conseil d'analyse économique

Focus

No 071-2021
November 2021

International Migration and Innovation: France in a Comparative Perspective

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Résumé en français

Immigration internationale et innovation : mise en perspective de la situation française

Plusieurs éléments permettent de penser qu'il existe un lien fort et positif entre l'immigration et l'innovation. Pour autant, les données concernant l'origine des inventeurs sont rares et les pays peu comparables entre eux. En se concentrant sur les immigrés très qualifiés, notamment dans le domaine des nouvelles technologies de l'information et des communications, et à l'aide de données originales, ce *Focus* parvient à établir des comparaisons entre pays. En utilisant les données bibliométriques issues des dépôts de brevet, notamment du Patent Cooperation Treaty (PCT), du European Patent Office (EPO) et du US Patents and Trademark Office (USPTO), les auteurs ont créé un algorithme permettant d'attribuer une origine probable (étranger ou natif) aux propriétaires du brevet.

Leur méthode permet d'observer l'évolution de la part d'inventeurs d'origine étrangère parmi les déposants de brevet dans six grands pays d'immigration et d'innovation. La France apparaît ainsi loin derrière les États-Unis, le Canada, les Pays-Bas ou la Grande-Bretagne, avec moins de 10 % de propriétaires de brevet d'origine étrangère entre 2011 et 2015. Comme l'Allemagne, elle est partie d'un niveau faible et n'est pas parvenue à augmenter fortement la part des inventeurs étrangers. Alors même qu'elle accueille un nombre important d'étudiants internationaux, ceux-ci ont tendance à moins rester dans le pays à la fin de leurs études, et les immigrés qu'elle attire s'engagent moins fréquemment dans des parcours propices à l'innovation, notamment dans le domaine des nouvelles technologies. L'étude montre également qu'en termes de qualité de l'innovation, la part des brevets avec au moins un inventeur étranger est plus importante dans la catégorie des brevets les plus cités, en particulier aux États-Unis, suggérant ainsi un apport supplémentaire des inventeurs étrangers par rapport aux natifs.

Si la causalité entre immigration et innovation est difficile à établir, les auteurs détaillent trois canaux principaux pouvant expliquer la façon dont l'immigration peut contribuer à l'innovation à l'échelle d'un pays. Le premier canal est celui du transfert de compétences, très bien décrits par de nombreuses études économiques et historiques : les mouvements migratoires de personnes très qualifiées et d'inventeurs permettent de diffuser les savoirs et les connaissances dans d'autres régions et participent ainsi à l'innovation du pays d'accueil. Deuxièmement, les inventeurs d'origine étrangère peuvent venir compléter l'offre de travail des natifs, qui peut être peu développée sur certains segments du marché du travail, en l'occurrence dans les secteurs requérant de très hauts niveaux d'études ou des compétences spécifiques, propres aux domaines de l'innovation : les inventeurs étrangers viennent ainsi dynamiser les secteurs innovants qui autrement manqueraient de personnel (domaines de l'informatique et des technologies de communication, ingénierie, recherche et développement…). Enfin, l'immigration peut être une source de diversité au sein des équipes et des entreprises, et cette diversité peut, dans certaines circonstances souvent réunies par les domaines concernés, être propice à développer des innovations, et de meilleure qualité, en particulier dans les entreprises multinationales.

Les effets décrits ici sont en partie dépendant des politiques publiques menées en faveur de l'immigration qualifiée, en particulier celles destinées à attirer les travailleurs très qualifiés dans les domaines de l'innovation, et à permettre aux étudiants étrangers de ces domaines d'intégrer rapidement le marché du travail national

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(*) GREThA UMR CNRS 5113, Université de Bordeaux. The authors acknowledge financial support from the French National Research Agency (TKC Project, reference: ANR-17-CE26-0016). We are grateful to Massimiliano Coda-Zabetta, Valentina Di Iasio and Gianluca Tarasconi for their collaboration with the data work.

1. Introduction

Investigating the links between international migration and innovation (in both the origin and destination countries) is nowadays a top item in many economists' research agenda, for at least three reasons.

First, both anecdotal and descriptive evidence for the United States (US) –the most important migration destination worldwide and a magnet for international students– indicates an over-representation of foreign-born among both hi-tech entrepreneurs and influential scientists and inventors, especially in top technological clusters such as the Silicon Valley or the Boston Area. This has spurred a number of studies trying to establish causality and quantify the contribution of immigration to innovation in the Unites States (Hanson *et al.,* 2018) and, by extension, in other OECD countries (Fink and Miguelez, 2017).

Second, a certain number of economic disciplines have explored the effect of migration on innovation, to the extent that it may cast light on long-standing research questions of more general relevance. Innovation economists, who are interested in the role of personal contacts in the diffusion of technical knowledge, have looked at historical displacement episodes affecting specific scientific elites and the associated knowledge transfer to the receiving countries (Cipolla, 1972; Hornung, 2014; Moser *et al.,* 2014). Economic geographers, instead, have examined the impact of migration-related cultural variety on the innovation and/or productivity rates of regions and cities (Kemeny and Cooke, 2018; Niebuhr, 2010; Ottaviano and Peri, 2006). Labour economists have focused on how migrant STEM (Science, Technology, Engineering and Mathematics), students and workers may augment the human capital endowment of the destination countries, with the possible side-effects of displacing their native peers (Borjas, 2004; Hunt, 2015; Hunt and Gauthier-Loiselle, 2010) or inducing them to specialize in different and complementary jobs and/or tasks (Peri and Sparber, 2009). As for innovation in the emigrants' home countries, development economists have questioned the traditional view of high skilled emigration as pure "brain drain" and hypothesized that it may favour access to the destination countries' knowledge, either through social networks, temporary or return migration, and foreign direct investments (Docquier and Rapoport, 2009; Kuznetsov, 2006).

Last, many governments of migrants' destination countries have put in place or experimented with selective immigration policies, often aimed at attracting STEM workers or retaining STEM students, and ranging from the creation of specific working permits to the introduction of a general point-based immigration system (Czaika, 2018). With a few exceptions, the innovation effects of such measures have not yet been tested nor simulated; but economists have increasingly motivated and interpreted their analyses by discussing them.

Reviewing this large body of literature, especially its implications for economic theory, goes beyond the scope of this piece. Instead, we will focus on two sets of questions:

1. Which economic mechanisms may suggest a positive migration-innovation link? What evidence does exist of the link to be causal and running in the preconized direction?
2. What impact may selective immigration policies have, compared to a more general relaxation of immigration restrictions and/or other systemic factors (such as the historical composition of immigration flows or the international reputation of educational institutions)?

We proceed as follows. First, we provide some information on recent trends concerning highly-skilled migrants, in particular STEM professionals and students. We devote a specific section to show the possibilities of bibliometric data to understand skilled migration patterns and trends. We examine, in turn, each one of the three questions and the related answers provided by economic studies. Last, we conclude by discussing the (limited) evidence on France and by proposing a research agenda.

2. High skilled and STEM migration: recent trends and levels

A cursory look at the most recent edition of the OECD International Migration Outlook (OECD, 2020) suggests that, despite two negative shocks in little more than 10 years (the Great Recession first, the Covid-19 pandemic now), international migration will not revert its growth trend any time soon. Foreign-born residents now account for over 10% of the OECD countries' population (15% for the European OECD members; around 10% for France).

Highly skilled (tertiary educated) individuals contribute decisively to this trend. First, access to tertiary education has increased worldwide. Second, in almost all countries, migration rates for the tertiary educated are higher than for the rest of the population and grows with the qualification level, especially for STEM graduates (d'Aiglepierre *et al.,* 2020; Kerr *et al.,* 2016). Last, far from taking place –as low skilled migration– mostly along a South-North or East-West axis, highly skilled migration occurs also between advanced economies (Franzoni *et al.,* 2012).

International university students contribute significantly to this dynamic, for two reasons. First, they acquire contacts and make experiences that increase their subsequent mobility (Parey and Waldinger, 2011). Second, when they complete their studies abroad, especially at the PhD level and/or in STEM disciplines, they may decide to stay (Finn and Pennington, 2018). In 2018, international students accounted for around 6% of the OECD tertiary-level student populations, a percentage that rises to 13% for master students and 22% of PhDs (for France, respectively: 9%, 12% and 38%). More than 60% of these students were concentrated in five countries: the US (25%), the United Kingdom (11%), Australia (11%), Germany (8%), and France (6%) (OECD, 2020) .

The higher the education level, the more STEM degrees are represented and the higher the concentration in just a few destination countries. UNESCO 2012 data for a sample of 44 among OECD and non-OECD EU countries, indicated that 53% in international PhD students were enrolled in STEM programmes, compared to 29% in other tertiary, non-doctoral programmes (the latter are dominated by students in social sciences, business and law, at 38%). The same data source indicates that, between 2005 and 2012, the number of international doctoral enrolments in STEM grew by 130%, compared to 120% in other disciplines. STEM international PhDs are also more concentrated than any other students, with the US hosting 49% of them (40% when considering all disciplines), followed at great length by the UK, with 9.2% (10.8% all disciplines), and France, with 7.4% (8.3% all disciplines) (Germany not in the sample; Baskaran, 2016).

3. Migration and innovation: evidence from bibliometric data

Overall, the above official statistics suggest that, in many destination countries, among which France, immigrants may play an important role in innovation. Putting this intuition to test, however, requires information on either the place of birth, nationality or country of primary/secondary education of R&D workers and/or managers of innovative firms. In principle, this can be obtained by accessing social security data or tax records, but not all countries provide access to them and, when they do, impose more or less stringent restrictions. When anonymized, as they most often are, these data can be put in relationship with equally anonymous firm–level information on R&D expenditures and/or productivity, as well as –occasionally– survey-based information on more specific innovative activities. When fully disclosed (with names and surnames), they can be matched to inventor or scientist data (see below), but often at the cost of severe restrictions (such as exclusive access to researchers affiliated to a national institution and no portability, which limits international comparisons). Career surveys of university graduates have proved useful too, but they are mostly national and do not provide much detail on the respondents' innovative activities.

These limitations have pushed innovation economists to find ways to exploit information on inventors' names and addresses, as reported on patent data, in several ways. First, by checking the inventors'

nationality, as reported on a particular class of patents (those filed according to the Patent Cooperation Treaty –PCT– procedure), and comparing it with the inventor's address country, thus identifying the foreign–national inventors as well as their country of origin (Miguelez and Fink, 2017). Second, by inferring the likely country of origin of inventors from their names and surnames, based on extensive data libraries assembled for either commercial or scholarly purposes (Breschi *et al.,* 2017; Coda-Zabetta *et al.,* 2021). Last, by matching inventor and social security data or tax record data, in countries where full access could be obtained (Bernstein *et al.,* 2018). We present evidence on the first two approaches below.

The PCT is an international treaty administered by the World Intellectual Property Organization (WIPO) that facilitates seeking of international IP protection (i.e., protection in more than one office) –at an extra cost. Using data from PCT for economic analysis reduces bias of using data from one single national office, where local applicants may be more likely to apply. Despite the advantages of using PCT data, they come also at the cost of (1) being only a selection of all patenting worldwide, (2) being limited on time, as nationality data is not available anymore from 2011 onwards, and (3) missing naturalized immigrants. Using name analysis overcomes some of these limitations, but, importantly, it misses out migrants who move between countries with the same dominant language, for example Canadian French–speaking inventors in France, as well as English–speaking ones in Great Britain, or Austrians in Germany, among others. In that respect, the name–based method tends to under–estimate the number of foreign inventors. It may instead over–estimate it when it comes to migration corridors with a long history, one that has left traces in the destination country's current distribution of surnames (such as Italian, German, or Scandinavian ones in the US). Here the risk is to count some native inventors with foreign ancestry or second-generation immigrants as foreign inventors. While checking for first names (in general more similar to native ones) often help to reduce this error, it cannot eliminate it. Overall, we suspect that name analysis over-estimate foreign inventors, but the entity of the error certainly varies across countries of origin and destination.

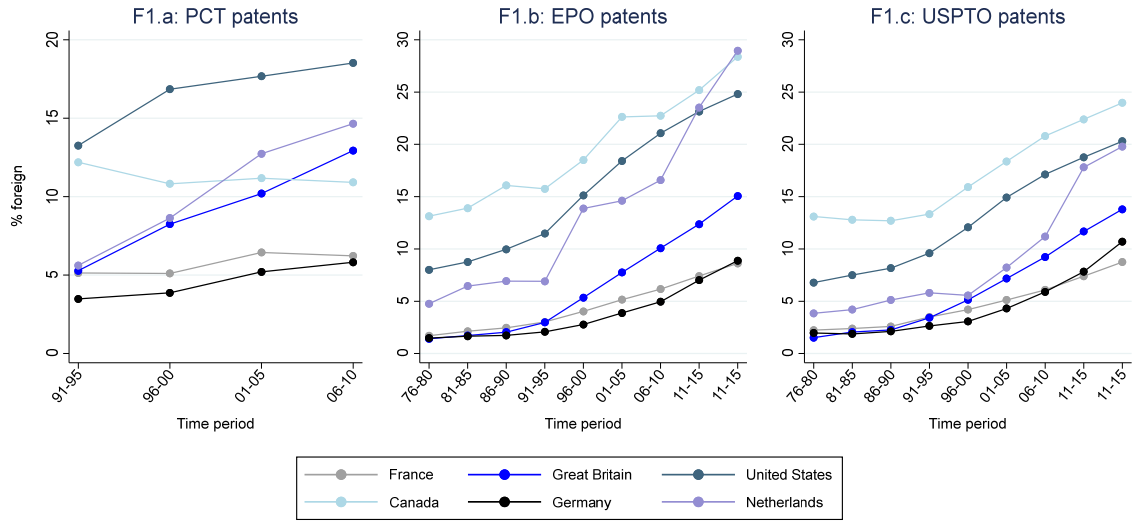
The same or similar data mining efforts directed at patents can be applied to scientific publications, in the attempt to identify the authors' likely country of origin. One data source that has attracted some attention is the ORCID database (Bohannon, 2017; Orazbayev, 2017). ORCID stands for "Open Researcher and Contributor ID" and it consists of a non-proprietary alphanumeric code to uniquely identify scientific and other academic authors and contributors, first introduced in 2009 as a collaborative effort by scientific publishers and research funding agencies. Registration by authors is voluntary, but often encouraged by the funding agencies, and large bibliographic archives such as Scopus and Web of Science include ORCID among their authors' identifiers. The 2019 version of the ORCID raw data contained profiles for 6.54 million scholars, albeit with unequal coverage across countries and some bias towards young scientists.

Figure 1.a displays the share of patent-inventor pairs from PCT patent applications where the inventor has foreign nationality. Figure 1.b does the same, but using data from the European Patent Office (EPO). This is one of the largest patent offices, though it is especially relevant for European countries. As PCT is unique in recording nationality data, Figure 1.b shares are computed by name analysis, as explained above. Finally, figure 1.c displays data using patents from the US Patents and Trademark Office (USPTO), historically the largest –only recently overcame by the Chinese office– and most attractive patent office worldwide. The use of USPTO data allows us to provide statistics by inventor, instead of patent-inventor pairs (so irrespective of the patents they produce), due to the fact that USPTO inventors' names are disambiguated –that is, it is possible to know who is who among the inventors listed in more than one patent (see disambiguated dataset at: PatentsView.org). The selection of countries displayed is arbitrary, but respond to a combination of having both a high patent volume (according to WIPO's Global Innovation Index, WIPO, 2021), and a high share of foreign-born, tertiary educated population (according to DIOC database, OECD). These include the US, Great Britain, Germany, France, Canada, and the Netherlands, but neither Japan, South Korea or China, whose immigrant population is rather small in percentage terms, nor Switzerland, whose migrant population comes mainly from same-language countries and therefore makes difficult the identification of foreigners via name analysis.

From Figure 1 we learn the following: countries such as Canada or the US are critical magnets of foreign talent, and this has been increasing substantially over the years. European countries such as the

Netherlands or the UK follow at a certain distance. Other small, highly innovative European countries, not reported here, show large shares of inventor immigration –such as Belgium, Luxemburg, Ireland or Switzerland, mainly fed by intra-European mobility. Canada's stable trend on PCT data, differently from EPO or USPTO, clearly witness the problem of naturalization mentioned above. Large and highly innovative European countries, such as France and Germany, lag behind; though have experienced reasonable improvements since 2005, too.

Figure 1. Share of foreign-origin inventors, PCT, EPO, and USPTO, various years



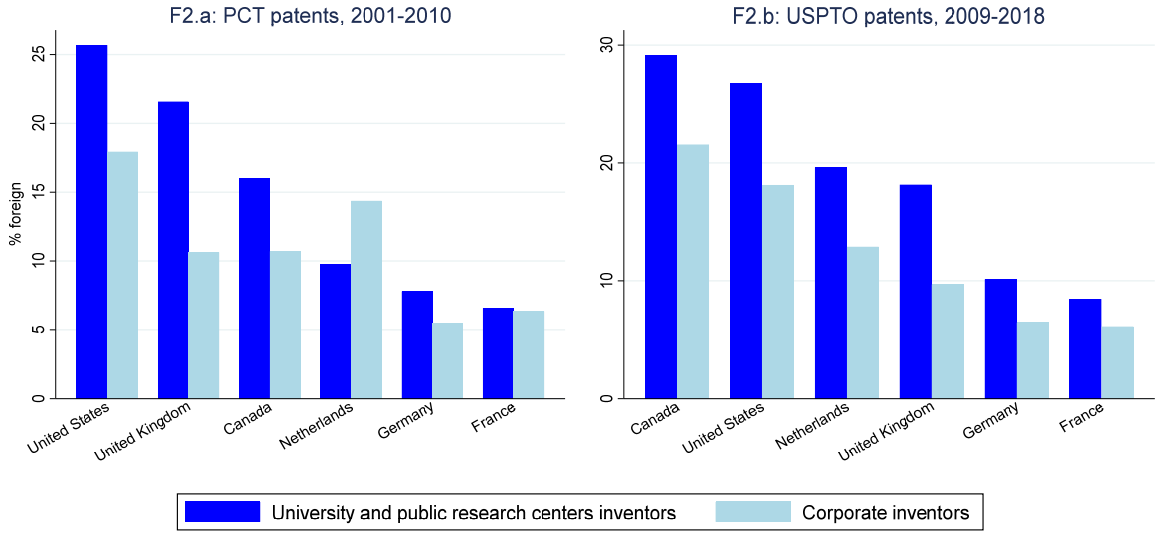
Source: Authors.

As discussed above, another critical aspect is the role played by universities and research centres in attracting talent, and even acting as entrance door for high-skilled migrants. As can be seen in Figure 2, in almost all countries analysed (both sources of data, PCT and USPTO, and both periods) the share of migrants among university inventors is significantly higher than among corporate ones, mindful that the business sector account for the vast majority of patents. In some cases, like the UK and the US, the differences between the two types of employers are particularly high. This is in line with the role played by universities in attracting foreigners discussed above, either as students and graduates, who may stay in the academia afterwards, or directly as academics, as shown in recent large-scale survey evidence (Franzoni *et al.,* 2012). For France, the difference in favour of university patents is also noticeable, especially in recent years. Yet, its shares in both cases are relatively low. This is in stark contrast with the share of foreigners among scientists with an ORCID profile, which we examine in Figure 3. In there, France is among the largest attractors of foreign talent, together with the traditional leading group formed by Canada, UK and US. The figure looks at ORCID profiles declaring to have a PhD, and locates them in space according to the country where they did the PhD and then the country where they work afterwards –different employment spells are possible.(1) Unfortunately, many profiles provide information on the PhD, but not employment spells after it, so we may lose many of them if they find a job in another country afterwards. This is clearly the case of France, which certainly attract many graduate students, especially from former colonies, who do not necessarily are retained in the country after finalizing their PhD –or even in the academia. This could explain the big difference with the share of foreigners among academic inventors. Note also that ORCID data include all scientific fields. Further research looking at STEM fields only would possibly reveal a lower share of foreigners in certain countries, such as France, in line with analogous survey data (Franzoni *et al.,* 2012).(2)

(1) As ORCID provides information on the starting year of the PhD, we identify profiles in time after 3 years of the starting date of the PhD, but not before.

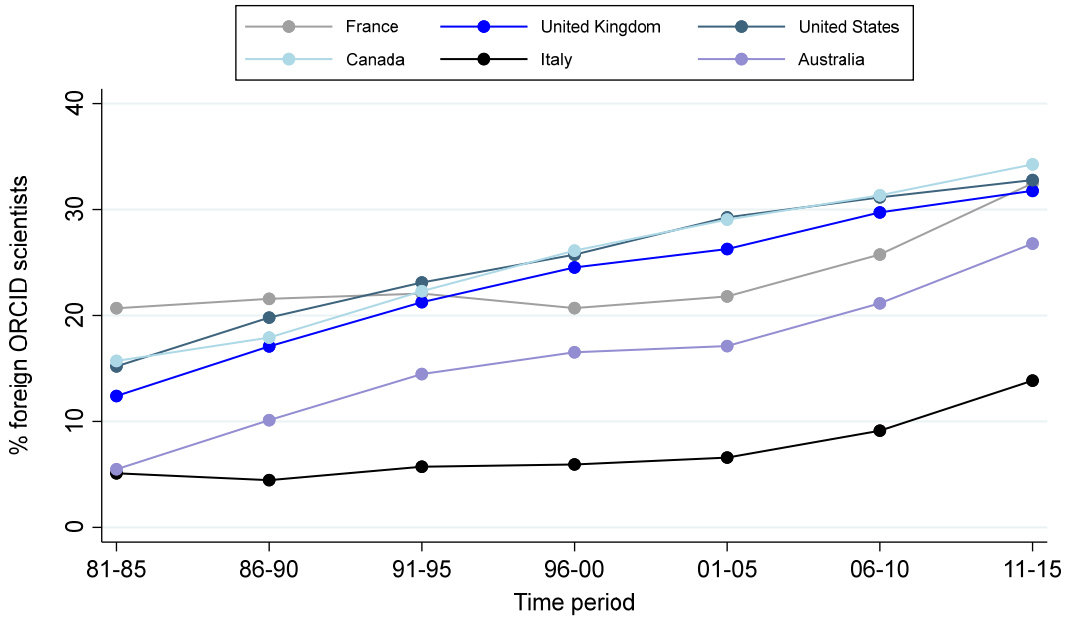
(2) Note also that certain countries are severely underrepresented in ORCID. This is the case, for instance, of Germany and the Netherlands. If migrants had a larger tendency to register in ORCID in these countries, which is not unlikely, their share of foreign scientists would be importantly biased upward. Germany and the Netherlands are replaced in Figure 3 by Italy and Australia.

Figure 2. Share of foreign-origin inventors, academia vs corporate, PCT and USPTO, various years



Source: Authors.

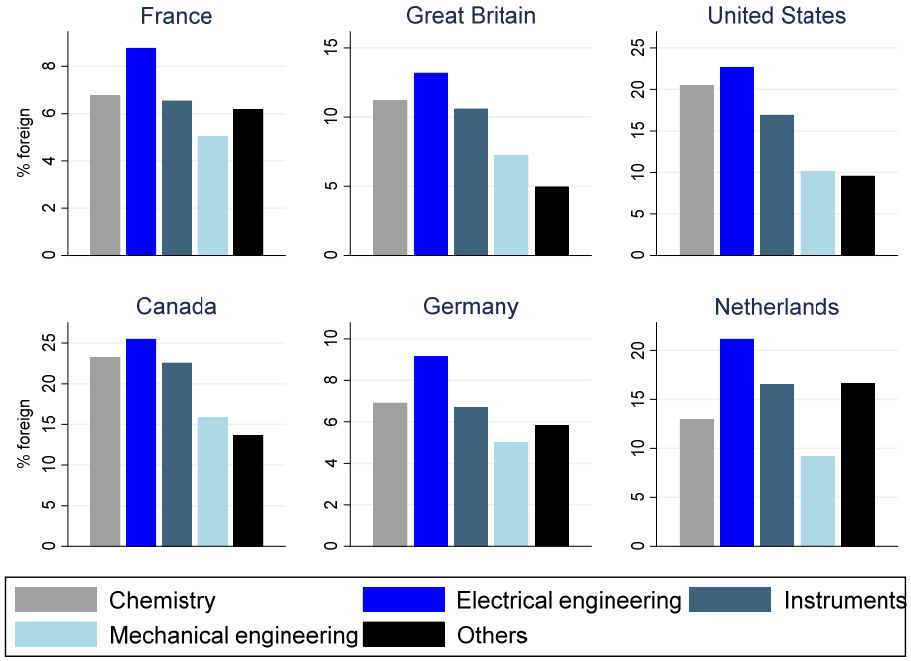
Figure 3. Share of foreign-origin PhDs among ORCID profiles, various years



Source: Authors.

Figure 4 shows that differences across technologies on how they rely on foreign-origin inventors are remarkable –data for USPTO patents only used, with PCT and EPO showing similar results. In all countries shown, electrical engineering shows the largest immigration rates. This includes, among others, telecommunications, computer technologies, or IT methods. Chemistry usually follows –e.g., biotechnology, pharmaceuticals, nano-technology, etc. On the other side of the spectrum, mechanical engineering fields show a smaller presence of foreign talent.

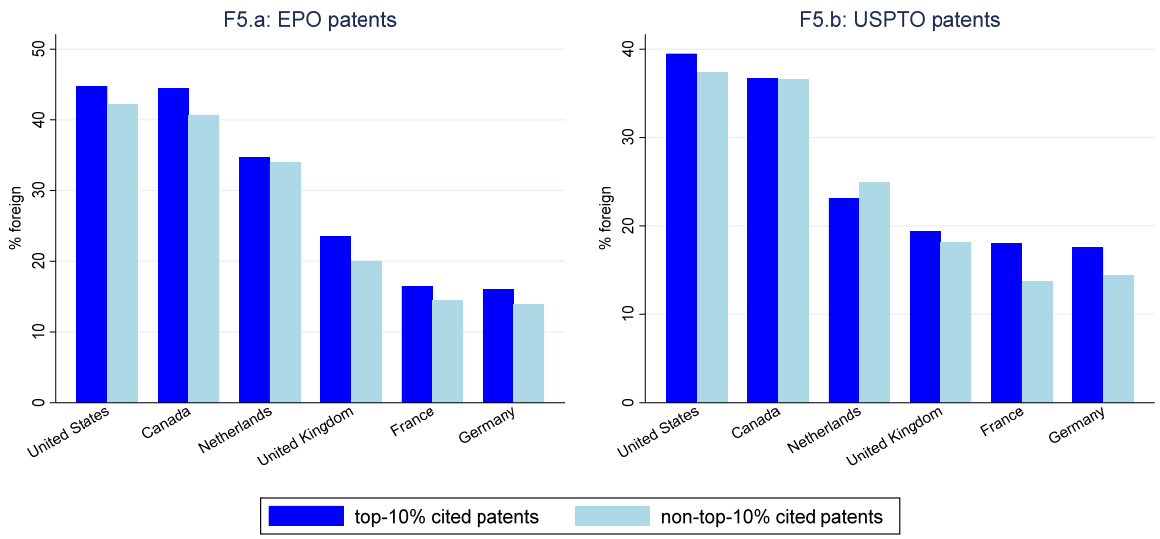
Figure 4. Share of foreign-origin inventors by tech field, from USPTO patents, 2009-2018



Source: Authors.

The question remains, however, on whether migrants' contribution goes beyond their numbers, or if they are capable to bring something different from natives to their host countries. This is difficult to assess by simply counting the number of foreign-origin inventors among residents, because migrants are self-selected at origin in terms of skills. Further, they tend to specialize in technical fields, more prone to patenting. One possible way to disentangle their real contribution is to investigate the quality of the innovations produced, vis-à-vis those produced by locals –at the exact same time and the exact same technology. Following the related literature, we exploit the forward citations received by patents as an indicator of quality. This is done in Figure 5, which exploits forward citations collected for EPO and USPTO patents in Squicciarini *et al.* (2013). In particular, we look at the top-10% cited patents per technology and cited patent year versus the rest of the patents, and compute the share of them having at least one foreign-origin inventor. Figure 5 shows that, in almost all countries analysed, migrants are more prevalent among highly cited patents, both in the US, as shown in previous studies (Bernstein *et al.,* 2018), but also in other countries. Admittedly, the differences are not extraordinary large, which in part could be attributed to the use of patents from the EPO and the USPTO, which are already internationally target markets attracting the technologies with higher potential –which we would possibly not find if the analysed was limited to national offices. Of course, this also relates to the literature indicating that the contribution of high-skilled migrants, particularly patentees, is important, but limited (Hunt, 2015; Kerr and Lincoln, 2010).

Figure 5. Share of foreign-origin inventors by patent quality (top-10% cited patents vs the rest), 2009-2018



Source: Authors.

4. The migration-innovation link: mechanisms and causality

Scholars from different fields of economics have investigated different potential mechanisms through which migration could affect innovation, as follows:

1. Knowledge transfer (diffusion) ;
2. Supply of in-shortage skills ;
3. Diversity.

To the best of our knowledge, none has undertaken a comparative study on their relative importance. Most papers focus on destination countries and, unless otherwise specified, we do the same.

Knowledge transfer is the mechanism that has received most attention. This is explained by the central role assigned by economic historians to the migration of technicians and entrepreneurs in the diffusion of innovation in Modern Europe (Cipolla, 1972; Hilaire-Pérez, 2008; Scoville, 1951). More recently, innovation economists have come back on specific shocks concerning ethnic minorities or social groups holding valuable knowledge assets, whose forced or otherwise unexpected migration can be regarded as a natural experiment (one in which no or little knowledge transfer had taken place between the migrants' origin and destination countries before the shock, nor it was the main reason why migrants decided to move). Examples include the displacement of Huguenots from France to Prussia in the XVII century, that of Jewish chemical scientists from Nazi Germany to the United States in the 1930s, and the flight of scientists from post-Soviet Russia to the United States and Germany in the early 1990s (Borjas and Doran, 2012; Ferrucci, 2020; Ganguli, 2015; Hornung, 2014; Moser *et al.,* 2014). The identification strategy of these exercises is such that they clearly indicate a causal link running from migration to innovation, but their immediate policy relevance is limited. Present-day migration flows, even when involving tertiary educated individuals, mostly concern graduate students or young professionals and post-docs, not established scientists and entrepreneurs. So, it is advisable to interpret this evidence not as an evaluation of current immigration policies, but just as a proof of concept. As such, it strengthens the case for physical mobility as a necessary condition for diffusion and it also lends credibility to the possibility that, by attracting highly talented, senior scientists and technologists with targeted visa or fiscal policies, a government may reinforce a more general knowledge transfer policy.

Some more general evidence of the migration-diffusion link comes from studies based on patent data. In most cases, diffusion is measured with prior art citations running from patents by inventors residing in the latter to patents by inventors residing in the destination ones, with a special focus on those filed by migrant inventors themselves. Miguelez and Temgoua (2020) show that pairwise cross-country patent citations increase with the cross-country flows of migrant inventors (an indication of knowledge transfer that Bahar *et al.,* 2020, confirm by looking at patent-based indicators of country specialization, which change per effect of inventors' immigration). Based on the same type of indicators, several studies show that migrant inventors are a source of "knowledge remittances"' to their home countries (Agrawal *et al.,* 2011; Breschi *et al.,* 2017; Kerr, 2008).

Skill shortage is a classic rationale of immigration policies, ranging from those addressed at seasonal workers in agriculture and tourism to the historical guest-worker programmes of Germany and other Western European countries in the 1950s and 60s. When it comes to innovation-related skills, their shortage may result not only in higher wages for R&D and other knowledge workers, but also in less innovation by both the potential employers and the economic system as a whole, due to the externalities this category of workers may generate.

Labour economists have paid special attention to this issue, especially in the US and in relation to one specific visa type, the H-1B one, that allows US employers from both the business and the public/academic sector to recruit tertiary-educated foreign temporarily (3 to 6 years), in specialty occupations. Their intensive use by Indian computer programmers, often employed by U.S. branches of Indian firms, has spurred controversy over its real impact on innovation (Bound *et al.,* 2015). At the same time, since 1990, the number of visas made available to employers in the business sector has been subject to a cap (with frequent variations of the cap itself), combined with a lottery to assign visas when demand surpasses supply. This gives the distribution of H-1B visas an experimental nature, which is a boon for empirical tests trying to establish a causation direction between migration and innovation (although this come at the price of an excessive focus on specific visa type).

Kerr and Lincoln (2010) find that the more H-1B visas are granted, the more Indian and Chinese inventors are found to be active in the US. Path-dependency in migration is such that the cities most exposed to Indian and Chinese immigration benefit more than others of this exogenous supply shock of STEM workers (their response to time variations in the supply of H-1B visa caps –as measured by the number of patent filings– is stronger). No adverse effects on native inventors are found but, at the same time, no evidence of knowledge transfer. Peri *et al.* (2015) find similar evidence for innovation measured with increases in the total factor productivity.

Other studies have produced similar evidence at the firm level, by comparing the impact of H-1B restrictions on firms with different propensity to recruit foreign workers and/or to use this type of entry permit (Dimmock *et al.,* 2019; Mayda *et al.,* 2020). The only exception is provided by Doran *et al.* (2014), which find null results for the innovation impact and some negative ones for natives' employment.

It is important to stress that immigrants may not only bring their skills along with them from abroad, but also acquire them at destination. On-the-job skill acquisition in co-ethnic firms has always played a key role in migration history, one that in the XVII century turned Huguenots farmers from France into English jewellers and silk waivers (Luu, 2005), and nowadays explains the entrepreneurial specialization of many foreign-origin groups worldwide (Kerr and Mandorff, 2015). When it comes to R& –and innovation– relevant skills, however, it is the host country's higher education system that plays a dominant role. In this respect, Hunt (2015) shows that over-representation of immigrants among US-based inventors is largely due by the higher propensity of international students in US universities to enrol in STEM programmes, combined with the large intake of such students we discussed above. In this respect, Canada provides an interesting contrast. Based on its point-based system, it admits many tertiary-educated immigrants, a large share of which with STEM degrees, who neither have a contract with a local employer (they look for it upon arrival) nor a local education. But this large intake does not show in patent statistics, in which foreign-origin inventors are under-, rather than over-represented (Blit *et al.,* 2020). One possible interpretation of this

evidence is that the formal qualifications acquired in the migrants' home countries do not correspond to the skill types or levels needed by innovation-oriented employers.

One final issue concerning the skill-based impact of immigration on innovation relates to the substitutability of native with foreign workers and students or, instead, their complementarity. In an innovation context, substitutability means that foreign STEM workers may be recruited, at least in part, not to remedy to any stringent skill shortage, but to replace native workers with similar qualifications, but higher reservation wages. With reference to H-1B visas, some descriptive evidence suggests that they may be routinely used to replace mature US computer programmers, with relatively high wages and obsolete coding skills, with freshly minted Indian graduates. More generally, concern that substitutability may lead to displacement of native workers is ingrained in all employer-based visas, which –like the H-1B– require employers to declare or prove to have tried and failed to recruit a native, and to offer higher-than-local-average wages to the foreign nationals they wish to employ. Causal evidence of displacement, however, is very limited.(3) The same is true for concerns over a potential student displacement, by which native candidates to admission in local STEM programmes could suffer the competition of international applicants, possibly due to the latter's willingness to pay higher fees.

At the opposite end of the substitutability and displacement concerns stand the possibility of a virtuous dynamic, based on migrant-native complementarity and specialization. A well-known stylized fact in the economics of immigration is that low-skilled migrants are complementary to highly skilled natives, which result in higher productivity (and wages) for the latter; and that –faced to low-skill immigration– natives have both the choice and the opportunity to move to more qualified jobs or tasks, in which they have relative advantage (based on mastering the language and local culture, and access to social capital and education) (Peri and Sparber, 2009). This line of reasoning can be extended to innovation: the inflow of international STEM students and workers push many natives to specialize in non-STEM fields and jobs, such as those related to law, social sciences, and management, in which they have a comparative advantage relative to STEM ones. The different specialization choices of migrants and natives increase their complementarity, and reduce displacement (Mayda *et al.,* 2020; Peri and Sparber, 2009).

Diversity is the other mechanism relating migration to innovation. Innovation is a collective activity that emerges from, among other things, the recombination of different knowledge items previously unrelated or combined together according to obsolete patterns. Diversity matters to the extent that the STEM workers and other knowledge workers whose cultural background is different are in a better position to exchange views and non-redundant information, with the ultimate results of increasing the scope and originality of the recombination. Several types of studies have explored this possibility: country-level studies, which originate in the political economy literature of the effects of population diversity on institutional stability and, ultimately, economic prosperity; regional and urban studies, which focus on cultural variety and innovation in regions and cities as well as firms therein; and management-oriented works on diversity in teams and the trade-off between coordination issues and variety-augmented creativity. The findings of the literature on diversity and innovation are too many and heterogeneous to be resumed here. Overall, they seem to point at a positive association, though causality is not always clearly determined (Kemeny and Cooke, 2018; Niebuhr, 2010; Ozgen *et al.,* 2013, 2012). Moreover, the relevant locus of the interaction between the diverse individuals (migrants and natives, interactions among diverse-origin migrants, urban areas vs workplaces vs R&D teams, etc.) it is not fully understood (Ferrucci and Lissoni, 2019; Nathan and Lee, 2013; Parrotta *et al.,* 2014).

It is important to stress that migration is not the only source of diversity, and that economists, traditionally, have been more interested to its negative, rather than positive effects. For example, what US scholar call

(3) The best-known study on displacement is a proof-of-concept paper dedicated by Borjas and Doran (2012) to the inflow of Russian mathematicians in U.S. universities after the collapse of the Soviet Union. The authors show that, faced to this inflow, US doctoral graduates in fields where Russian scientific leadership was well established, met more difficulties than their peers in other fields both to publish their results and to get an academic job. None, however, is said on whether these PhD graduates remained unemployed (which is unlikely) or simply moved out of academia into other sectors, or requalified.

"racial" diversity in their states and cities originate from a combination of past forced immigration (slavery), recent and less recent migratory movements, and continuous segregation; and its expected outcome is more often described in terms of polarization of opinions and mistrust, rather than cultural variety (Sparber, 2009). Similarly, a long tradition of managerial studies on multinational companies emphasizes the coordination problems affecting teams composed of individuals from different countries and with different attitudes towards authority, cooperation, uncertainty and work ethics (Hofstede and Usunier, 2003; Kirkman *et al.,* 2006). Last, some technical issues have to be carefully considered when it comes to tell apart the possible diversity effect of migration on innovation from the diffusion and skill supply effects we discussed above, as well as the positive versus negative consequences of diversity itself. In the first case, what is required is always testing at the same time for the effects of the overall share of migrants in the population (or workforce or team) as well as for that of diversity this may, also in view of the migrants' country of-origin mix or lack thereof. In the second case, one must distinguish between diversity-induced variety from separation and disparity, which may come with it but generate negative effects. Separation and disparity are both conceptually different from variety and measured by different indexes.(4)

5. Which policies do matter the most?

Immigration policies worldwide place increasing emphasis on the distinction between high- and low-skilled migrants, witness the multiplication of measures aimed at attracting the former and, in contrast, a general orientation towards limiting the latter (Czaika, 2018). STEM migrants and high-tech entrepreneurs rank high among the categories targeted by such policies, but little evidence is available on their effectiveness. Three reasons explain the difficulty of both designing and evaluating such targeted immigration policies.

First, as discussed by Belot and Hatton (2012), the high- versus low-skill composition of immigration depends to a large extent from the country-of-origin composition of the immigration flows, which in turn are determined by strong, path-dependent factors such as language and physical proximity as well as chain-migration. Even the introduction of a point-based system for immigration (a much heralded measure of the post-Brexit British government and one often advocated by opinion-makers in other European countries) is not expected to produce dramatic effects. *A fortiori*, this applies to the plethora of special entry and residence permits introduced –and frequently reformed– by many European countries and the European Union itself (Cerna and Czaika, 2016; de Lange, 2018).

Second, when it comes to STEM immigration –and its impact on innovation– two actors stand out, the higher education institutions and the local and foreign multinationals, whose international recruitment strategies depend on the prevailing migration policies, but also contribute to shape them (or bend their application to their needs) (Choudhury, 2020; Kerr, 2018).

Multinational companies are at the same time the source and locus of most R&D activities worldwide and a very relevant, albeit under-studied source of international movements of STEM workers (Kerr *et al.,* 2015). They engage in R&D on a global scale, by looking for collaborations with local public and private actors and/or opening up research facilities in order to source local knowledge and skills (and not just, like in the past, to support their foreign branches' production activities) (Awate *et al.,* 2015; Florida, 1997). The

(4) Variety is a categorical concept, best measured by the so-called "fractionalization index", whose baseline version is nothing else than the reciprocal of the Hirschman-Herfindhal concentration index. The index takes its maximum value when a city's or country's residents (or a firm's workers) come from many countries of origin and are uniformly distributed across them. Separation is a relational concept and it measures the diversity of goals and beliefs. As discussed by Esteban and Ray (1994), separation indexes reach their maximum value with a bipolar distribution (for example, natives versus one and only one large ethnic minority or a coalition of several minorities sharing the same goals and beliefs). Disparity is an ordinal concept and it refers to the distribution of some resources, ranging from income to social status, to different groups in a population. One classic indicator, when it comes to monetary values, is the Gini index. To the extent that both separation and disparity may, respectively, disrupt cooperation and engender resentment, their outcome on innovation is expected to be negative.

transfer of such knowledge and skills occurs largely through international, intra-firm mobility. Once again, however, the literature has produced evidence mostly (if not exclusively) for the Unites States (Branstetter *et al.,* 2018; Chung and Yeaple, 2008; Glennon, 2020; Morales, 2020; Yeaple, 2018). US multinationals as well as foreign multinationals in the US are the top applicants for employer-based H1-B permit (see above) as well as L-1 ones (which are reserved for intra-firm, temporary staff transfers). The more R&D intensive they are, the more applications they file, other things being equal. Compared to companies with no facilities abroad, they suffer less of asymmetric information problems when it comes to recruiting foreign STEM workers, witness the fact that the country composition of their foreign STEM workforce follows closely that of their foreign direct investments (Foley and Kerr, 2013; Useche *et al.,* 2020). Some causal evidence also exists, based on the random variations in H-1B visa allocations we discussed above, that multinationals operating in US react to STEM immigration restrictions by outsourcing more of their R&D, and vice versa (Glennon, 2020).

As for higher education institutions, as discussed in section 2, they are major attractors of foreign students that, especially when getting a master or doctoral degree, have a high or very high propensity to stay in the destination country. Koslowski (2018) suggests that commentators that compare unfavourably the US immigration system to the Canadian one (the former being overall dependent on family visas, the latter on point-based work permits), generally ignore the importance of US universities. Bound *et al.* (2021, 2015) and Roach and Skrentny (2021) show that a very large share of foreign doctoral graduates, once their student visa expire, chase actively for H-1B-based contracts. Thanks to them, they can prolong their stay in the country, in view of obtaining a permanent residence permit (green card) of the EB type (for individuals for “extraordinary” or “exceptional” ability). In this way, they end up competing for a type of visa that was originally conceived for graduates from other countries, with inferior qualification levels. This may explain the paradox by which, as discussed in the previous section, the supply of H-1B has such a strong impact on innovation in the U.S., despite being mostly addressed (at least in principle) to master level professionals, mostly in computing.

While these studies do not have immediate implications for France or other important student destination countries, they bear witness to the importance of investigating the complex ways in which the STEM foreign students manage the transition to the labour market. In particular, we need to investigate whether the prevailing immigration laws in each country stand in the way or favour both the transition to the labour market both in general and, specifically, to the most innovation-oriented activities.

6. Questions for France

Is the migration-innovation link worth investigating in France? We think it is, for two reasons. First, France is an important destination for international students, especially graduates ones: How important is higher education as an immigration channel, especially for STEM workers? How much do these foreign students contribute to local innovation as well to innovation in their origin countries?

Second, multinational companies play a key role in the French economy and national innovation system (Cantwell and Iammarino, 2005; Emlinger *et al.,* 2019; Vicard, 2020). But some evidence suggests that French multinationals’ foreign R&D activities are relatively underdeveloped (Bertrand, 2009; Harfi and Mathieu, 2008): Do they also contribute less than others to the immigration of highly-skilled workers? If yes: Does this indicate that they suffer less of a skill shortage than their foreign counterparts? Or do they possibly suffer, instead, of lack of diversity in their STEM workforce and management teams?

Answering such policy-relevant research questions may require to bring data production for France in line with the current trends based on mining large archival resources on individual students and/or firm employees and link them up to patent and scientific publication data.

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