4

Measuring the International Mobility of Inventors

A New Database

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4.1 Introduction

The international mobility of knowledge workers and the associated brain-drain/brain-gain phenomena have gained prominence in public policy discussions on innovation and economic growth – in both developed and developing economies. Many governments have made efforts to attract skilled migrants from abroad – inciting what may be colloquially called a global competition for talent.

This chapter focuses on a special set of knowledge workers, namely, inventors. In particular, we introduce a new database that maps migratory patterns of inventors, extracted from information contained in patent applications filed under the Patent Cooperation Treaty (PCT). In addition to describing this newly constructed database, we provide a descriptive overview of inventor migration patterns around the world.

As described in Chapters 1 and 2, the economic importance of high-skilled migration has long been recognized in the literature, even if empirical research on the topic is of more recent vintage. Indeed, advances in our understanding of the effects of skilled worker migration to a significant extent have been due to new data becoming available over

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the last fifteen years. In particular, the pioneering study by Carrington and Detragiache (1998) represents the first systematic attempt to construct a comprehensive data set on emigration rates by educational attainment. Their study provides 1990 emigration rates for sixty-one sending countries to countries of the Organization for Economic Cooperation and Development (OECD). They estimate skill levels by extrapolating the schooling levels of US immigrants by origin country to other receiving countries. Since then, other macro approaches have followed, including that of Docquier and Marfouk (2006), who estimate immigrant stocks in thirty OECD countries for 174 origin countries for 1990 and 2000, and Defoort (2008), who extends this work by providing immigrant stocks by schooling level for five-year intervals from 1975 to 2000, but only to six OECD destination countries. Docquier et al. (2009) provide a gender breakdown, and Beine et al. (2007) provide data broken down by the entry age of immigrants.

Çağlar Özden and Christopher Parsons provide a detailed overview in Chapter 2 of this book of the different data sets available from census records and describe in detail their own data work, which offers, to date, the largest available census-based data set – including numerous sending and receiving countries by gender, age, and educational attainment (see also Artuç et al. 2015). Özden and Parsons also review some of the main drawbacks of census-based data sets. Among them, it is worth highlighting two. First is the fact that the way to define educational attainment differs across OECD countries, complicating comparability, which is exacerbated when the sample includes non-OECD countries. Second, skill levels still differ markedly among skilled workers. Census-based data sets provide a skills breakdown based on three schooling levels, which offers only a rough differentiation of skills. In particular, tertiary education may include nonuniversity tertiary degrees, undergraduate university degrees, postgraduate degrees, and doctoral degrees. However, migration rates in certain skill-intensive professions – for instance, Ph.D. holders – tend to be higher than the general population. Likewise, their contribution to science and innovation in both sending and receiving countries will differ substantially from that of other tertiary-educated workers.

Recent research has shown that skilled migration, and especially that of scientists and engineers (S&Es), is the most dynamic component of total migration worldwide (Freeman 2010). Among them, inventors arguably are both a representative sample of high-skilled workers and a special category among them. Focusing on inventor migration as captured in patent applications constitutes an interesting and underexploited alternative to the use of more common migration stock data retrieved from censuses. It captures one specific class of high-skilled workers that is bound to be more homogeneous than the group of tertiary-educated workers as a whole. In addition, inventors have special economic importance because they create knowledge that is at the forefront of technological innovation and ultimately the genesis of technological and industrial transformation.

Patent and inventor data are increasingly exploited for migration research, as witnessed in other chapters of this book and the related literature. In particular, Agrawal et al. (2011) and Kerr (2008) look at the relation between ethnic inventors in the United States and knowledge flows back to the ethnic inventors' country of origin, finding relatively weak evidence of a positive relation between the two – stronger for the most valuable innovations and for certain technological fields and particular ethnic groups. At the same time, Foley and Kerr (2013), Kerr and Kerr (2015), and Miguelez (2016) find stronger effects on the relationship between inventor diasporas and the formation of international co-inventorship teams – all these contributions using the same type of data source we embrace here.

Yet empirical evidence is still scarce and generally focused on a limited number of sending and receiving countries. This lack of evidence is especially serious considering the economic importance of migrant inventors, as well as the possibilities made available to researchers with patent and inventor information. For instance, inventor information can be exploited together with patent citations and information on co-inventors, thereby tracking, respectively, knowledge flows and social networks either within the same destination country or reaching back to inventors' country of origin. After careful disambiguation of inventors' names (see Chapter 3), it is also possible to track returnee inventors and thus explore their impact on origin countries. Foreign and native inventors can further be grouped across regions and metropolitan areas, technological sectors, and firms (especially multinationals), increasing in this way our understanding of the spatial distribution of skilled immigrants across regions, immigrants' specialization in certain technologies, and the role of the firm in the migration process, including the business consequences of recruiting foreign talent.

Most of the inventor migration research has sought to identify the likely cultural origin of inventor names disclosed in patent data (see again Chapter 3). This approach has produced important insights. However,

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the cultural origin of inventor names may not always indicate recent migratory background. For example, the migration history of certain ethnicities spans more than one generation – think of Indian and Chinese immigrants in the United States or Turkish immigrants in Germany. Conversely, one may overlook immigrant inventors with names sharing the same cultural origins as the host country – think of Australian or British immigrants in the United States.

In this chapter we describe a new data set on the international mobility of inventors that overcomes many of the data limitations described so far. In particular, we make use of information on both the residence and the nationality of inventors contained in patent applications filed under the PCT. This approach offers several benefits. First, we directly rely on migratory background information revealed by inventors rather than indirectly inferring a possible migration history through the cultural origin of names. Second, patent applications filed under the PCT are less influenced by the peculiarities of national patent systems, and the underlying inventions are likely to have a larger economic value than the average national patent application. Third, PCT filing data cover a large number of countries and a long time span (from 1978 to 2012). Of course, our database shares some of the drawbacks associated with existing migration databases, and relying on patent information has drawbacks on its own, to which we will return.

The rest of this chapter is organized as follows. Section 4.2 describes the PCT system underlying our new database, and we outline, in particular, what types of information patent applications record. Section 4.3 describes the main features of our inventor migration database. In Section 4.4, we provide a descriptive analysis of inventor migration patterns as they emerge from our newly constructed database. Section 4.5 offers concluding remarks.

4.2 The PCT System as a Source of Inventor Migration Data

4.2.1 Patents and the PCT System

We derive information on the migratory background of inventors from patent applications filed under the PCT. Accordingly, we first provide some background on the patent system and especially on the PCT system, which facilitates the process of seeking patent protection in multiple jurisdictions.

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A *patent* is the legal right of an inventor to exclude others from using a particular invention for a limited number of years. To obtain a patent right, individuals, firms, or other entities must file an application that discloses the invention to the patent office and eventually to the public. In most cases, a patent office then examines the application, evaluating whether the underlying invention is novel, involves an inventive step, and is capable of industrial application. Economic researchers have long used patent applications as a measure of inventive activity. The attraction of patent data relies on such data being available for a wide range of countries and years and for detailed technology classes (Hall 2007). In addition, patent documents contain information on the application's first filing date and on the applicants and inventors, including their geographic origin – down to the level of street addresses. Studies have made use of patent data to investigate the innovative behavior of firms (Griliches 1979; Hausman et al. 1984), localized knowledge spillovers (Jaffe et al. 1993), international knowledge flows (Peri 2005), networks of co-inventors (Breschi and Lissoni 2009; Singh 2005), and inventor mobility (Almeida and Kogut 1999; Breschi and Lissoni 2009; Miguelez and Moreno 2015).

The PCT is an international treaty administered by the World Intellectual Property Organization (WIPO) offering patent applicants an advantageous route for seeking patent protection internationally. The treaty came into force in 1978; starting with only eighteen members back then, there were 148 PCT contracting states in 2015.[1]

The key to understanding the PCT system's rationale is to realize that patent rights are territorial in nature, meaning that they apply only in the jurisdiction of the patent office that grants the right. A patent applicant seeking to protect an invention in more than one country has two options. He or she can file applications directly at the patent offices in the jurisdictions in which the applicant wishes to pursue a patent – this approach is referred to as the *Paris route* toward international protection.[2] Alternatively, the applicant can file an application under the PCT. Choosing the *PCT route* benefits the applicant in two main ways. First, he or she gains additional time – typically eighteen months – to decide whether to continue to seek patent protection for the invention in question and, if so, in which jurisdictions. Second, an International Searching Authority issues a report on the patent application that offers information on the potential patentability of the invention; this information can assist the applicant in deciding on whether and where to pursue the patent.[3]

Note that under the PCT system, the applicant still has to file applications in all jurisdictions in which he or she eventually seeks protection. An international patent right as such does not exist; the ultimate granting decision remains the prerogative of national and regional patent offices. However, the additional time gained and the first opinion on the invention's patentability can be valuable for applicants at a relatively early stage of the patenting process, at which the commercial significance of an invention is still uncertain.[4] Accordingly, applicants have opted for the PCT route for a significant share of international patent applications (see below).

For the purpose of economic analysis – including migration analysis – the PCT system has two key attractions. First, the system applies one set of procedural rules to applicants from around the world and collects information based on uniform filing standards. This reduces potential biases that would arise if one were to collect similar information from different national sources applying different procedural rules and filing standards. Working with only a single national source may be a viable alternative for studying inventor immigration behavior for a particular country, but this approach could not reliably track migrating inventors on a global basis. In any case, as will be further explained later, national patent data records generally do not offer information on both the residence and nationality of inventors.

Second, PCT patent applications are likely to capture the commercially most valuable inventions. Patenting is a costly process, and the larger the number of jurisdictions in which a patent is sought, the greater are the patenting cost. An applicant therefore will only seek a patent internationally if the underlying invention generates a sufficiently high return – higher than for patents that are only filed domestically.[5] Turning to the migration angle, one may hypothesize that the most valuable patent applications emanate from the most skilled inventors, so while the focus on PCT patent applications clearly does not capture all patenting inventors, it is likely to capture the more important ones.

Before turning to how we extracted migratory background information from PCT filing data, we review a number of characteristics of the PCT system that are important to take into account when using these data for economic analysis. As already mentioned at the outset, not all countries are members of the PCT. Fortunately, the countries that have accounted for the great majority of patent filings over the past three decades – especially China, France, Germany, Japan, the Republic of Korea, the United Kingdom, and the United States – have either been founding members or joined the system before experiencing rapid patenting growth. Nonetheless, incomplete membership should be taken into account when interpreting data for different filing origins and especially when performing regression analysis.

In 2010, around 54 percent of all international patent applications went through the PCT system. The PCT share has continuously risen over the past two decades; in 1995, it stood at only 25.4 percent of all international patents (WIPO 2012a). In February 2011, the two millionth application was filed under the PCT system. However, the system has seen uneven growth since its inception in 1978. In particular, it took twenty-six years to reach the first million but only seven years to reach the second million (WIPO 2012a). Over the 1978–2011 period, the United States accounted for most filings (35.1 percent of all applications), followed by Japan (15.1 percent), Germany (11.9 percent), the United Kingdom (4.5 percent), France (4.4 percent), the Republic of Korea (3.2 percent), and China (2.9 percent).

Note that the total number of patent applications filed worldwide – at 2.14 million in 2011 – is considerably larger than the number of PCT filings – at 181,900 in the same year (WIPO 2012b). Two considerations account for this difference. First, for the majority of patents – around two-thirds in 2011 – applicants seek only domestic protection and do not apply for protection abroad. Second, each PCT filing may result in several national patent filings depending on the number of jurisdictions in which the applicant seeks protection.

While the PCT thus captures a sizable and important share of patent activity worldwide, there are considerable differences in how residents of different countries use the system. First, the propensity of patent applicants to seek protection beyond their national jurisdiction differs markedly. For instance, in 2011, residents of China filed fewer than 20,000 applications outside of China, or only 4.54 percent of all the applications by Chinese residents worldwide. In contrast, this share is considerably higher for the Republic of Korea (26.4 percent), Japan (39.1 percent), the United States (42.7 percent), Germany (57.6 percent), the United Kingdom (59.7 percent), France (62.8 percent), the Netherlands (74.7 percent), and Switzerland (78.6 percent).[6]

Countries also differ in the extent to which they rely on the PCT system – rather than the direct Paris route – for their international filings. Recall that in 2010 the PCT share of international filings for the world stood at around 54 percent. However, we see substantial variation around this average: the PCT share was between two-thirds and three-quarters for

Finland, France, the Netherlands, Sweden, and the United States; it was between one-half and two-thirds for Australia, Germany, Russia, Switzerland, and the United Kingdom; and it was between one-quarter and one-half for Canada, China, Japan, and the Republic of Korea.

4.2.2 Information on Inventor Nationality and Residence in PCT Applications

Similar to other patent documents, PCT patent applications contain information on the names and addresses of the patent applicant(s) (generally, the owner) but also the names and addresses of the inventor(s) listed in the patent application. What is unique about PCT applications is that in the majority of cases they record both the residence and the nationality of the inventor. This has to do with the requirement under the PCT that only nationals or residents of a PCT contracting state can file PCT applications. To verify that applicants meet at least one of the two eligibility criteria, the PCT application form asks for both nationality and residence.

In principle, the PCT system only records residence and nationality information for applicants and not inventors. However, it turns out that US patent application procedures until recently required all inventors in PCT applications to also be listed as applicants. Thus, if a given PCT application included the United States as a country in which the applicant considered pursuing a patent – a so-called designated state in the application – all inventors were listed as applicants, and their residence and nationality are, in principle, available. Indeed, this is the case for the majority of PCT applications, reflecting the popularity of the United States as the world's largest market. In addition – and fortunately for our purposes – a change to PCT rules in 2004 provided that all PCT applications automatically include all PCT member states as designated states, including the United States.

Unfortunately – for our purposes – the United States enacted changes to its patent laws under the Leahy-Smith America Invents Act (AIA) that effectively removed the requirement that inventors be also named as applicants. Starting on September 16, 2012, PCT applicants (automatically) designating the United States became free to list inventors without facing the requirement of indicating their nationality and residence – and, indeed, many applications quickly made use of this freedom. [7]

In a nutshell, this means that we have good coverage of inventors' residence and nationality information before 2004, excellent coverage

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from 2004 to 2011, and deteriorating coverage starting in 2012. Section 4.3 explains this in greater detail.

4.3 Data Coverage

By December 31, 2012, the total number of PCT applications stood at 2,361,455. Incorporating all the entities taking part in a PCT patent application, this figure translates into 10,725,384 records – unique combinations of patent numbers and names. This includes, for each patent application, the names of the applicants, agents, inventors, common representatives, special addresses for correspondence, and so-called applicant-inventors. Given our interest in studying the migratory background of inventors, we focus our attention only on inventor and applicant-inventor records. This subgroup accounts for exactly 6,112,608 records.

Ideally, we would like to group these 6,112,608 records along uniquely identified inventors and applicant-inventors in order to describe their migration patterns. However, the database does not provide for a single identifier for each inventor or applicant-inventor. The prior literature has disambiguated individual inventors through their names and surnames, as well as other information contained in patent documents.[8] However, these approaches are far from perfect (see Raffo and Lhuillery 2009), and the raw records on inventors and applicant-inventors already enable meaningful analysis at the aggregate (country) level or at the patent level. In particular, we can calculate immigration and emigration rates across countries and map bilateral inventor flows, whereby aggregate indicators are weighted by the productivity of inventors in terms of their number of patents. Clearly, name disambiguation would add important value to our database, though the best disambiguation approach may depend in part on the research question at hand. Indeed, we encourage other researchers to apply their own disambiguation methods to our database. In what follows, our unit of analysis will be the *inventor/applicant-inventor name–patent number pair*.

We observe both nationality and residence information for 4,928,076 of the 6,112,608 records, a coverage rate of 80.6 percent. The main reason for the less than complete coverage was already pointed out in Section 4.2.2: even though nationality and residence information is a compulsory field for applicants and applicant-inventors, it is not required for inventors who are not at the same time applicants. However, we observe other reasons for incomplete coverage. For some records, either the nationality

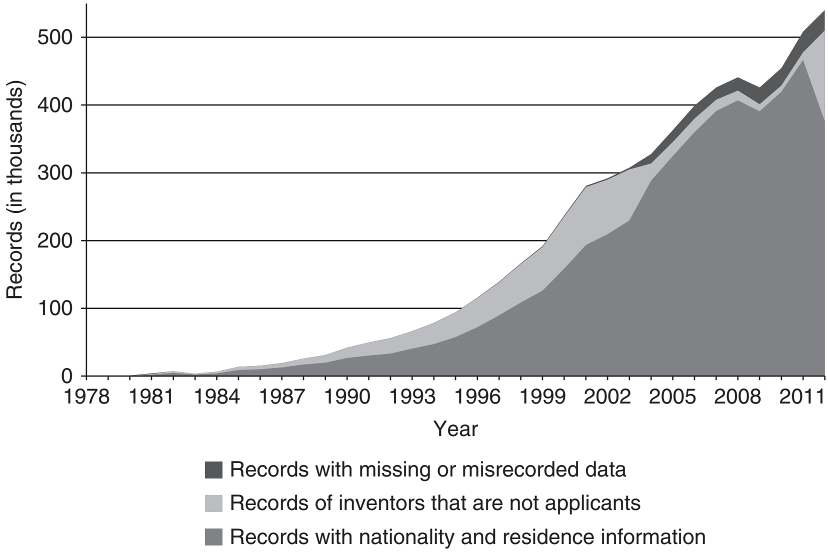

Figure 4.1 Coverage of nationality and residence information in PCT patents

field or the residence field is missing; in selected cases, both are missing. This could be due to the applicant omitting these fields in the original application or to errors in transferring information from the original patent application to the electronic filing system.[9]

Of the 1,184,532 records that do not offer complete nationality and residence information, 970,336 records – or 81.9 percent – relate to inventors who are not applicants; the remaining 214,196 records – or 18.1 percent – show missing or misrecorded information.

Figure 4.1 shows the availability of nationality and residence information for all inventor and applicant-inventor records from 1978 to 2012. It shows that we observe this information for the majority of records throughout the PCT system's history. However, the coverage varies over time, standing between 60 and 67 percent during the 1990s and between 70 and 92 percent during the 2000s. It increases markedly after 2004, reflecting the PCT rule change described earlier. Unfortunately, we already observe a marked decline in the availability of nationality and residence information in 2012. As described earlier, following implementation of the AIA, PCT applications did not have to list all inventors as applicants any more as of September 16, 2012. Indeed, the incentive to not list inventors as applicants is strong because it facilitates the

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Table 4.1 *Total Records and Coverage of Nationality and Residence Information (Selected Countries)*

Country/territory name	Total records	Records with information	Records of inventors only	Coverage (percent)
Austria	40,411	37,755	1,773	93.43
Australia	70,720	67,621	2,491	95.62
Belgium	46,488	41,743	4,200	89.79
Brazil	14,116	12,983	947	91.97
Canada	112,627	91,166	20,399	80.95
Switzerland	84,521	78,600	4,847	92.99
China	233,506	213,837	18,684	91.58
Germany	751,509	712,426	35,547	94.80
Denmark	46,493	42,097	4,115	90.54
Spain	51,020	48,440	2,085	94.94
Finland	64,450	59,677	4,464	92.59
France	248,541	233,372	13,030	93.90
UK	257,266	236,760	15,807	92.03
Israel	63,644	58,599	4,682	92.07
India	50,777	45,552	4,656	89.71
Italy	95,691	90,309	4,726	94.38
Japan	909,360	854,176	42,204	93.93
Netherlands	128,236	94,616	22,773	73.78
Norway	24,294	23,139	978	95.25
New Zealand	11,806	11,258	433	95.36
Russia	39,865	35,590	3,869	89.28
Sweden	114,614	101,894	12,134	88.90
Singapore	18,053	16,270	1,469	90.12
US	2,130,268	1,402,203	703,389	65.82
South Africa	10,594	10,015	502	94.53

subsequent management of the patent; in particular, decisions such as withdrawal or reassignment of the patent only require the consent of a smaller number of parties – indeed, in most cases, there will only be a single applicant. As a consequence, the coverage of inventor nationality and residence information is bound to decline dramatically in 2013.

Table 4.1 shows how the coverage of nationality and residence information differs across countries. It includes origins that account for most

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filings under the PCT. For the majority of countries shown, coverage lies above 90 percent, and for most others, it is above 80 percent. US applications stand out as showing the lowest coverage, of around 66 percent. This has to do with the special US filing rule discussed earlier. Before 2012, non-US PCT applications needed to list inventors as applicant-inventors if they indicated the United States as a designated state. However, US applicants generally file their applications at the US Patent and Trademark Office before submitting a PCT filing; thus, before 2004, they did not need to list the United States as a designated state. The same reason likely explains the low coverage of nationality and residence information for Canada and the Netherlands. Due to their geographic proximity, many Canadian applicants first file an application at the US Patent and Trademark Office before filing under the PCT. In the case of the Netherlands, a relatively small number of applicants account for a large share of PCT filings, and those applicants appear to have a long-standing tradition to first apply directly at the US Patent and Trademark Office.

Similar to Figure 4.1, Figure 4A.1 in Appendix 4A shows the evolution of inventor nationality and residence information for a selection of countries accounting for substantial filing shares under the PCT. Importantly, it shows that the relatively low coverage for Canada, the Netherlands, and the United States is due to pre-2004 records. From 2004 to 2011, these three countries equally show high coverage shares. In addition, all countries show a marked decline in coverage in 2012, reflecting the procedural change introduced by the AIA.

In sum, PCT records generally offer good coverage of inventor nationality and residence information and, as such, represent a promising data source for migration research. Coverage is high for all countries between 2004 and 2011. Before 2004, it is high for most countries except Canada, the Netherlands, and the United States. Unfortunately, as of September 16, 2012, the ability of PCT records to provide information on inventors' migratory background appears seriously undermined.

4.4 Descriptive Overview

This section presents a descriptive overview of the database introduced in Section 4.3. It focuses on inventor immigration and emigration stocks and rates (see Box 4.1) in different parts of the world and for a selection of countries. It also identifies the most important bilateral migration corridors. Further, the overview looks at differences across technologies, subnational regions, and the largest applicants in each receiving country.

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BOX 4.1: METRICS USED IN THIS CHAPTER

In this study, the *stock of immigrants* is defined as the number of individuals with foreign nationality residing in a given country *i* in a given year or period of time. For the case of this chapter, this will be the stock of immigrant inventors.

The *stock of emigrants* is defined as the number of people of a given nationality *i* residing abroad in a given year or period of time. Again, this chapter refers to the stock of emigrant inventors.

The *immigration rate* of a given country *i* in a given year is defined as the share of the foreign population over all residents of that country

$$IM_i = \frac{\text{immigrants}_i}{\text{residents}_i}$$

The *emigration rate* of a given country *i* in a given year is defined as the share of the native population residing abroad over all nationals of that country *i*. To make the figures comparable to tertiary-educated emigration rates, the denominator also includes immigrant inventors residing in country *i*

$$EM_i = \frac{\text{emigrants}_i}{(\text{emigrants}_i + \text{residents}_i)}$$

In the migration literature, when the emigration rate is computed for tertiary-educated individuals, the resulting ratio is often termed the *brain-drain rate*.

Finally, it tests the hypotheses of outstanding contribution of migrant inventors in receiving economies, as well as whether migrant inventors in frontier knowledge economies engage with their homelands in the production of new ideas.

4.4.1 Receiving Countries

We find exceptionally high migration rates for inventors. Recall that the prior literature has estimated a global migration rate in 2000 for the population of age twenty-five and older of 1.8 percent. It has also established that the migration rate increases with migrants' skills; in particular, estimates suggest a 1.1 percent migration rate for the unskilled population, a 1.8 percent rate for the population with secondary education, and a 5.4 percent rate for the population with tertiary education.[10] Our data, in turn, point to an inventor migration rate of 8.62 percent in 2000 – taking the skills bias in the propensity to migrate one step further.

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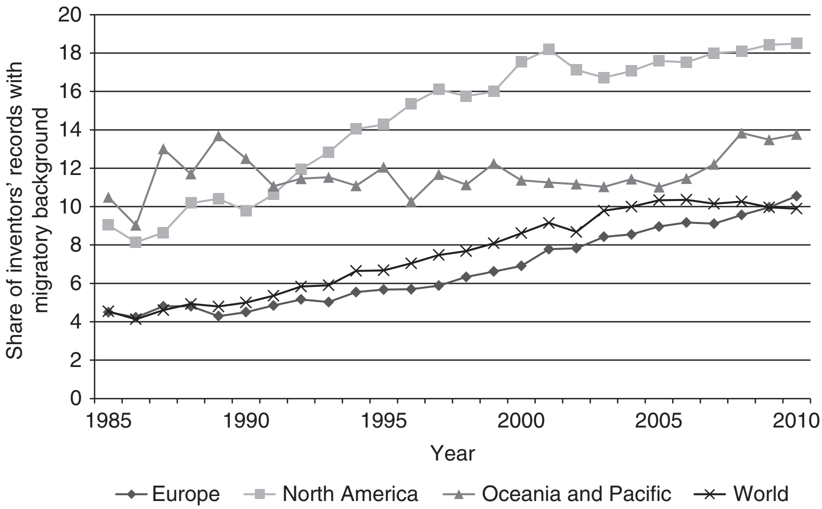

Figure 4.2 Share of immigrant inventors, 1985–2010

Figure 4.2 shows the evolution of the share of inventors in PCT patent applications with migratory background for the world as a whole and for selected continents. As can be seen, the share of migrant inventors has increased steadily over time. North America stands out as seeing the highest shares of immigrant inventors relative to the continent's population of resident inventors, followed by Oceania and the Pacific and Europe. These patterns and trends are in line with those observed for high-skilled migration more generally, whereby countries such as the United States, Canada, Australia, and New Zealand stand out as exhibiting the largest shares of immigrant workers, whereas European economies are lagging behind in attracting talent.[11]

Figure 4.3 shows the same inventor immigration shares for selected countries and confirms this point. In particular, Australia, Canada, and especially the United States stand out as the primary receiving countries relative to their population of inventors. While at the forefront of technological innovation, Germany and France have consistently seen lower inventor immigration rates. Of special interest is the United Kingdom, which has experienced a substantial increase in its share of immigrant inventors. Japan, in turn, remains the only country in this chart with an inventor immigration rate of less than 2 percent.

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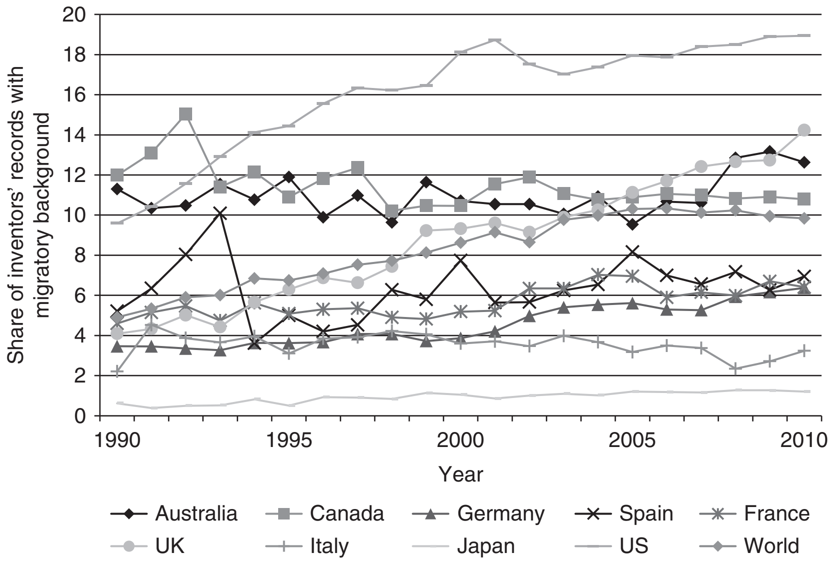

Figure 4.3 Share of immigrant inventors, 1990–2010

Figure 4.4 includes additional high-income economies and shows the immigration rates of inventors for the two separate time windows. The chart shows that relatively small countries see even larger immigration rates than the United States – notably, Belgium (19 percent), Ireland (20 percent), Luxembourg (35 percent), and Switzerland (38 percent). Moreover, countries such as Switzerland, Luxembourg, the Netherlands, Austria, and the United Kingdom, as well as the Scandinavian economies, have considerably increased their immigration rates in the 2000s versus their figures for the 1990s.

Table 4.2 lists the same immigration rates as shown in Figure 4.4 and compares them with immigration rates of college graduates using Census 2000 data. It shows, first of all, a US immigration rate of college graduates far more in line with those of other large OECD countries, suggesting that the popularity of the United States is somewhat unique to inventors. More generally, it is instructive to compute the ratio between inventor immigration rates and the immigration rate of college graduates. This ratio indicates to what extent inventor and tertiary-educated immigration figures differ. The first thing to notice is that with the exception of Finland (ratio 3.88 in favor of inventors), the ratios range from 0.34 (Australia) to 1.75 (Belgium). This suggests that for the majority of

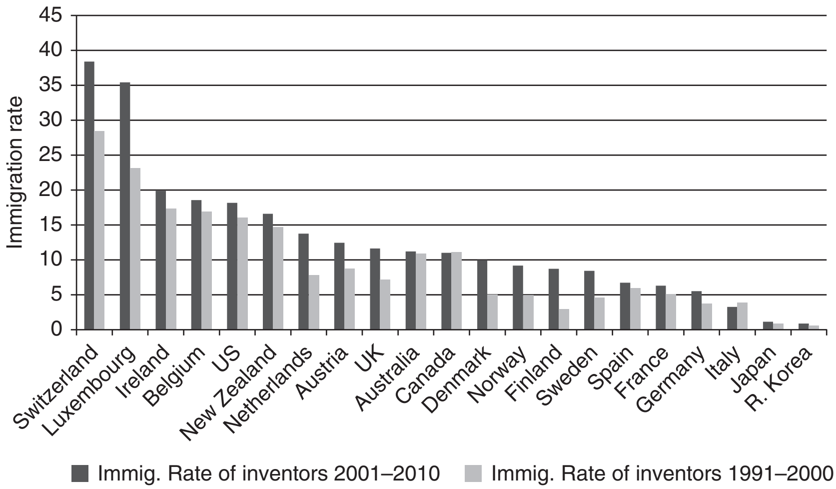

Figure 4.4 Immigration rates of inventors, 1991–2000 and 2001–10

countries, the estimated inventor immigration rates emerging from the PCT data are broadly consistent with census data. At the same time, smaller countries, similar to the United States, seem to be disproportionately popular among inventors compared to college graduates (ratio larger than 1.25). This is the case for Belgium, Denmark, Switzerland, and especially Finland.

4.4.2 Which Are the Largest Sending Countries?

We next turn to inventor emigration patterns and trends. Recall that the prior literature has estimated a 5.4 percent global migration rate for tertiary-educated workers. However, this figure hides considerable variation in emigration propensities across continents: in high-income countries, the emigration rate stood at 3.6 percent versus 7.3 percent for low- and middle-income countries. It was much higher for least developed countries (13.1 percent) and for small island developing states (42.4 percent).[12]

These differences turn out to be even more marked when looking at inventor data. The global share of inventors with migratory backgrounds stood at 7.46 percent from 1991 to 2000 and at 9.94 percent from 2001 to 2010. However, the emigration rate of high-income countries for these two time periods stood at only 4.99 and 5.92 percent, respectively.[13] It

Table 4.2 *Immigration Rates of Inventors and College Graduates*

Country	Immigration rate, 1991–2000 (a)	Immigration rate, 2001–2010 (b)	Immigration rate college (c)	Ratio (a)/(c) (d)	Ratio (b)/(c) (e)
Australia	10.89	11.20	33.17	0.33	0.34
Austria	8.80	12.45	14.33	0.61	0.87
Belgium	16.89	18.56	10.61	1.59	1.75
Canada	11.16	11.03	25.84	0.43	0.43
Denmark	5.07	9.98	8.00	0.63	1.25
Finland	2.93	8.74	2.25	1.30	3.88
France	5.12	6.32	12.38	0.41	0.51
Germany	3.76	5.54	11.39	0.33	0.49
Ireland	17.38	19.89	18.07	0.96	1.10
Italy	3.88	3.27	6.11	0.64	0.54
Japan	0.87	1.15	1.05	0.83	1.09
Luxembourg	23.14	35.42	49.04	0.47	0.72
Netherlands	7.80	13.77	11.36	0.69	1.21
New Zealand	14.72	16.60	24.85	0.59	0.67
Norway	4.96	9.17	8.09	0.61	1.13
R. of Korea	0.59	0.90	0.88	0.67	1.02
Spain	5.95	6.72	6.38	0.93	1.05
Sweden	4.61	8.44	14.26	0.32	0.59
Switzerland	28.45	38.41	28.38	1.00	1.35
UK	7.17	11.62	16.00	0.45	0.73
US	16.07	18.18	13.86	1.16	1.31

was much higher for low- and middle-income countries – standing at 41.73 and 36.40 percent, respectively.[14]

Table 4.3 provides top-thirty lists of immigrant and emigrant counts for the time period 2001–10, respectively. Unsurprisingly, the top-thirty immigrant list consists mostly of high-income economies, probably reflecting the attractive employment, education, research, and entrepreneurship opportunities offered by these economies. Interestingly, most high-income countries also show sizable diasporas abroad, although China and India come out as the top two inventor-sending countries.

It is also worth looking at the net balance of immigrant and emigrant inventors for selected countries. Figure 4.5 shows for the 2001–10 period

Table 4.3 *Immigrants, Emigrants, and Emigration Rates, Time Window 2001–10*

Country/territory	Immigrants	Nationals	Country/territory	Emigrants	Residents
US	194,609	875,962	China	53,610	141,902
Germany	25,341	432,136	India	40,097	38,486
Switzerland	20,416	32,737	Germany	32,158	457,477
UK	15,758	119,824	UK	27,746	135,582
Netherlands	9,665	60,513	Canada	21,315	65,808
France	9,540	141,413	France	19,123	150,953
Canada	7,257	58,551	US	11,131	1,070,571
Singapore	6,720	6,311	Italy	9,820	62,973
Japan	6,715	578,101	Netherlands	9,132	70,178
Belgium	5,042	22,122	R. of Korea	9,127	164,078
Sweden	4,832	52,451	Russia	7,878	20,561
Australia	4,427	35,088	Japan	6,986	584,816
China	4,251	137,651	Australia	5,631	39,515
Austria	3,113	21,896	Spain	5,154	35,786
Finland	3,095	32,314	Austria	5,122	25,009
Denmark	2,589	23,364	Sweden	4,025	57,283
Spain	2,406	33,380	Israel	3,668	42,001
Italy	2,060	60,913	Belgium	3,567	27,164
Ireland	1,689	6,803	Greece	3,209	2,025
R. of Korea	1,472	162,606	Turkey	3,119	6,202
N. Zealand	1,249	6,277	Switzerland	3,005	53,153
Norway	1,245	12,327	Ireland	2,686	8,492

Table 4.3 (*cont.*)

Country/territory	Immigrants	Nationals	Country/territory	Emigrants	Residents
Israel	694	41,307	Malaysia	2,682	4,154
S. Arabia	569	524	Romania	2,589	771
India	532	37,954	Poland	2,537	4,559
Malaysia	524	3,630	Denmark	2,411	25,953
South Africa	426	6,355	Iran	2,253	76
Brazil	376	9,050	Ukraine	1,911	2,464
Luxembourg	322	587	Brazil	1,859	9,426
UAE	273	54	N. Zealand	1,839	7,526

Note: The last column shows the emigration rates only if the country has at least ten nationals (both abroad and residents).

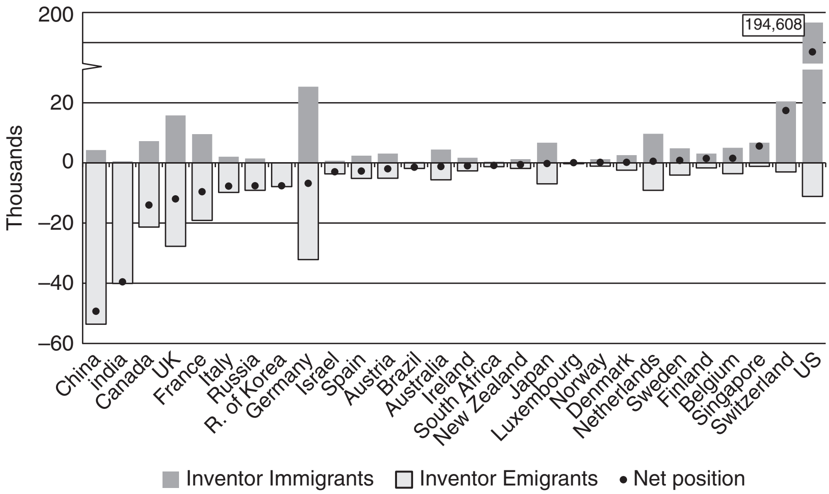

Figure 4.5 Net migration position, 2001–10

the number of immigrant and emigrant inventors and order countries according to their net immigration position. Again, the United States stands out in showing by far the largest immigration surplus; indeed, there are more than fifteen times as many immigrant inventors in the United States as there are US inventors residing abroad. By contrast, Canada and the three largest European economies – France, Germany, and the United Kingdom – see negative net immigration positions. The cases of Germany and the United Kingdom are especially interesting because they host considerable numbers of immigrant inventors, but even greater numbers of German and UK inventors reside abroad.

When looking at relative emigration rates – which take into account the size of the local inventor endowments – low- and middle-income countries dominate the top-thirty list, especially small and African economies. Figure 4.6 shows emigration rates – or *brain-drain rates* – in a map for the same time period. The map confirms that low- and middle-income countries and especially African economies are the most severely affected by inventor brain drain.

4.4.3 *Identifying the Largest Migration Corridors*

Due to the bilateral nature of our data, we can identify the main inventor migration corridors. The left-hand side of Table 4.4 lists the thirty most

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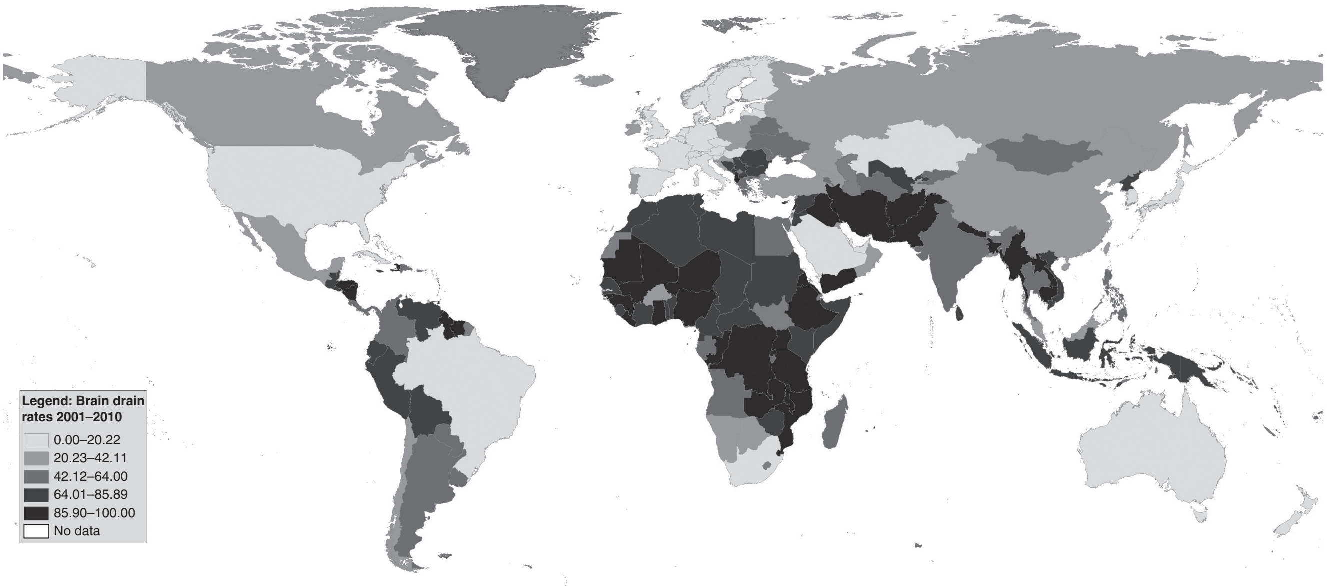

Figure 4.6 Brain-drain rates, 2001–10

important corridors for the 2001–10 period. These thirty corridors account for only 0.08 percent of country pairs in our data set. However, they represent 58.70 percent of overall migration counts for the whole period. In other words, inventor migration is a phenomenon that is highly concentrated among a relatively small number of countries. The United States appears most frequently in this list as a destination country.[15]

The right-hand columns in Table 4.4 list the thirty most important corridors for which the sending country is not an OECD member. This allows us to look more carefully at south-north migration and possibly also south-south migration. The United States emerges by far as the most frequently listed destination country in both periods. Germany is the only continental European country appearing on this list, confirming the earlier finding that European countries lag behind in attracting inventors from non-OECD countries (Docquier and Rapoport 2009). Interestingly, Singapore – despite its relatively small size – appears several times as a destination country on this list, with China, India, and Malaysia as the most important inventor origins.

Table 4.5 lists all the bilateral country pairs where the ratio of the flow from origin to destination over the reverse flow is between 0.5 and 2; it orders pairs by the sum of the two flows for two different time windows – 1991–2000 and 2001–10. The corridors listed can be considered as having fairly balanced inventor migration flows. The resulting flows appear to reflect in large part the establishment of a single labor market in Europe.[16] Aside from EU corridors, other interesting corridors that feature in the top-thirty list include United States-Israel (1991–2000), Switzerland-United States, China-Germany, and Singapore-United States. Interestingly, China features in several of these corridors in the second period, witnessing the rise of the country not only as a source of inventors for other countries but also as a host for inventors from many other economies – especially other Asian and European economies.

4.4.4 Do Migrant Inventors Differ across Technological Fields?

This section explores differences in inventor migration patterns across technology domains. This is partly motivated by previous research that has found that immigrants' contribution to their host countries' productivity is mainly driven by those specializing in specific sectors that happen to be more productive – the so-called composition effect (Hunt and Gauthier-Loiselle 2010). In light of these claims, this section provides

Table 4.4 *Largest Inventor Migration Corridors, 2001–10*

Largest inventor migration corridors			Largest inventor migration corridors, limited to non-OECD sending countries[a]		
Origin	Destination	Counts	Origin	Destination	Counts
China	US	44,452	China	US	44,452
India	US	35,621	India	US	35,621
Canada	US	18,734	Russia	US	4,339
UK	US	14,893	China	Japan	2,510
Germany	US	10,297	China	Singapore	1,923
Germany	Switzerland	8,198	Turkey	US	1,922
R. of Korea	US	7,267	Iran	US	1,438
France	US	6,543	Romania	US	1,220
Japan	US	5,045	Russia	Germany	1,207
Russia	US	4,339	Mexico	US	1,161
Australia	US	3,241	Brazil	US	1,115
Israel	US	2,966	Malaysia	Singapore	1,090
France	Switzerland	2,747	Ukraine	US	977
Netherlands	US	2,698	China	UK	920
Austria	Germany	2,672	China	Germany	892
France	Germany	2,607	India	Singapore	847
China	Japan	2,510	Argentina	US	820
Italy	US	2,501	Singapore	US	775
Germany	Netherlands	2,285	Malaysia	US	729
Netherlands	Germany	2,138	South Africa	US	719
France	UK	2,044	Egypt	US	667
UK	Germany	2,043	China	Canada	652
China	Singapore	1,923	Bulgaria	US	626
Turkey	US	1,922	Pakistan	US	626
Germany	Austria	1,829	Turkey	Germany	601
Germany	UK	1,612	India	UK	556
Germany	France	1,609	India	Germany	542
Spain	US	1,559	Colombia	US	532
UK	Switzerland	1,555	Thailand	US	494
Italy	Switzerland	1,536	Philippines	US	450

[a] We include Mexico and Chile – as the only middle-income OECD countries – among the sending countries.

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Table 4.5 *Largest Bilateral Migration Corridors, 1991–2000 and 2001–10*

Largest dual-direction migration corridors, 1991–2000				Largest dual-direction migration corridors, 2001–10			
Origin (A)	Destination (B)	A → B	B → A	Origin (A)	Destination (B)	A → B	B → A
UK	Germany	780	476	Austria	Germany	2,672	1,829
France	UK	513	435	Germany	Netherlands	2,285	2,138
Germany	France	432	403	France	Germany	2,607	1,609
Israel	US	522	273	UK	Germany	2,043	1,612
Belgium	France	373	330	France	UK	2,044	1,121
Netherlands	Germany	384	296	Switzerland	US	1,348	734
Ireland	UK	419	210	UK	Australia	977	609
UK	Netherlands	304	205	Netherlands	Belgium	890	535
Germany	Belgium	290	147	Ireland	UK	808	568
Italy	UK	225	146	China	Germany	892	468
UK	N. Zealand	180	98	Singapore	US	775	518
Italy	France	177	100	Netherlands	France	644	580
UK	Sweden	164	84	Germany	Belgium	694	406
Denmark	UK	120	102	China	Canada	652	387
France	Netherlands	98	86	Japan	Germany	502	280
Japan	Germany	83	81	UK	N. Zealand	418	342
Norway	Sweden	75	56	Spain	France	420	304
Singapore	US	65	52	Germany	Denmark	402	292
Japan	UK	73	39	Sweden	Denmark	377	250
Ireland	Germany	54	53	UK	Sweden	363	251
Netherlands	Sweden	67	39	UK	Denmark	367	214
Sweden	France	58	40	Australia	China	327	246
Finland	UK	50	47	Finland	Sweden	317	182
Germany	S. Africa	54	42	Germany	Finland	264	188
Canada	Japan	61	33	Japan	UK	255	175
Australia	Canada	54	39	France	China	211	183
UK	Singapore	54	39	Sweden	Norway	196	179
Germany	Finland	48	42	UK	Norway	238	119
Israel	UK	57	31	S. Africa	UK	172	128
Canada	Switzerland	54	31	Ireland	Germany	149	141

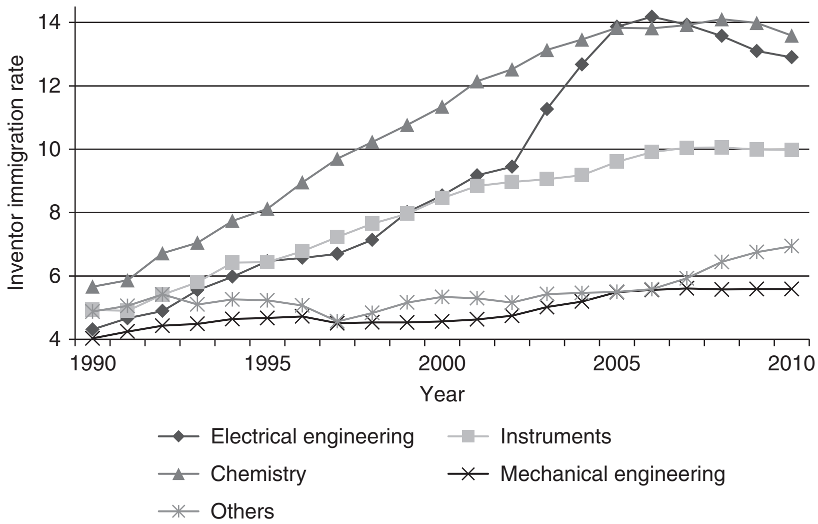

Figure 4.7 Inventor immigration rates over time by field of technology: three-year moving averages

some initial insights into differences in inventor mobility patterns across different technology sectors. It follows Schmoch's (2008) classification of International Patent Classification (IPC) codes into thirty-five technology fields and groups them into five broad sectors – namely, electrical engineering, instruments, chemistry, mechanical engineering, and others (see Table 4A.1 in Appendix 4A).[17]

Figure 4.7 looks at the migration rate of inventors across sectors over time. As is apparent from this figure, immigrant inventors' contribution to patenting differs markedly across technology fields. Electrical engineering and chemistry emerge as the most important technology fields. The case of electrical engineering – audiovisual technology, telecommunications, digital communications, computer technology, IT methods, semiconductors, and so on – is especially remarkable, showing a sudden jump in its migration rate around 2003–4.[18]

Figure 4.8 reports inventor immigration rates for selected technology fields for a number of countries.[19] Generally, countries such as Switzerland, the Netherlands, and the United States had high inventor immigration rates in all the reported fields for the 2006–10 period. In contrast, China, India, and Japan reported low inventor immigration rates for the same period. However, across countries and technology fields, there were considerable variations in inventor immigration rates.

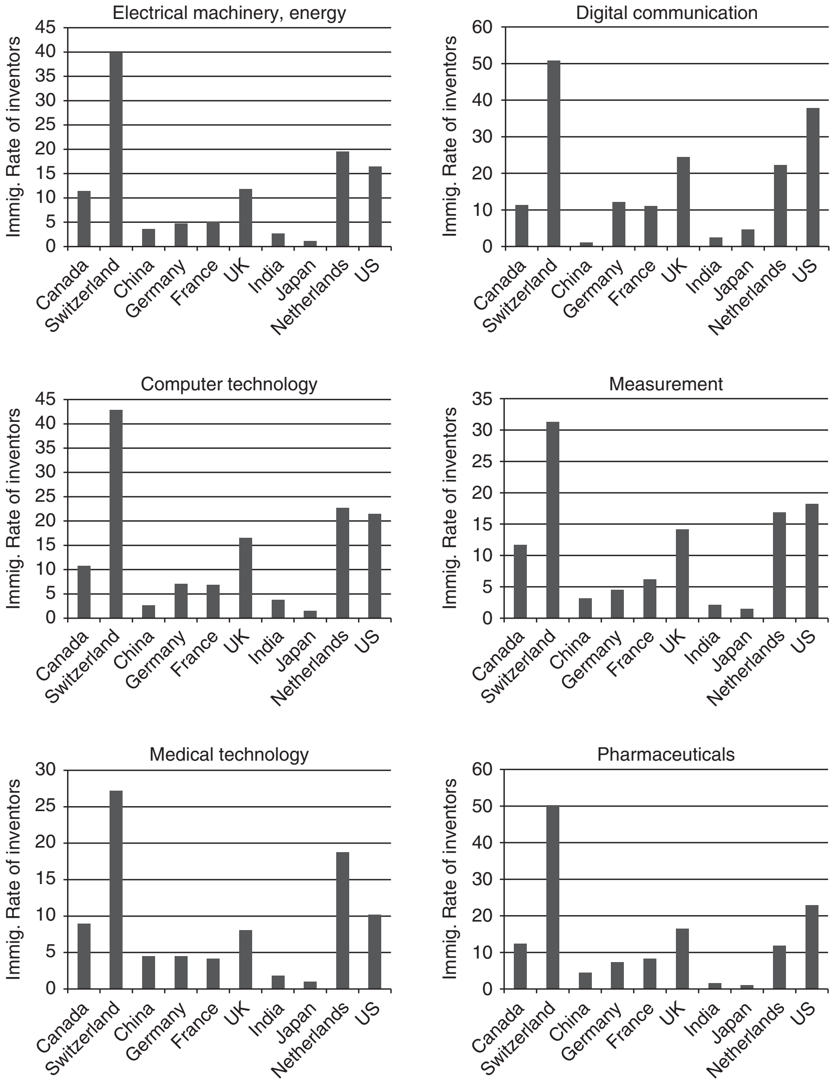

Figure 4.8 Inventor immigration rates, selected fields and countries, 2006–10

4.4.5 Which Regions Attract Knowledge Workers?

One striking aspect of immigration, and particularly skilled immigration, is that migrants tend to concentrate in specific geographic areas within countries. In particular, immigrant inventors appear to cluster in metropolitan areas, thus contributing to the spatial concentration of inventive activity. This issue is analyzed by matching PCT applications with

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OECD's REGPAT database (Maraut et al. 2008; refer to Miguelez and Raffo 2013 for details of the matching procedure).[20] By linking inventor nationality information with REGPAT, it is possible to study the settlement patterns of immigrant inventors within countries beyond the settlement patterns of native inventors.

Table 4.6 ranks the top thirty European NUTS2 regions in terms of stocks of migrant inventors from 2001 to 2010 (left-side columns).[21] As can be seen, in absolute numbers, regions of the core of Europe attract large numbers of inventors from other countries. However, this is partially related to their size and their innovative capacity. The right-side columns normalize these numbers using the number of resident inventors in each region. As is shown, some regions, particularly Swiss regions, are high in both rankings. Interestingly, the Swiss region of Nordwestschweiz leads both rankings. Recall that Switzerland was the country with the largest share of foreign inventors among the OECD countries. Luxembourg, Ireland, and Belgium also ranked high, which regional figures also reflect – the regions of these four countries dominate the ranking. Other important poles of attraction are London, Wien, and the Dutch region of Noord-Brabant, where the Phillips facilities are located.

Table 4.7 repeats the same exercise as before but for the case of Metropolitan Statistical Areas (MSAs) of the United States. In terms of immigrant inventor counts, MSAs are generally larger than European NUTS2 regions – as they are in terms of total inventor counts. Leading the ranking we see some of the biggest and most innovative MSAs, as expected – San Diego, San Jose, New York, San Francisco, and Boston. When one looks at the ratio of immigrant inventors in MSAs, San Diego and San Jose still rank quite high – San Diego leads both rankings. In comparison with Table 4.6, one can see that the top four European regions attract more talented individuals (in relative terms) than San Diego. However, while the share of immigrant inventors in NUTS2 European regions drops rapidly over the ranking, a large number of MSAs show immigration ratios over 20 percent. That is to say, immigrant inventors' settlement in European regions seems to be more skewed than in the case of the United States.

4.4.6 Migrant Inventors and the Role of Firms

Inventor immigration rates differ not only across countries and regions but also across different types of applicants. For example, Table 4.8 lists the immigration rates for the top ten PCT applicants – based on the residence of the first-named applicant for the 2006–10 period for a selection of countries. It shows that the distribution of immigrant inventors was very uneven across applicants, even between enterprises of a

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Table 4.6 *Top Thirty European NUTS2 Regions by Immigration Stocks and Rates, 2001–10*

Country	NUTS2 region	Immigrant count	Country	NUTS2 region	Immigration rate
CH	Nordwestschweiz	6,733	CH	Nordwestschweiz	0.470
NL	Noord-Brabant	6,014	CH	Rég. Lémanique	0.460
CH	Rég. Lémanique	4,219	BE	Bruxelles	0.409
FR	Île de France	3,895	CH	Zurich	0.391
CH	Zurich	3,777	LU	Luxembourg	0.339
DE	Oberbayern	3,049	CH	Zentralschweiz	0.334
DE	Karlsruhe	2,734	CH	Ostschweiz	0.299
DE	Köln	2,473	GB	Inner London	0.261
SE	Stockholm	2,331	BE	Brabant Wallon	0.248
GB	East Anglia	2,286	CH	Ticino	0.239
DE	Darmstadt	2,275	IE	Southern and Eastern	0.206
GB	Inner London	2,264	BE	Prov. Antwerpen	0.194
DE	Rheinhessen-Pfalz	2,181	CH	Espace Mittelland	0.194
FI	Etelä-Suomi	2,037	BE	Vlaams-Brabant	0.190
DE	Düsseldorf	1,920	NL	Noord-Brabant	0.179
GB	Berkshire, Buckinghamshire and Oxfordshire	1,913	BE	Prov. Hainaut	0.171
DK	Hovedstaden	1,707	GB	Outer London	0.171

Table 4.6 (*cont.*)

Country	NUTS2 region	Immigrant count	Country	NUTS2 region	Immigration rate
DE	Stuttgart	1,688	AT	Wien	0.170
FR	Rhône-Alpes	1,685	BE	Prov. Luxembourg	0.167
CH	Espace Mittelland	1,460	GB	East Anglia	0.163
CH	Ostschweiz	1,398	DK	Nordjylland	0.158
NL	Zuid-Holland	1,287	GB	Eastern Scotland	0.153
IE	Southern and Eastern	1,122	AT	Tirol	0.151
ES	Cataluña	1,098	BE	Prov. Liège	0.148
BE	Bruxelles	1,085	AT	Kärnten	0.148
DE	Berlin	1,051	ES	Illes Balears	0.145
BE	Prov. Antwerpen	1,012	IE	Border, Midland And Western	0.144
CH	Zentralschweiz	1,000	GB	Berkshire, Buckinghamshire and Oxfordshire	0.144
NL	Noord-Holland	957	GB	Northern Ireland	0.142
AT	Wien	921	NL	Noord-Holland	0.141

Note: For calculation of regional immigration rates, regions with fewer than thirty resident inventors for the period 2001–10 are not displayed.

Table 4.7 *Top Thirty US MSAs by Immigration Stocks and Rates, 2001–10*

MSA	Immigrant counts	MSA	Immigration rate
San Diego	20,752	San Diego	0.351
San Jose-Santa Clara	20,386	Evansville	0.321
New York	17,396	San Jose-Santa Clara	0.307
San Francisco	15,246	Stockton	0.303
Boston	14,753	Trenton	0.296
Los Angeles	6,500	Champaign-Urbana	0.294
Philadelphia	6,167	New Haven	0.285
Chicago	6,001	Albany	0.282
Houston	5,742	Lansing-East Lansing	0.263
Dallas	3,593	Ithaca	0.262
Washington	3,523	Ann Arbor	0.255
Minneapolis	2,921	Gainesville	0.255
New Haven	2,608	Athens	0.249
Seattle	2,514	College Station-Bryan	0.248
Trenton	2,248	Columbus	0.246
Portland	2,231	Santa Barbara	0.238
Atlanta	2,013	New York	0.237
Detroit	1,776	Dallas	0.226
Albany	1,755	San Francisco	0.224
Austin	1,722	Boston	0.223
Raleigh-Cary	1,598	Greensboro-High Point	0.221
Durham-Chapel Hill	1,565	Ames	0.219
Phoenix-Mesa-Glendale	1,556	State College	0.212
Ann Arbor	1,467	Portland-Vancouver-Hillsboro	0.210
Baltimore-Towson	1,399	Columbia	0.209
Hartford-West Hartford-East Hartford	1,224	Lafayette	0.206
Cincinnati-Middletown	1,189	Lexington-Fayette	0.198
Bridgeport-Stamford-Norwalk	1,161	Fayetteville-Springdale-Rogers	0.196
Indianapolis-Carmel	1,106	Sacramento–Arden-Arcade–Roseville	0.194
Worcester	1,099	Little Rock-North Little Rock-Conway	0.192

Note: For calculation of regional immigration rates, the areas with fewer than 300 resident inventors for the period 2001–10 are not displayed.

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Table 4.8 *Inventor Immigration Rates for Top Ten Applicants, Selected Countries, 2006–10*

Applicant name	Immigration rate	Patents	Inventors	Applicant name	Immigration rate	Patents	Inventors
United States				**Germany**			
Qualcomm Incorporated	50.8	6,528	19,907	Robert Bosch Corporation	2.8	6,480	17,484
Microsoft Corporation	57.4	3,020	11,297	Siemens Aktiengesellschaft	6.4	4,555	11,753
3 M Innovative Properties Company	11.0	2,577	8,852	Basf Se	14.4	3,562	15,427
Hewlett-Packard Development Company, L.P.	18.6	2,360	6,114	Bosch-Siemens Hausgerate Gmbh	3.2	1,679	4,575
E.I. Dupont De Nemours and Company	17.0	2,118	5,916	Fraunhofer-Gesellschaft Zur Forderung Der Angewandten Forschung E.V.	5.4	1,532	5,521
International Business Machines Corporation	21.4	2,006	6,854	Continental Automotive Gmbh	8.6	1,337	3,447
University of California	28.2	1,754	5,598	Henkel Kommanditgesellschaft Auf Aktien	6.4	1,210	4,420
Motorola, Inc.	23.4	1,573	4,488	Daimler Ag	3.8	1,196	3,601
Procter & Gamble Company	10.2	1,540	4,953	Evonik Degussa Gmbh	5.6	974	4,103
Baker Hughes Incorporated	12.8	1,461	3,552	Zf Friedrichshafen Ag	2.4	958	2,702

Switzerland			
Nestec S.A.	56.4	619	1,781
F. Hoffmann-La Roche Ag	46.6	564	1,385
Novartis Ag	62.6	489	1,179
Syngenta Participations Ag	66.6	308	972
Actelion Pharmaceuticals Ltd	30.2	272	879
Alstom Technology Ltd	67.6	212	506
Abb Research Ltd	65.0	201	529
Swiss Federal Institute of Technology	49.2	186	534
Sika Technology Ag	30.4	179	426
Inventio Ag	23.6	174	338
Singapore			
Agency of Science, Technology and Research	62.2	791	2,690
National University of Singapore	57.6	213	735
Nanyang TechnologicaL University	61.4	148	474

United Kingdom			
Unilever Plc	10.4	594	1,536
Glaxo Group Limited	12.6	409	1,590
British Telecommunications Public Limited Company	20.2	389	861
Bae Systems Plc	3.2	305	644
Imperial Innovations Ltd.	29.8	246	648
Isis Innovation Limited	29.8	242	618
Dyson Technology Limited	10.4	237	579
Astrazeneca UK Limited	8.2	210	640
Cambridge University	36.6	205	572
Qinetiq Limited	2.2	185	458
France			
Centre National De La Recherche Scientifique (CNRS)	8.0	1,892	7,002
Commissariat A L'Energie Atomique Et Aux Energies Alternatives	2.6	1,514	4,240
Renault S.A.S.	0.2	1,065	2,357

Table 4.8 (*cont.*)

Applicant name	Immigration rate	Patents	Inventors	Applicant name	Immigration rate	Patents	Inventors
Creative Technology Ltd	21.6	88	217	France Telecom	11.6	963	2,188
Nanyang Polytechnic	23.0	74	166	L'oreal	1.8	849	1,730
Singapore Health Services Pte Ltd	37.4	35	160	Peugeot Citroen Automobiles Sa	2.4	772	1,502
Temasek Life Sciences Laboratory Limited	70.6	28	78	Thales Ultrasonics Sas	0.4	626	1,473
Razer (Asia-Pacific) Pte Ltd	4.6	27	44	Institut National De La Sante Et De La recherche Medicale (INSERM)	9.2	517	1,633
Siemens Medical Instruments Pte. Ltd.	25.0	27	76	Arkema	3.4	506	1,279
S*Bio Pte Ltd	77.6	17	49	L'air Liquide Société Anonyme Pour l'etude Et L'exploitation Des Procedes Georges Claude	5.0	471	1,332

relatively similar size. In France, for example, France Telecom's rate of immigrant inventors was between four and five times greater than that of Peugeot-Citroen – an imbalance that cannot be attributed solely to differences across technology fields. Peugeot-Citroen had an immigration rate that was more than ten times greater than that of Renault SAS. One interesting aspect of the data highlighted in Table 4.8 is the role played by universities and public research centers in the recruitment of talent from abroad. The top patenting universities and public research centers feature some of the highest inventor immigration rates among the top PCT applicants. This is the case for the University of California in the United States, for example, and also for Cambridge University, Imperial Innovations (Imperial College London), and Isis Innovation (Oxford University) in the United Kingdom, among others.

4.4.7 Testing the Outstanding Contribution of Foreign Inventors

PCT-based inventor immigration data can offer a perspective on an ongoing debate in both the academic literature and journalistic discussions on the extent of foreign researchers' contribution to scientific advancement and innovation. In the United States, some scholars remain skeptical about immigrants' contribution to overall economic performance (Borjas 1999). Others have found strong evidence for a positive and important role played by skilled immigrants on receiving countries' economic development.

In order to investigate the contribution of immigrants in their host country economy, it is insightful to explore the number of citations received by PCT applications with and without migrating inventors. The economic literature has used the number of citations as a measure of a patent's underlying quality. Table 4.9 presents the share of all patents with at least one listed inventor with migratory background residing in the top twenty largest receiving countries – for all the years – and compares it with the share of inventors with migratory background listed in breakthrough patents – defined as the top 5 percent of patents in terms of forward citations received, by priority year and technology (five IPC broad technologies).

As can be seen, the proportion of immigrants is systematically larger among breakthrough inventions than among the whole universe of PCT patents. This supports the idea that immigrants disproportionately contribute to their host country productivity – measured here by citations received, even after controlling for time and technology differences. Note that the differences are statistically significant in most cases (see the last column in Table 4.9) except for the Republic of Korea.

Table 4.9 *Share of Immigrants in Highly Cited Patents, All Years*

Country	Percent foreigners in all patents	Percent foreigners in most-cited patents	z
US	30.9	41.3	46.5***
Germany	10.9	14.4	14.9***
Switzerland	47.6	54.5	9.1***
UK	16.1	20.1	12.2***
France	10.8	14.7	10.1***
Netherlands	20.3	23.2	5.1***
Canada	19.8	23.8	6.3***
Japan	2.7	3.5	7.2***
Singapore	66.3	73.5	3.9***
Australia	17.6	20.3	4.1***
Belgium	28.6	34.2	5.8***
Sweden	10.9	16.3	12.1***
China	6.7	16.8	15.2***
Austria	16.4	21.3	5.0***
Finland	11.1	16.3	8.7***
Denmark	14.3	17.0	4.1***
Spain	13.4	19.0	5.4***
Italy	5.7	7.5	4.7***
Ireland	32.7	37.6	2.4**
R. of Korea	2.4	2.7	1.0

*** $p < 0.1$; ** $p < 0.5$; * $p < 0.10$.

4.4.8 *Do Foreign Inventor Diasporas Engage with Their Homelands?*

Despite the adverse consequences of the brain drain of high-skilled people on a country's development potential, it is also well recognized that emigrants do not necessarily sever their ties with their homelands, and as diasporas, they may constitute a valuable resource in terms of accessing foreign knowledge and technologies. One way to obtain insight into such diaspora-homeland links is to analyze how extensively immigrant inventors collaborate with their conational colleagues at home. To explore this empirically, we assemble all PCT applications for which one inventor resides in the United States and another inventor resides outside the United States regardless of inventors' nationality. We refer to this set

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of patents as *global collaborative patents* (Kerr and Kerr 2015). We focus on the United States, which is arguably the world's most technologically advanced country.

Focusing on the 2001–10 period, we look at global collaborative patents in two ways. First, we identify the nationality of the inventor(s) residing in the United States and calculate the shares attributable to the main origin nationalities, as shown in column 1 of Table 4.10. Thus 13.49 percent of global collaborative patents include US-resident inventors of Chinese nationality, 10.37 percent include US-resident inventors of Indian nationality, 15.44 percent include US-resident inventors of Canadian nationality, and so on. Note that these patents often include inventors of multiple nationalities; therefore, adding up all the percentages – including those not listed in Table 4.10 – would result in a value greater than 100. In addition, the US nationality – not shown in Table 4.10 – is represented in 81.65 percent of these global patents.

Second, we identify cases whereby the nationality of the US-residing inventor coincides with the country of residence of the inventor outside the United States and calculate the share of those patents in all *bilateral* collaborative patents that involve the United States and the origin country in question. If foreign inventors in the United States were not especially engaged with their homelands, we would expect the resulting shares to be similar to the ones shown in column 1 of Table 4.10. However, if they are more inclined to collaborate with inventors in their homelands, they would be over-represented in bilateral collaborative patents, and we should observe a higher share. Indeed, column 2 of Table 4.10 reveals higher shares for the majority of nationalities, and in most cases, the differences are statistically significant based on the test of proportions. For example, while 13.49 percent of all global patents between the United States and other countries include US-resident inventors of Chinese nationality, this proportion almost doubles to 24.20 percent when we focus only on collaborative patents between the United States and China. Only US-residing inventors with Canadian, German, Dutch, Swiss, and UK nationalities do not show any special engagement with their respective homelands; other linkages above and beyond high-skilled migration may explain this result – notably, cultural linkages as well as the role of multinational corporations (Breschi et al. 2017).

Table 4.10 *Share of International Copatents Including Conationals, 2001–10*

	(1)	(2)	(3)
Origin country	Global copatents with foreign inventors (percent)	Bilateral copatents with foreign inventors (percent)	z
China	13.49	24.20	16.20***
India	10.37	30.65	26.60***
Canada	15.44	12.79	−5.15***
UK	18.33	13.70	−8.99***
Germany	19.70	19.90	0.40
R. of Korea	3.36	24.30	33.13***
France	10.87	17.36	11.71***
Japan	7.10	22.67	29.93***
Russia	2.77	21.38	27.77***
Australia	3.71	13.42	17.31***
Israel	3.97	25.06	38.51***
Netherlands	5.44	6.07	1.17
Italy	4.17	6.04	3.18***
Turkey	0.79	6.03	6.33***
Spain	2.16	8.81	11.10***
Sweden	2.98	9.06	11.61***
Switzerland	3.21	2.48	−1.86*

*** $p < 0.1$; ** $p < 0.5$; *$p < 0.10$.

4.5 Conclusion

This chapter describes a new global data set on migrant inventors that we built using information on inventor nationality and residence available in PCT applications. By using patent data to map the migratory patterns of high-skilled workers, we can overcome some of the limitations faced by existing data sets on the world's migrant population.

In particular, our database covers a long time period, provides information on an annual basis, and includes a large number of sending and receiving countries. By focusing on inventors, we capture a group of high-skilled workers of special economic importance and with more homogeneous skills than tertiary-educated workers as a whole. Our data set relies on the PCT system, which applies a uniform set of procedural rules worldwide and has close to universal coverage – promoting the cross-country comparability of our data. In addition, patents filed under the PCT system are likely to include the most valuable inventions, as revealed in the willingness of applicants to potentially bear the patenting costs in multiple jurisdictions.

Of course, using patent data for economic analysis does not come without limitations. One important caveat is that we only observe inventors when they seek patents. However, not all inventions are patented; indeed, the propensity to patent for each dollar invested in R&D differs considerably across industries.[22] In addition, there is no one-for-one correspondence between the number of patent applications filed and the commercial value of the underlying inventions or their contribution to technological progress. Studies have documented a skewed distribution of patent values, with relatively few patents yielding high economic returns.[23] Similarly, as this chapter has pointed out, the propensity to patent abroad – and in particular through the PCT route – differs across countries, affecting the selection of inventors included in our data set.

As is the case for most other migration data sets, we can only identify inventors with migratory background, but we do not know where those inventors were educated. Anecdotal evidence suggests, for example, that many immigrant inventors in the United States received a scientific degree from US universities – although such cases may still involve a "drain of brains." Another limitation is that our data set misses inventors with migratory backgrounds who have become nationals of their host countries. To the extent that it is easier to gain citizenship in some countries than in others, this introduces a bias in our data. A related bias stems from the possibility that migrants of some origins may be more inclined to adopt the host country's nationality than migrants from other origins. Unfortunately, our data do not allow us to assess the severity of these biases. Researchers using our data should be aware of these limitations, especially when drawing policy conclusions.

Notwithstanding these caveats, we believe that our new database meaningfully captures a phenomenon of growing importance. Indeed, the descriptive overview presented in this chapter suggests that our database is consistent with migratory patterns and trends as they emerge from census data. At the same time, our database opens new avenues for research, promising to generate fresh empirical insights that can inform both innovation policy and migration policy.

Appendix 4A

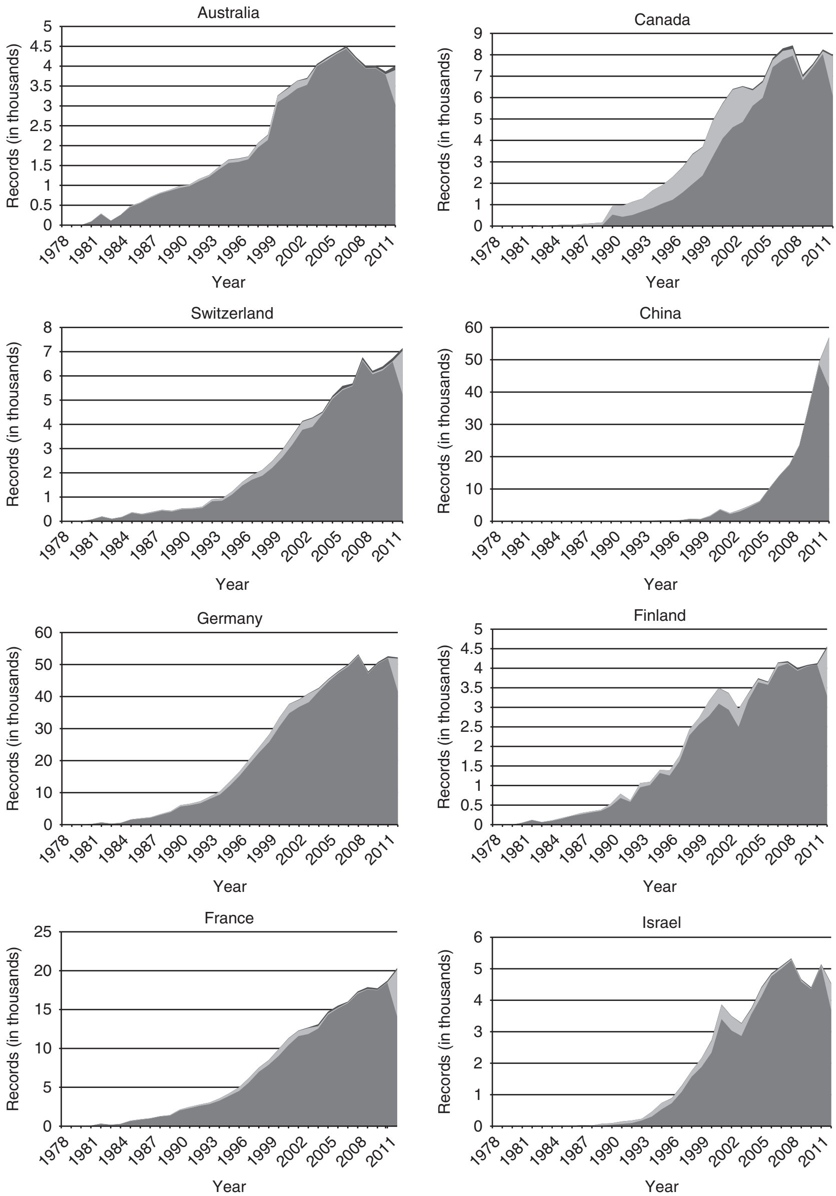

Figure 4A.1 Coverage of nationality and residence information, selected countries

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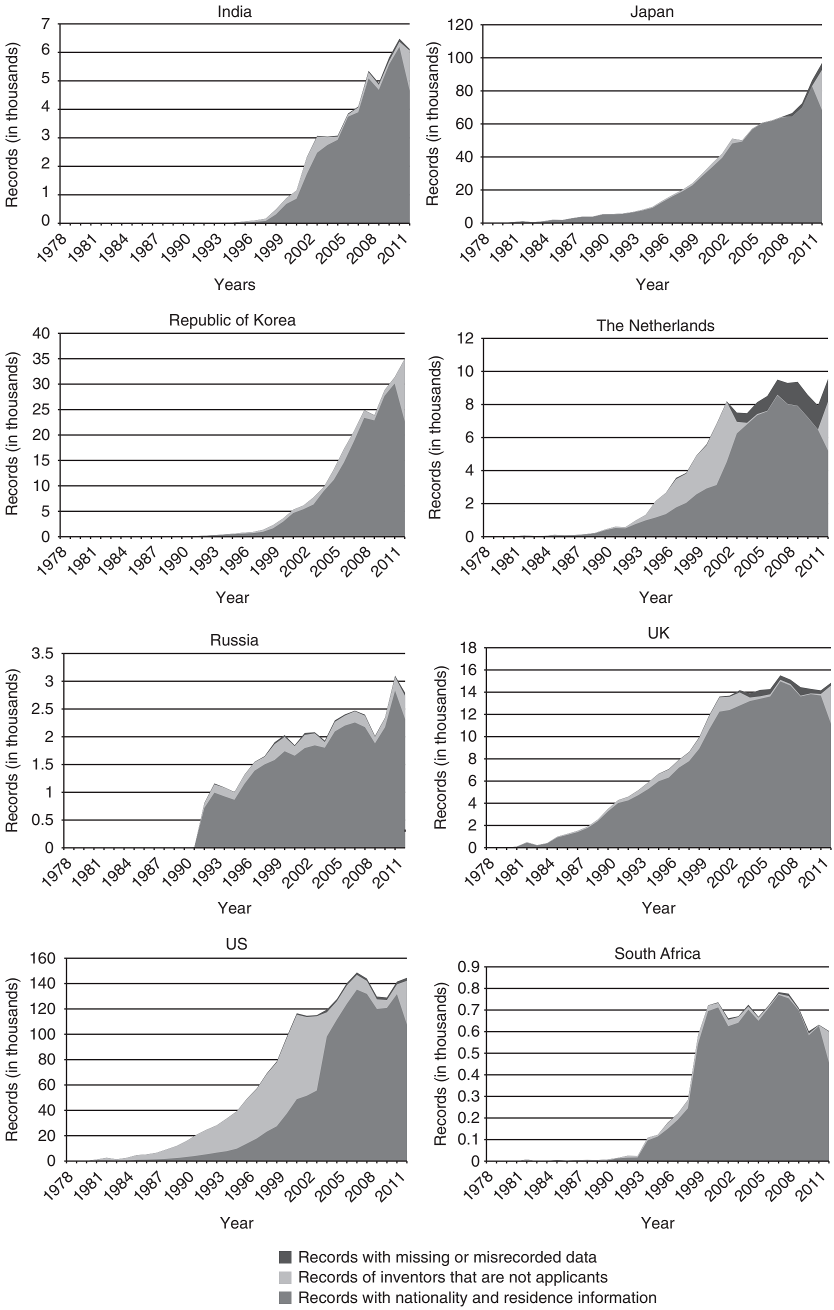

Figure 4A.1 (*cont.*)

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Table 4A.1 *Patent IPC-Technology Mapping*

Technology	Disaggregated technology
Electrical engineering	Electrical machinery, energy
Electrical engineering	Audiovisual technology
Electrical engineering	Telecommunications
Electrical engineering	Digital communication
Electrical engineering	Basic communication processes
Electrical engineering	Computer technology
Electrical engineering	IT methods for management
Electrical engineering	Semiconductors
Instruments	Optics
Instruments	Measurement
Instruments	Analysis of bio materials
Instruments	Control apparatus
Instruments	Medical technology
Chemistry	Organic fine chemistry
Chemistry	Biotechnology
Chemistry	Pharmaceuticals
Chemistry	Macromolecular chemistry, polymers
Chemistry	Food chemistry
Chemistry	Basic materials chemistry
Chemistry	Materials metallurgy
Chemistry	Surface tech coating
Chemistry	Micro-structure and nanotechnology
Chemistry	Chemical engineering
Chemistry	Environmental technology
Mechanical engineering	Handling
Mechanical engineering	Machine tools
Mechanical engineering	Engines, pumps, turbines
Mechanical engineering	Textile and paper
Mechanical engineering	Other spec machines
Mechanical engineering	Thermal processes and apparatus
Mechanical engineering	Mechanical elements
Mechanical engineering	Transport
Other	Furniture, games
Other	Other consumer goods
Other	Civil engineering
Other	Other

Notes

1. For a list of member states and the date at which the state became bound by the PCT, see www.wipo.int/pct/en/pct_contracting_states.html (accessed January 5, 2016).
2. The Paris Convention for the Protection of Industrial Property affords applicants with a priority international filing privilege of twelve months in order to file subsequent patent applications.
3. In addition, applicants can request a preliminary examination of the patent application by an international preliminary examining authority, which further assists them in their international filing decisions.
4. See van Zeebroeck et al. (2009), cited in van Zeebroeck and van Pottelsberghe de la Potterie (2011).
5. Several empirical studies have shown that PCT patent applications are more valuable, as captured by different value proxies (Guellec and Van Pottelsberghe de la Potterie 2002; van Zeebroeck and van Pottelsberghe de la Potterie 2011).
6. The higher share of European countries partly reflects the availability of an alternative regional filing route administered by the European Patent Office (EPO).
7. Even though the PCT rule change giving effect to the flexibility provided by the AIA only entered into force on January 1, 2013, a transitional arrangement allowed PCT applicants to not list inventors as applicants any more as of September 16, 2012 – the date at which the relevant provision in the AIA took effect.
8. Lissoni et al. (2006) and Trajtenberg et al. (2006) have pioneered these disambiguation techniques.
9. In a number of cases, the nationality and/or the residence field include the characters "**," "–," or "ZZ." These cases include records for which the country code specified in the address field does not coincide with the country code specified in the residence field; there are 28,600 such records. In addition, we find other causes for these characters: (1) geocoding mistakes (e.g., Israeli cities geocoded in Iceland or Chinese cities geocoded in Switzerland), (2) commuting (e.g., workplace in Denmark, close to the German border and residence in Germany), (3) colonial ties (e.g., addresses in the French Antilles, Hong Kong [China], and Faroe Islands are linked to individuals residing in, respectively, France, Great Britain, and Denmark), and (4) temporary mobility (e.g., an inventor has an Israeli residence and nationality but a US address country code).
10. See Docquier and Marfouk (2006) and Beine et al. (2007).
11. See Bertoli et al. (2012) and Docquier and Rapoport (2009).
12. As extracted from 2000 Census data; see Docquier and Marfouk (2006).

13. We report emigration rates as defined in Box 4.1.
14. At first reading, it may not be entirely obvious why the global migration share increases by 2.48 percentage points, but the emigration rate of high-income countries rises by only 1.07 percentage points and that of low- and middle-income county falls by 5.33 percentage points. The underlying reason is that low- and middle-income countries account for a larger share of the inventor population in the 2001–10 period, giving greater weight to the higher emigration rate of those countries. The main reason for the falling emigration rate of low- and middle-income countries is the falling inventor emigration rate of China, which, in turn, is due to China's inventor population growing substantially faster than the number of emigrating inventors.
15. This also holds for the general population of migrants (Docquier and Rapoport 2012).
16. Within Europe, some of the largest bilateral flows are among countries sharing the same or similar languages or those which are contiguous.
17. Note that some patents, and therefore some inventors, might be classified in more than one technology. Adding up the absolute number of inventors across the five broad sectors thus results in a larger number of inventors than those considered in previous sections.
18. The abrupt shift around 2003–4 may reflect the change in PCT rules in 2004 that provided that all PCT applications automatically include all PCT member states as designated states, which increased considerably the nationality/residence information coverage for US-origin applications (see Figure 4A.1).
19. The selection of technology fields was based on the total number of PCT applications filed in 2010.
20. The latest version of REGPAT provides detailed regional information on all EPO and PCT applicants and information on inventors for all OECD and EU countries, as well as a few other selected countries.
21. NUTS stands for the French acronym *"Nomenclature des unités territoriales statistiques"*.
22. See Hall and Ziedonis (2001) and WIPO (2011, special section).
23. See Hall et al. (2005).

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