vaccine, is Stéphane Blancel, born in Marseille (France), with a master's degree in engineering earned in Paris and a subsequent degree at the University of Minnesota.

All three channels through which migration can affect innovation are the objects of an increasing number of empirical studies, many of which make use of patent and inventor data. Patent data have limitations: not all inventions are patented and many inventions protected by patents turn out not to be worth developing or commercializing. Yet they are a very detailed source of information on both technologies and the individuals behind them, especially in R&D-intensive economies.

In this paper, we first discuss how to access and treat patent data to extract information on inventors in general and migrant ones in particular. We also produce some descriptive statistics that both summarize important facts and serve as cautionary reminders of the data limitations. We emphasize that migrant inventors are a heterogeneous group, which includes not only senior figures holding precious knowledge assets and capable of transferring them across countries, but also junior figures, who may have little knowledge to transfer upon arrival in the host country yet may play a key role in easing R&D labor shortages, swelling the ranks of the highly productive researchers and increasing diversity at the team, firm, and city levels.

We then discuss the empirical research on both roles. When discussing the available evidence on migrant inventors' role in international knowledge diffusion, we emphasize how these research methods come from the convergence of different traditions, such as economic geography and migration economics, whose contact point is the emphasis they place on interpersonal exchanges as key means of knowledge diffusion.

Migrant Inventors: Data and Facts

Quantifying migrant inventors and their contribution to innovation is not a straightforward task, first and foremost because "inventor" is not an occupation listed in professional registers or official national statistics, let alone international ones. However, a functional definition of inventor would refer to those named as such on patent documents, which in most countries must indicate both the generalities of the assignee (the legal owner of the exclusivity rights claimed in the patent) and those of the physical person who conceived the new technology described in the application (the inventor, most often more than one per patent). Assignees and inventors may coincide, but in most cases they do not, with the former being the firm or other organization employing the latter in its R&D labs. Besides, in most countries (including the United States since 2012), it is the assignee that files the patent application and is referred to, in legal jargon, as "applicant." This convention has implications that we discuss below.

The inventor information reported in patents (when available) includes family and given names as well as the country and place of residence. The same is true for assignees, although for large firms the address may not be that of the R&D laboratory in which the inventors work, but that of the headquarters or a subsidiary dedicated to the management of the company's intellectual property rights. With one exception (discussed later), patents do not report information on the inventors' birthplace or nationality, from which one could immediately deduce the inventor's status as migrant or native. Before delving into the solutions to this problem, it is useful to recall a few more features of patent data.

Patent Data

With the very recent exception of the Unitary Patent, valid throughout the European Union since June 2023, patents offer a protection of intellectual property rights at the national level, with each country having its own patent office. Applicants seeking protection for the same invention in more than one country need to file for patents in each one of them, which generates what in legal jargon are called "patent families" (Martínez 2010). Such "families" consist of sets of patent documents referring to the same invention and applicant, produced by different patent offices, in different languages and with very similar, but not identical, information (for example, information on inventors may be collected more accurately by some national patent offices than others).

Besides including a very fine technological classification of the inventions (as well as the full text and drawings describing them), patents include cross-references in the form of citations to other patents (Jaffe and de Rassenfosse 2017). Most cross-references have a legal function, as they help the patent examiners to establish how much of the invention for which the patent is requested is new relative to the existing body of scientific and technical knowledge. Other cross-references just serve the purpose of better explaining how the invention works. Many citations are inserted in the patents by the inventors, while others are inserted by the patent attorneys or the examiners themselves. Broadly speaking, economists exploit citations in two main ways. First, they look at the number of citations a patent receives ("backward" citations) as a measure of its importance for follow-up technical advancements. Second, they look at the citations a patent makes to other patents ("forward" citations) as an indirect (and noisy) measure of knowledge diffusion, from the inventors of the cited patents to those of the citing one. These can be combined with measures on the similarity between patents, based on their coclassification in the same technological classes or text analysis (Arts, Cassiman, and Gomez 2018). Patents can also report citations to scientific publications and other documents, which researchers use as measures of knowledge diffusion, in this case from science to technology (Marx and Fuegi 2022).

Because patent offices in countries with meaningful R&D activities (for example, the United States, European countries, or Japan) systematically collect and exchange their data, the geographical coverage of information on inventors is virtually global, with multiple data sources. In what follows, we focus on two of them, namely the US Patent & Trademark Office (USPTO) and the World Intellectual Property Organization (WIPO), a UN agency in charge of easing the application and updating of the international treaties on intellectual property rights.

The US Patent & Trademark Office is today the second-most important office worldwide in terms of yearly patent filings, just behind the Chinese office, and the most important in cumulative terms. This is due both to the innovation propensity of US firms and to the many foreign companies that seek protection for their intellectual property rights in the United States, in order to export or invest there (WIPO 2022). Many patent applications filed at the US Patent & Trademark Office belong to large patent families—that is, they concern inventions for which patent applications are also filed in other countries. This makes them quite representative of inventive activities worldwide, despite a clear overrepresentation of US-based inventions (de Rassenfosse et al. 2013). All patents granted by the US Patent & Trademark Office can be easily retrieved online from the PatentsView website, produced by the Office of the Chief Economist. PatentsView provides a unique identification for all the inventors listed on such patents, an important piece of information to which we return below.[1]

As for the World Intellectual Property Organization, it collects and publishes information on patent applications that go through the Patent Cooperation Treaty. This treaty, now signed by over 150 countries, allows patent-seekers from signatory countries to file applications in one another's patent offices by following, at an additional cost, a special procedure. Under some conditions, this treaty is more favorable than that established by older international conventions (WIPO 2023). Generally speaking, patent applications under the Patent Cooperation Treaty are highly relevant for economic research purposes, because they are all meant for international extension and hence generally related to more valuable inventions than those filed only at national offices. In addition, they are treated according to more similar administrative rules, in particular for what concerns their submission procedure. Last but not least, for a bureaucratic accident, the patent applications filed through the procedure of Patent Cooperation Treaty and seeking protection in the United States include, from around the 1980s to 2011, the nationality of the inventors (Miguelez and Fink 2017). These data total a little more than two million patents, but cover 15 percent of all patent families worldwide in the mentioned period. While now outdated, this information continues to be important for both historical and methodological reasons.[2]

[1] Notice that, when referring to patent statistics in general, we speak of "patent applications," as the available data generally include both those that end up with the patent being granted and those for which the application is rejected by the patent office or abandoned by the applicant. Instead, when referring specifically to data from the US Patent & Trademark Office, we speak of granted patents only. This is because, until the Patent Reform Act of 2005, the US Patent & Trademark Office published only the granted patents and not, like the patent offices of all other countries worldwide, all the applications subject to examination. As a consequence, for patent statistics based on US Patent & Trademark Office data and spanning across year 2005, the best practice is to use only granted patents.

[2] In brief, the Patent Cooperation Treaty procedure requires all applicants to indicate their residence and nationality, at least one of which must correspond to a member state of the treaty (either residence or nationally). At the same time, until the Leahy–Smith America Invents Act of 2011, US law treated all inventors as joint applicants along with the assignee. Hence, on all Patent Cooperation Treaty applications extended to the United States, inventors were required to disclose their nationality, too. When, starting 2012, the US patent system finally introduced a clear distinction between applicants and inventors, assignees took up the role of applicants and the information on the inventors' nationality disappeared.

Defining Inventors

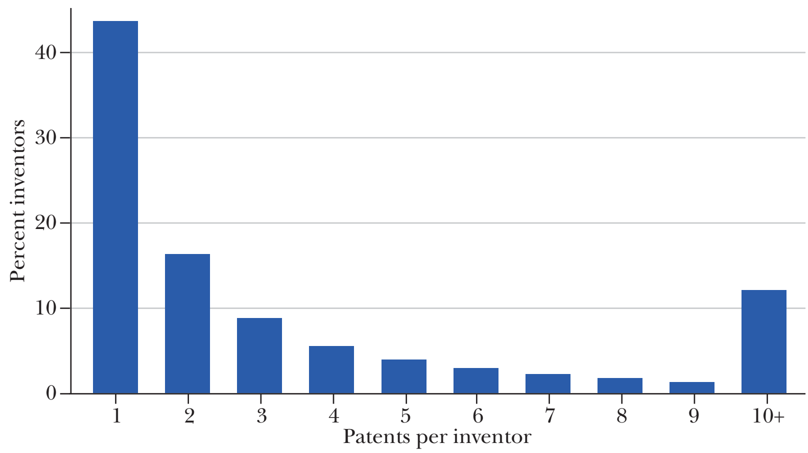
The personal information on inventors that we can extract from patent data is rather noisy. To make it useful for research purposes, it requires two types of treatment: "disambiguation" and "geolocalization."

Disambiguation consists in assigning a unique identification to each inventor, in order to measure their productivity (number of patents signed) and track their mobility across employers and locations. One specific issue for identifying migrant inventors is that the accuracy of the exercise varies inevitably by linguistic group. In some cases, the difficulty arises from very small numbers of extremely frequent names and surnames, as is the case with East Asian and Scandinavian names. In others, such as with English and Spanish names, identification issues can arise from their diffusion over many countries or continents due to colonial heritage. The available open access data vary across time and by patent office, and the algorithms for disambiguation vary according to the methodology they follow, which in turn affects the incidence of false positives (homonym inventors treated wrongly as the same person) and false negatives (the same inventor treated as two or more different ones). Many disambiguation projects exist, each based on a different set of algorithms and for patents from different offices and time intervals. Only one of them, that of Monath, Jones, and Madhavan (2021) for the US Patent & Trademark Office, has led to a database—PatentsView—that is both freely accessible online and frequently updated.

Geolocalization concerns the relatively simple task of assigning inventors to the residence country whose code is reported by the patent document, as well as more complex operations such as placing them in subnational administrative units (regions, cities, neighborhood or even coordinate points) based on text analysis of the address (de Rassenfosse, Kozak, and Seliger 2019; Maraut et al. 2008; Miguelez et al. 2019; Morrison, Riccaboni, and Pammolli 2017). Geolocalizing inventors is necessary not only to track their mobility in space, but also to second-guess the location of the actual R&D labs in which they have produced their inventions. As explained above, the patent assignee's address is not always useful to this end, as it may refer to a company's unit far away from the R&D facilities. The inventors' residence, instead, can be presumed to be close to their workplace. Hence, the inventor addresses can be used to locate the R&D lab where the invention was produced. For example, when many inventor addresses for patents with the same assignee concentrate in or around the same city, we can presume the R&D lab to be there even if the assignee's address tells otherwise (for a discussion, see Cristelli and Lissoni 2020).

The results of disambiguation and geolocalization reveal several patterns. For many inventors, patenting is an occasional or intermittent activity. Figure 1 illustrates the distribution of the number of patents per inventor, derived from disambiguated data in the PatentsView database. Approximately half of inventors generate no more than one patent throughout their entire careers, while an additional one-third produce no more than four. The distribution exhibits significant skewness, with an average of approximately 5.3 patents per inventor, a median of 2, and a mode of 1. Some exceptional inventors appear to have signed over 6,000 patents.

Figure 1
Share of Inventors Grouped by Patents Produced, USPTO, 1976–2020



Source: Authors' own computation based on disambiguated inventor data from Patentsview (US Patent & Trademark Office. "Data Download Tables." PatentsView: https://patentsview.org/download/data-download-tables).
Note: Figure illustrates the distribution of inventors according to the patents their have produced in their whole inventive lifes, derived from disambiguated data in the PatentsView database.

This observation suggests that many inventors are scientists or engineers engaged in industrial R&D for a brief period before transitioning to other professions, while others are practitioners who occasionally come up with inventions based on their experiences on the factory floor. Additionally, there are academics who dabble in technology transfer from time to time. Even the few inventors who consistently file patents over an extended period of time do not do so with a frequency comparable to that of academic scientists who regularly publish scientific research.

These data leave many time gaps in the information provided exclusively by patent documents. In particular, we do not know the inventors' whereabouts and activities before their first patent, after their last one, or between subsequent ones. We can fill these gaps only with survey data or by matching inventor data to a variety of archival sources, such as social security or historical census data. Survey data suggest that most inventors have received an education in science or technology, often at a graduate level. Out of 9,017 European inventors surveyed by Giuri et al. (2007), 77 percent had a university degree and 26 percent a PhD. Toivanen and Väänänen (2012) for Finland and Jung and Ejermo (2014) for Sweden find that, respectively, 67 percent and 76 percent of inventors held a tertiary degree (with 14 percent and 29 percent holding a doctoral degree). The same figures for Japan and the United States, as per Walsh and Nagaoka (2009), are, respectively, 88 percent and 94 percent (13 percent and 45 percent for doctoral degrees). Also, according to Giuri et al. (2007), the most educated inventors are usually found on Chemical and Life Science patents (92 percent with a university degree and 59 percent with a

PhD), while the least educated are in Mechanical Engineering (66.3 percent with a university degree and 9.3 percent with a PhD).

Archival sources suggest that inventors are neither very young, possibly due to the long years many of them spend in education, nor very old, possibly because they are more likely to work in R&D early on in their careers and then move on to other tasks. For the United States, Jones (2009) estimates the average inventor to be aged 30–32 at the time of their first patent, a value confirmed by Cristelli and Lissoni (2020) for foreign inventors in Switzerland. When all patents are considered, the average ages range from 37 in Finland to 46 in the United States (Toivanen and Väänänen 2012; Bell et al. 2019; Akcigit and Goldschlag 2023).

The majority of inventors are men, with women being even more under-represented than in scientific research and, more generally, among science and technology graduates. In 2015, only around 12 percent of all US-based inventors were women (Toole et al. 2019). Causes for this bias are multiple, ranging from women's weak bargaining position in R&D teams to the influence of role models on their career decisions (Bell et al. 2019).

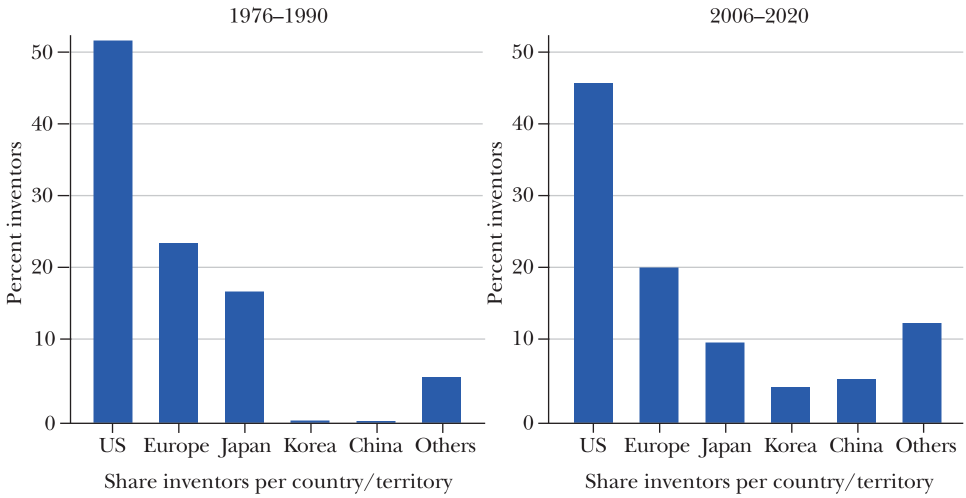
Finally, because patenting is a very uneven geographical phenomenon, both across countries and within them, most inventors are concentrated in a few locations. Figure 2 shows the percent distribution of inventors on US Patent & Trademark Office patents, according to their country of residence, but a similar pattern is found regardless the dataset used (for example, it can be observed from the worldwide analysis using all international activity recently made available by WIPO 2019). Inventors concentrate in a handful of countries such as the United States, European countries, Japan, China, and South Korea, as well as in a few cities and regions therein (Miguelez et al. 2019). In the last 15 years or so, the share of Korea, China, and other countries has been rising, while the share of the United States and Japan has been falling.

This broad portrait of inventors has important implications. First, the supply of inventors is likely to be rigid in the short- and even the medium-term. Becoming an inventor requires, at least in some fields, a high and increasing number of years of scientific or technical education, which cannot be adjusted rapidly and are not accessible to everyone. It may also require pushing back against a diffused gender bias. Second, the demand for inventors is disproportionately concentrated in space, which suggests the importance of a high degree of internal and international mobility of the highly educated. Third, inventors are likely to be in short supply because only a few of them keep patenting throughout their working lives. At the same time, among those who do it, we find the technological leaders who may play an important role in knowledge diffusion.

Defining Migrant Inventors

Assigning migrant status to inventors involves two main difficulties. First, there is the conceptual problem of whether migrants should be defined as such according to their nationality, country of birth, or education place. The appropriate answer will depend both on data availability and the nature of the migration-innovation

Figure 2
Distribution of Inventors' Country of Residence, USPTO Data



Source: Authors' own computation based on geolocalized inventor data from Patentsview (US Patent and Trademark Office. "Data Download Tables." PatentsView: https://patentsview.org/download/data-download-tables). "Europe" refers to the sum of the member states of the European Patent Convention: https://www.epo.org/en/about-us/foundation/member-states.
Note: Figure shows the percent distribution of inventors on US Patent & Trademark Office patents, according to their country /territory of residence, in two five-year different time windows.

connection we want to study. For example, a country-of-birth definition for migrant inventors may include individuals who moved to the host country at an early age and were entirely educated there, which for some research questions makes them part of the local supply of R&D labor rather than the foreign one. For other research questions, it might make sense to include second-generation migrants or even members of longstanding diasporas (to whom we will refer as "foreign-origin" inventors), as long as they maintain strong ties with their countries of origin and we are interested in the extent to which they send "knowledge remittances" back to origin countries.

Second, practical difficulties arise in retrieving the necessary information from patent documents. As already mentioned, we can find the inventors' nationality only on applications that went through the Patent Cooperation Treaty procedure, up until 2011. Besides time truncation, information on nationality is limited to a specific time period, given by the patent filing dates. As a result, we lack details about the length of the migrant inventor's stay in the host country both before and after the filing date, as well as the type of visa the inventor may have held upon entry. Moreover, nationality can be acquired, meaning that many inventors in these data who are treated as natives may, in fact, be naturalized migrants. This is especially true for those with numerous patents over an extended period, as they are more likely to have resided in the host country long enough to gain citizenship.

Without access to nationality information, we can resort to three alternative strategies for identifying migrant inventors: (1) examining the cross-country mobility of inventors with multiple patents; (2) conducting name analysis to infer the ethnic background of inventors; (3) cross-referencing inventor data with archival sources containing relevant biographical information. We discuss these in turn.

The first approach is an extension of early work on inventors' mobility across firms and organizations to the analysis of mobility first across cities or clusters, then across countries too. It has been used, among others, by Prato (2022) and Bahar et al. (2022, 2023). For an inventor to be qualified as an international migrant, that person must appear on at least two patents with as many or more addresses in different countries.

The second approach, name analysis, has been pioneered by Kerr (2008). It infers the inventors' likely country or region of origin from names and surnames, based on extensive data libraries on their frequency across and within countries. For example, Breschi, Lissoni, and Miguelez (2017) and Coda-Zabetta et al. (2021) make use of IBM's Global Name Recognition system (IBM-GNR), which associates each available name and surname to a vector of countries in which that name or surname is attested, plus information on its frequency inside each country and across all of them. Name analysis may be also used to complement the inventor's mobility method, in order to distinguish between immigrants (those moving to a country where their name and surname are not frequent) from returnees (whose name and surname are frequent), as in Bahar et al. (2023). Similarly, it may help detecting migrants who acquired local nationality on patents that went through the Patent Cooperation Treaty process (Ferrucci and Lissoni 2019).

A third and more recent approach involves linking patent and inventor data with administrative records in the host country, such as Social Security datasets, tax records, censuses, or extensive employee surveys. Bernstein et al. (2022) match US-based inventors with patents from the US Patent & Trademark Office with a commercial database that provides information on over 230 million adult US residents, including their year of birth and Social Security number, the first few digits of which indicate when the number was obtained. Because most US-born individuals receive their Social Security number at birth, while immigrants do so upon their arrival, the authors assume that all the matched inventors whose year of birth differs from that in their Social Security records can be treated as immigrants (whose home country, however, they cannot identify). In particular, they focus on those who obtained their Social Security number after their twentieth birthday. In a different approach, Akcigit and Goldschlag (2023) link disambiguated US-based inventors from the Patentsview database to person-level identifiers, such as the Protected Identification Keys (PIKs) produced by the US Census Bureau. Then, they can match inventors to other data sources, such as the Decennial Census, the American Community Survey, or the Longitudinal Employer Household Dynamics, from which one can obtain information on the inventors' country or region of birth. Examples of this approach for other countries include Toivanen and Väänänen (2012) for

Finland, Jung and Ejermo (2014) for Sweden, and Cristelli and Lissoni (2020) for Switzerland.

These different approaches all have pros and cons, and the choice between them may depend on the research question at hand.

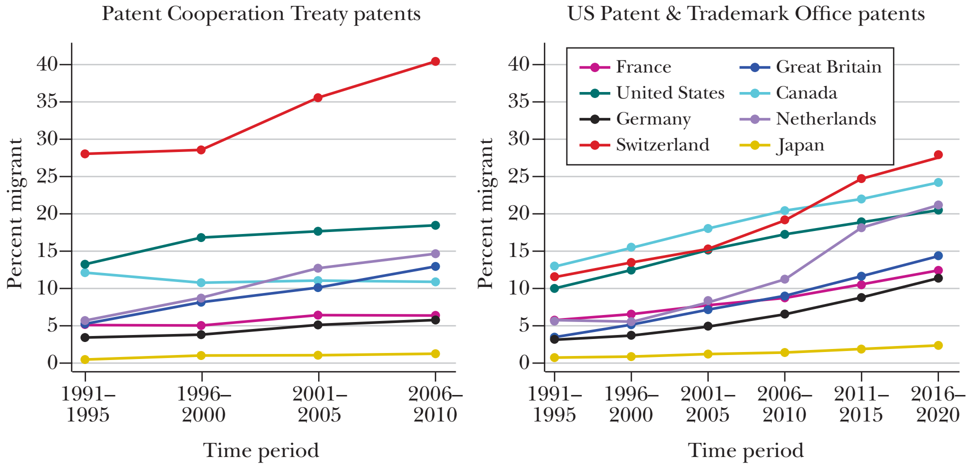
Computing migration through inventor mobility is straightforward, as one only needs the data extracted from patent applications. Therefore, it can be used for many technologies and countries and over long time periods. Yet, besides requiring careful disambiguation, this method results in oversampling the highly productive and senior migrant inventors relative to the less productive and junior ones. Ethnic classification of inventors based on name analysis is more helpful in this respect, but only under certain circumstances. It misses out on migrants who move between countries with the same dominant language—for example Great Britain and the United States or Germany and Switzerland, just to name two very important migration corridors. In this case, the method necessarily underestimates the number of foreign inventors migrating from one country to the other. At the same time, in other cases, it may lead to an overestimation, as in country pairs with a long migration history that has left noticeable traces in the current distribution of surnames in the destination country (like Italian, German, or Scandinavian names in the United States). This situation bears the risk of blending migrant inventors and native inventors with distant foreign ancestry. While cross-referencing with first names can aid in mitigating this error, as they are better indicators of ethnic identity, it cannot completely eliminate the potential for misclassification.

Linking patent data with administrative records provides the most accurate information, but it also has some drawbacks. First, it can be costly and time-consuming. This applies not only to the creation of new datasets, but also to the updating of existing ones. Second, access to detailed administrative data is possible only for a limited number of host countries. Together, these drawbacks pose obstacles for replicability over time and across countries. In addition, not all the archival resources report the migrants' country of origin nor the age at which they migrated, and thus do not reveal where the inventor was educated.

In conclusion, each of these the approaches might be valid under certain circumstances. Users need to assess what type of error a given approach might produce relative to the research question asked. For example, studying the effect of migrant inventors on the diversity and productivity of inventor teams would require administrative data reporting the inventors' country of birth or education. In the absence of such data, name analysis may provide a second-best approach, but only for host countries that receive most of their migrants from countries with a different language, and the inventor mobility approach would be useless, as most teams include a majority of one-time inventors with no mobility record. However, inventor mobility may be of some use when the research focuses on more senior inventors and their role in knowledge diffusion.

Figure 3

Presence of Migrant Inventors in Selected High-Intensity R&D Countries, 1991–2020



Source: Authors' own computation based on geolocalized inventor data from the World Intellectual Property Organization (Miguelez and Fink, 2017) (left panel) and from Patentsview (US Patent and Trademark Office, "Data Download Tables," https://patentsview.org/download/datadownload-tables) (right panel).
Note: Figure shows the percent of inventors that are of foreign origin, for a selection of eight high-intensity R&D countries. The figure uses data from the Patent Cooperation Treaty in the left-hand side panel (1991–2010) and data from the US Patent and Trademark Office in the right-hand panel (1991–2020), by five-year intervals.

How Many Migrant Inventors? And Where?

We can compare the outcome of different methods for counting migrant inventors. In Figure 3, for example, we combine different patent data sources and migrant detection methods, namely nationality as reported on Patent Cooperation Treaty data (left-hand panel) and name analysis (right-hand panel). Time units are five-year intervals ranging from 1991 to 2010 in the left-hand panel (due to data constraints) and up to 2020 in the right-hand panel.

Whatever method we use, we find that the weight of migrant inventors has been increasing over the entire period in North America and Europe, while remaining negligible in East Asia. But we also observe some differences that may be indicative of measurement error in one or another method. This is evident in the case of Switzerland, which primarily receives immigrants from neighboring countries (France, Germany, and Italy), with which it shares its official languages. Moreover, Switzerland grants its nationality to foreigners rather sparingly. Consequently, the figures obtained using name analysis (right-hand panel) are notably lower compared to those based on nationality (left-hand panel), with the name analysis method being the more unreliable in this case. Canada presents a different scenario, where acquiring nationality is more straightforward, and a substantial number of immigrants come from countries that do not predominantly speak

English or French. In this case, the left-hand panel suggests that the share of immigrant inventors has remained constant over time, while the right-hand panel indicates a growing trend, more in line with what we know about highly skilled immigration trends.

For the United States, the nationality-based estimates suggest a higher share of migrant inventors than the name-based ones, but also a slower growth. This estimate is not far from the figures based on administrative records and concerning only adult immigrants (16 percent in 1990–2016 according to Bernstein et al. 2022), but much lower than those including also child immigrants (24 percent in 2000 and 35 percent in 2016 according to Akcigit and Goldschlag 2023).

The detailed information contained in patent data makes it possible to assess whether migrant and native inventors differ in terms of productivity, specialization, and access or contribution to global knowledge. For instance, Bernstein et al. (2022) estimate that migrants represent 16 percent of all inventors in the United States, but produce 23 percent of US patents, due to their superior productivity. Our own estimates also suggest that migrant inventors have a higher than average productivity, but only in the United States. This may be due to the most productive or promising inventors worldwide having an incentive to move to the United States, the United States offering especially good conditions for migrant inventors to thrive, or a combination of both.

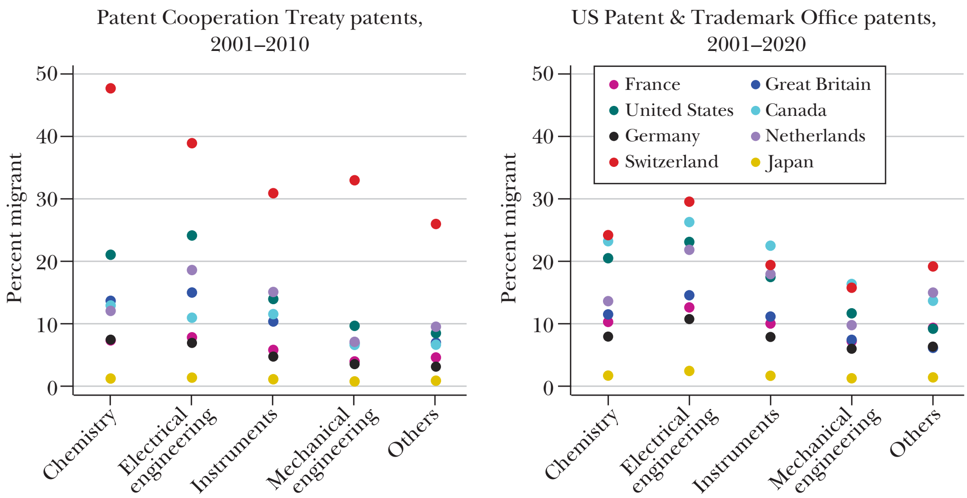
In what areas of science and technology are migrant inventors especially important? Figure 4 reports the share of migrant inventors in different technological fields. Across all countries we consider, this share is higher in the fields of Chemistry and Electrical Engineering, which include many science-based technologies such as Basic communication processes, Micro-structural and nano-technology, Semiconductors, Digital communication, Pharmaceuticals, Computer technology, Organic fine chemistry, and Biotechnology. Such patterns suggest that university education in the host country may be a key channel for immigration, as discussed above.

Do migrant inventors play a special role in the international diffusion of knowledge? A cursory look at patent citations suggest that this may be the case. Figure 5 shows the average percentage of forward (left panel) and backward (right panel) foreign citations of US-based inventors, using data only from the US Patent & Trademark Office. As can be seen, in all technological fields, immigrants tend to be systematically more visible internationally (their patents are more cited internationally than those by natives), and tend to fish from a more global pool of knowledge (their patents cite more foreign patents than those by natives). This pattern indicate that migrant inventors belong to a more internationalized community than do native ones.

Migrant Inventors as International Knowledge Carriers

Knowledge diffusion is, by far, the most extensively researched topic in migration and innovation. Its predominance stems from the theoretical importance attached to the study of tacit knowledge as a source of innovation in both economics

Figure 4
Presence of Migrant Inventors in Selected High-Intensity R&D Countries, 1991–2020, by Broad Technology Field



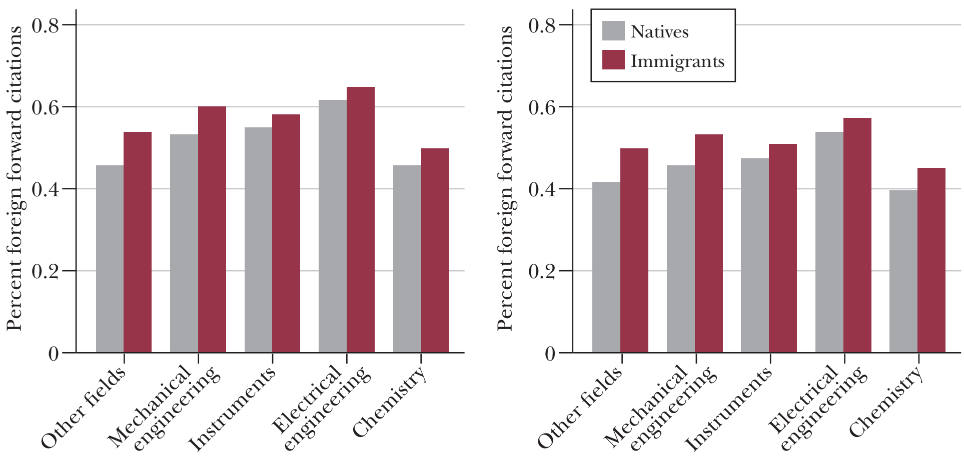
Source: Authors' own computation based on geolocalized inventor data from the World Intellectual Property Organization (Miguelez and Fink 2017) (left panel) and from Patentsview (US Patent and Trademark Office. "Data Download Tables." PatentsView: https://patentsview.org/download/datadownload-tables) (right panel).
Note: Figure shows the percent of inventors that are of foreign origin, for a selection of eight high-intensity R&D countries. The figure uses data from the Patent Cooperation Treaty in the left-hand side panel (2001–2010) and data from the US Patent and Trademark Office in the right-hand panel (2001–2020), by five broad technology fields.

and business studies and to the role played by individuals in disseminating it across organizations and physical locations. The international migration of inventors can be seen as an extreme form of mobility among a highly relevant category of knowledge workers, which lends itself to be studied with migrant inventor data.

Geographic and Social Proximity

In a classic study using patent citations as knowledge diffusion indicators, Jaffe, Trajtenberg, and Henderson (1993) showed the higher probability for two inventors located in the same metropolitan statistical area within the United States to cite one another's patents, relative to the same probability for two inventors who are not colocated. This finding suggested that knowledge spillovers are concentrated in space and favor the agglomeration of innovative activities in certain locations, due to the crucial role of interpersonal communications. But while personal exchanges are expected to take place more frequently, all else being equal, between individuals closely located in space, it is clear that what matters most is social rather than physical proximity. Two colocated inventors with no contractual or moral obligations to exchange their personal knowledge would not

Figure 5
Share of US-based, Internationally Cited (Citing) Patents, by Inventors' Migrant Status



Source: Authors' own computation based on disambiguated inventor and citation data from Patentsview (US Patent & Trademark Office, "Data Download Tables," https://patentsview.org/download/data-download-tables).
Note: Figure shows the average percentage of forward (left panel) and backward (right panel) foreign citations of US-based inventors, using data only from the US Patent & Trademark Office. As can be seen, in all technological fields, immigrants tend to be systematically more visible internationally (their patents are more cited internationally than those by natives), and tend to fish from a more global pool of knowledge (their patents cite more foreign patents than those by natives).

do so; for two distant inventors, instead, such obligations may be binding (Breschi and Lissoni 2001). Some indirect evidence supporting this interpretation comes from studies showing that inventors who move apart after a colocation spell still have a higher-than-expected probability to cite each other's subsequent patents (Agrawal, Cockburn, and McHale 2006); as well as from similar findings for former co-inventors or inventors at close distance on a collaboration chain, other things being equal (Breschi and Lissoni 2009).

Subsequent searches for other sources of social proximity with similar effects brought ethnic ties under the spotlight. Such ties may proxy for otherwise unobservable communications between migrant inventors and other co-ethnic inventors, whether located in the same host countries, in different host countries, or in the country of origin. For example, based on a combination of name analysis and the Jaffe, Trajtenberg, and Henderson (1993) methodology, Agrawal, Kapur, and McHale (2008) identify a number of patents by Indian-origin inventors in the United States and show how these are disproportionately cited by other US-based inventors of the same origin, after controlling for their spatial distribution and specialization. Agrawal et al. (2011) extend the analysis to citations from India. The evidence on a role of ethnic ties considerably weakens, but it does not disappear, especially for patents in Computers & Communications and/or owned by multinational firms, as well as for very important (highly cited) patents.

Similar analysis has been applied to other groups of migrant and foreign-origin inventors in the United States, including Chinese, Koreans, Iranians, Russians, and some Western European countries. Again based on name analysis, Breschi, Lissoni, and Miguelez (2017) find that ethnic ties between migrant inventors matter for Asian and Russian inventors. As for evidence concerning diffusion back to the home countries, this appears significant for China and Russia, but not for India. Instead, patents by Indian-origin inventors in the United States appear to be disproportionately cited by other members of the Indian diaspora, such as those residing in the United Kingdom or other former Commonwealth countries.[3]

One limitation of this kind of study concerns the reliability of patent citations as indicators of knowledge diffusion. Instead of some knowledge transfer from the inventors of the cited patent to those of the citing one, a citation could indicate the existence of some background knowledge embodied in both patents (Thompson and Fox-Kean 2005; Arora, Belenzon, and Lee 2018). In this case, a disproportionate number of citations between inventors from the same ethnic group could be attributed to their common specialization in a narrow set of technologies, rather than to any privileged access to each other's knowledge. While this common specialization might also result from interactions outside the patenting activity, such as shared education or joint professional experiences, the causal link between proximity and diffusion would be, in such a case, less clear.

It is also possible to track knowledge transfers by focusing on the inventors who move and patent across countries and by examining the technical classification of both their patents and of follow-up ones. Bahar et al. (2023) consider the cumulative patenting activity of around 200 countries in 600 technological fields, from 1975 to 2015. In particular, the authors focus on the first years in which each country starts patenting in any given field. Using disambiguated data from US patents, they track the inventors with foreign experience active in any given country, field, and year and find them to be disproportionately represented in the early years of a country's patenting activity in any given field. Interestingly, the effect is stronger for returnees than for immigrants (with name analysis used to distinguish between the former and the latter).

Country-level Data: The Preference and Information Channels

The migration and innovation studies bear a relationship with broader studies that investigate how international migration affects trade and foreign direct investment. The latter developed a number of concepts and methods that can be extended

[3] The lack of evidence for Europeans (excepting Russians) may be explained by a cohort effect and/or a composition effect. In the first case, name analysis may mistakenly identify as foreign-origin inventors some individuals with only a remote European ancestry, and few or no co-ethnic ties. In the second case, inventors may be temporary migrants working for multinational companies, whose corporate ties matter more than ethnic ones.

to the former. For example, from the migration and trade literature we learn that the two may be linked through two main channels: a preference channel, where migrants increase the host country's demand for home-country products; and, more importantly for our purposes, an information channel, where migrants reduce transaction costs of international trade operations through social networks, business contacts, and improved reputation for both host and home countries (Rauch 2001). These effects are particularly significant the more distant two countries are, whether in the physical, cultural, or legal space (Parsons and Winters 2014). Studies examining the relationship between migration and foreign direct investment flows also reveal that migrants play a crucial role in providing valuable information on investment opportunities, costs, and business contacts in their home or destination countries (Burchardi, Chaney, and Hassan 2019; Hernandez 2014).

Patent and inventor data can contribute to the evidence on the importance of the information channel. The work by Kerr (2008) has paved the way. Based on name analysis, the author looks at migrant inventors in the United States and at their patents' forward citations from abroad (excluding company self-citations). He groups the citations over around 100,000 cells, each cell consisting of two-plus-two dimensions: the foreign origin of the citing inventor and that of the cited one; and the technology class of the citing and cited patents. He finds that cells with inventors from the same country of origin are more populated than mixed cells, controlling for technology, which he interprets as evidence of knowledge diffusion from the United States to the migrant inventors' home countries.

More recent studies have followed up and provided a more global perspective. Miguelez and Temgoua (2020) exploit patent citations across countries in a "gravity equation" framework, in which the cost of transmitting information increases with distance. The authors incorporate cross-country data of migrant inventors, using the nationality information on data from Patent Cooperation Treaty patents. Based on both instrumental variable and Poisson estimates, they find that knowledge remittances from migrant diasporas to their home countries are significant, but that knowledge transferred by migrant inventors to their host nations is negligible, with the exception of knowledge flows occurring within multinational enterprises.[4]

Other studies have investigated whether migration can help countries, regions or cities to diversify their technological portfolio. For example, Bahar, Choudhury, and Rapoport (2020) relate the technological diversification of countries to the overall inflows and outflows of migrant inventors, based on nationality information from data from patent using the Patent Cooperation Treaty process. They find that immigrant inventors make it more likely that their host countries will start patenting in technological fields in which their home countries are specialized. But they do not

[4] Similar to Kerr (2008) and Miguelez and Temgoua (2020), other studies have looked at patent collaborations across countries (international co-inventorship, or Global Collaborative Patents). This alternative indicator is less controversial than citations, and it might be somehow related to the latter, though encompassing a broader phenomenon, like international team formation (Kerr and Kerr 2018; Miguelez 2018).

find consistent evidence that emigrant inventors help their home countries to diversify into technologies in which the host countries are specialized. Following up this research, Di Iasio and Miguelez (2022) adopt a similar approach, with several novelties. First, they account for the uneven settlement of emigrant inventors in their host countries across the space and the different specialization of the cities and regions therein. Second, they account for the different specialization of the emigrant inventors themselves. In this way, results for emigrant inventors become far more robust, especially when other internal means to reach these new technologies, like a portfolio of related technologies, are absent (see also Miguelez and Morrison 2023).

Skill Supply and Diversity

Migration can affect innovation not only through knowledge diffusion, but also by increasing the supply of scientists and engineers in the host country and by increasing diversity, whether at the team, firm, or local level. Despite having received less attention than knowledge diffusion, these two channels also bear on broader topics: supply analysis is closely connected to studies on how immigration affects the labor market of the host countries; and the effects of diversity on innovation are one key aspect of the analysis of diversity in team and multinational settings.

Skill Supply: Quantity and Quality

Migrants may affect the supply of inventors in the host country in two ways. First, they may alleviate any shortage of potential inventors due to the lack of local skills, relative to the demand. Second, they may raise the average skill level of inventors due to positive self-selection. A scarcity of skilled labor, including of scientists and engineers, is perceived as a major issue in several innovation-oriented economies (for a recent discussion, see Branstetter, Glennon, and Jensen 2019). At the same time, it is a highly charged political topic, which touches upon sensitive subjects such as education and immigration policies.

To the extent that a skill shortage exists and constrains innovation, international students who decide to stay in the host country after graduation may alleviate it (Chellaraj, Maskus, and Mattoo 2008). These students generally exhibit a higher propensity than natives to enroll in science and technology programs, with the difference increasing when moving from undergraduate to graduate studies (OECD 2022). In addition, at least in the United States, foreign students in science, technology, engineering, and mathematics tend to specialize in fields closer to industrial R&D, which results in a higher propensity to become inventors (Hunt and Gauthier-Loiselle 2010; Hunt 2011).

These findings support a hypothesis of complementarity between native and migrant graduate students and more generally highly-skilled workers, with the potential to increase the productivity of both groups (Peri and Sparber 2009). Conversely, they suggest a lower risk that skilled immigrants will displace native-born workers or have a negative effect on wages. Based on this premise, easing the restrictions for foreign graduates to move from a student to a work visa or for young, foreign-educated workers to get one would affect both the number of foreign inventors and the total patenting activity in their host countries.

One such restriction that has received considerable attention in the research literature concerns the access to H-1B visas in the United States. While formally conceived for allowing US employers to recruit foreign workers in all "specialty occupations" (those requiring, among others, some university education), these visas have been extensively sought after by foreign-born PhDs employed in industrial R&D as a first step toward permanent residency (Roach and Skrentny 2021). At the same time, they have come under political fire due to their disproportionate use by information technology companies, including US subsidiaries of foreign ones, allegedly for replacing US natives and foreign resident computer scientists with younger, lower paid immigrant ones, and with no appreciable positive effect on innovation.

The supply of H-1B visas has been subject to both national quotas from sending nations and relatively frequent variations, with many employers often being unable to meet their foreign recruitment targets. Scholars investigating migrant inventors have exploited these variations in quasi-experimental studies.

Based on instrumental variable analysis, Kerr and Lincoln (2010) compare the patenting activity of cities and firms with a different historical record of dependence on inventors with Indian and Chinese names, and find the more dependent ones to be more affected by the H-1B visa supply shocks. More importantly for our discussion, the authors show that this effect is mostly due to variations in the number of patents by migrant inventors, rather than by native ones. This suggests that the former do not produce major externalities in favor of the latter, as would occur with knowledge diffusion, and yet they may prove necessary to R&D staff and other inventive teams. These results are also consistent with related city- and firm-level evidence, respectively by Peri, Shih, and Sparber (2015) and Kerr, Kerr, and Lincoln (2015), on the positive effects of H-1B visa supply shocks on the employment and wages of native highly skilled workers following the recruitment of highly skilled foreign workers.

Contrary to such results, however, Doran, Gelber, and Isen (2022) find no evidence that US firms having obtained one or more H-1B visas through a special lottery mechanism innovate more than other, unsuccessful participants to the same lotteries. They also find that H-1B visa-holders are recruited to replace current employees, which suggests that they are mere substitutes of natives (that is, they do not come with complementary skills).

In a different context, a natural experiment in Switzerland also allows a look at how shifts in immigration policy can affect invention. The Swiss education system pushes many natives toward vocational training, rather than toward graduate education in science and technology. At the same time, Switzerland has a R&D system much larger than one would expect based on its population, which makes it highly dependent on foreign talent (as shown earlier in Figure 3). Despite this dependence, due to internal political reasons, its immigration policy remained quite restrictive until 1999, when it signed an Agreement for the Free Movement of Persons (AFMP) with the European Union as part of a broader cooperation package. While full implementation of the treaty took eight years, restrictions were waived immediately for a special category of immigrants, namely the cross-border workers commuting daily from France, Germany, Italy, and Austria to the Swiss cities close to the international frontier. This makes it possible to compare, during the implementation years, the Swiss regions receiving these cross-border workers to other Swiss regions with similar economies, but too far from the frontier for being touched by the liberalization of cross-border worker visas.

Based on this comparison, Beerli et al. (2021) find that the Swiss regions close to the international frontier saw their intake of foreign skilled workers increasing substantially relative to the others. Cristelli and Lissoni (2020) find the same for foreign inventors, most of whom had no patenting experience prior to their entry in the Swiss labor market (but subsequently signed all their patents with Swiss companies). These foreign inventors do not appear to have displaced the native ones, and instead have increased the productivity of those already active before their entry through direct collaborations. In addition, patenting in the migrant inventors' countries of origin did not react negatively of the migration outflow, which suggests that the lifting of the immigration restrictions allowed a large number of foreign graduates with backgrounds in science and technology to become inventors, which they would not have done if moving to Switzerland had not been possible.

Besides easing possible skill shortages, migrant inventors may be positively self-selected. According to the classic model by Borjas (1987) and Borjas and Bratsberg (1996), positive self-selection of migrants from country A to B occurs when the skill premium in the latter is higher than in the former, so that it is the best and brightest who both move in first place and are more likely to stay (not to return to A). Were the original skill distribution in the two countries similar enough, it may turn out that migrants will be, on average, more skilled than natives, possibly due to the role played by a few exceptional individuals.

This pattern may hold for the United States. As mentioned earlier, Bernstein et al. (2022) find that migrant inventors contribute disproportionately to their host country's patent production, both in general and with respect to highly cited and valuable inventions. These results hold after controlling for many potentially confounding factors, such as the higher concentration of migrant inventors in science-based technologies (whose patents may be more cited or more valuable than others) and in highly innovative hubs, such as the Silicon Valley, where they can benefit from positive externalities. In addition, migrant inventors appear to be technological leaders, to the extent that they also increase significantly the productivity of their collaborators. It is important to stress that the migrants considered in this study include a large number of individuals who arrived in the United States in their twenties, possibly as students or young researchers. When examining their professional life cycles, the authors find that their productivity advantage over natives builds up over time and reaches its peak in their senior years. That is, the pattern does not reflect, at least not exclusively, a few superstar scientists or technologists moving to the host country after establishing their reputation at home, but instead represents gifted individuals who build their careers in the host country. Quite interestingly, however, they appear to retain strong links outside the United States, as measured by their higher propensity, relative to natives, to cite foreign prior art and to collaborate with foreign inventors. This is compatible with the findings on the diffusion literature we reviewed in the previous section.[5]

Diversity and Innovation

The literature on migration-induced diversity and innovation is extensive, especially in economic geography (as an example, see Bosetti, Cattaneo, and Verdolini 2015). Most studies find a positive link between diversity and innovation, with the latter being often measured with patent-based indicators. A general understanding of these results is that the interaction between diverse individuals may generate more new ideas, or more path-breaking ones, due to complementarity of the inventors' information sets, cognitive differences, and heuristics (Lazear 2008).

One major limitation of this literature so far has been the difficulty of disentangling the different levels at which this diversity interaction occurs, whether at the team, firm, or spatial level. The answer to this question has theoretical, managerial, and policy implications (Kemeny 2017). For example, one possibility is that the fruits of interaction internal to teams or firms may be largely appropriated by the same teams or firms. On the other hand, interaction outside the firm would generate knowledge spillovers and a potential agglomeration force (Olfert and Partridge 2011). This externality would be complementary, but logically different, to that generated by the local access to a diverse workforce (Brunow and Blien 2014).

Another issue concerns the costs of diversity, such as difficulties in communication, polarization of opinions, and disparity of treatment (Harrison and Klein 2007). These may depend on both the number of countries of origin within a team, organization, or location and the size of value differences between individuals from such countries.

Inventor data may contribute to elucidating these issues insofar the co-inventors appearing on the same patent can be treated as a team, whose diversity can be measured by assessing the number of migrants and their distribution across different countries of origin. In addition, information on the patent assignees and the inventor addresses allows an opportunity to control for firm- and location-level diversity. Ferrucci and Lissoni (2019) use this approach to produce a descriptive study on a large number of inventor teams in both Europe and the United States. They establish the migrant status and the countries of origin of inventors by making use of the nationality information on Patent Cooperation Treaty patents, corrected by name analysis. They measure diversity at the team, firm, and location level, based

[5] Notice that Bernstein et al. (2022) cannot establish whether the migrant inventors' foreign ties are with their home countries or with fellow migrants to other host countries, as they do not have information on their nationality or country of birth.

on a simple fractionalization index and its variations. They find a positive association between diversity and the quality of patents, as measured by the number of citations received over three years after filing, and this applies across team, firm, and location differences. Based on Esteban and Ray (1994), they also calculate a "polarization index" capturing possible differences across ethnic groups in working practices and find that, at least for Europe, a negative association with patent quality exists, which indicates that the existence of inventor diversity comes at some cost.[6]

The diversity-innovation literature also suffers from major identification problems; specifically, very innovative firms or cities may attract talented workers and innovators from all over the world, which could create an upward bias in the estimated effect of diversity. Some remedies are available for studies at the firm and location level, such as shift-share analysis as applied by Parrotta, Pozzoli, and Pytlikova (2014), as well as other instrumental variables as in Campo et al. (2022). However, no fully satisfactory solution to this identification problem in the context of inventor teams has been found so far. A primary difficulty is that these teams are not stable entities, composed of a fixed set of inventors working on several inventions in a row. Rather, they are project-oriented assembling of individuals, also including many one-time inventors, who will not appear on subsequent patents.

Conclusion

Migrant inventors are a heterogeneous set of workers, most likely with qualifications or experience in the fields of science, technology, engineering, and mathematics, who appear on patent documents. Senior and highly experienced migrant inventors may play a key role in transferring knowledge from their home countries to their host ones. Such inventors are likely to belong to the right tail of the productivity distribution of inventors and will often have patents filed in both countries.

However, these "star" inventors represent a minority of today's migrant inventors, who instead consist primarily of those who migrate as international students and young graduates, as Nobel Prize winner Katalin Karikó did when she moved to the United States three years after completing her PhD in Hungary. Migrants like her move more to acquire knowledge rather than to transfer it, and their early postmigration jobs often involve work as junior staff in R&D teams. They contribute positively to innovation in the host countries, to the extent that they come with or are willing to acquire any skill in short supply in the host countries. Their

[6]The simplest fractionalization index is equal to one minus the Herfindahl index of the inventors' nationality shares, whether in a team, firm, or city. Variations occur mainly by attaching weights to the different shares so to take into account the cultural or linguistic heterogeneity across ethnic groups. For a discussion, see Nijkamp and Poot (2015). As for the polarization index, this measures how distant the team members' opinions are with respect to different propositions as measured, for example, by a Likert-scale assessment of agreement/disagreement (that is, a scale with a range of perhaps five or seven numerical choices ranging from full agreement to full disagreement).

presence in teams, firms, or cities may also enhance innovation through diversity, to the extent that it sustains creativity. Like Karikó, many migrant inventors are positively self-selected, as long as they move to host countries where their skills and determination are better rewarded than at home. As such, they may turn out to be particularly productive and establish themselves as technological leaders. So far, however, evidence in this respect has been gathered only for the United States.

Even when moving in their junior years, migrant inventors may contribute to knowledge diffusion in two ways. First, by maintaining some links to their home countries—for example, by collaborating with local inventors—they may in be in a better position than native inventors to source foreign knowledge (Miguelez and Morrison 2023). Second, they can contribute to innovation in their home countries via knowledge remittances, but evidence on this point needs to be strengthened.

Future investigations of the effect of migration on the supply of inventors will require not only innovative uses of patent data, but also more investments in matching inventor data to administrative records where evidence is lacking, especially outside the United States. One relatively untapped resource is the information one can extract from the Electronic Theses and Dissertations database, which has already been used to track foreign PhD careers in science (Kahn and MacGarvie 2016). Some early examples of this approach have been conducted for Sweden and Germany (Zheng and Ejermo 2015; Buenstorf, Heinisch, and Kapa 2022).[7] Similarly, one could experiment with retrieving and matching information from social media profiles. This approach may come at a considerable cost in terms of sampling bias, but it may provide otherwise missing information on return patterns (Breschi, Lissoni, and Miguelez 2020).

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[7] See also Delgado and Murray (2023), albeit with an application to gender studies.

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