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Migration and invention in the age of mass migration

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Abstract

More than 30 million people migrated to the US between the 1850s and 1920s. In the order of thousands became inventors and patentees. Drawing on an original dataset of immigrant inventors to the US, we assess the city-level impact of immigrants patenting and their potential crowding out effects on US native inventors. Our study contributes to the different strands of literature in economics, innovation studies and economic geography on the role of immigrants as carriers of knowledge. Our results show that immigrants' patenting is positively associated with total patenting. We find also that immigrant inventors crowd-in US inventors. The growth in US inventors' productivity can be explained also in terms of knowledge spill-overs generate by immigrants. Our findings are robust to several checks and to the implementation of an instrumental variable strategy.

Keywords: immigration, innovation, knowledge spill-over, patent, age of mass migration, US.

JEL codes: F22, J61, O31, R3

1. Introduction

Between 1850 and the mid-1920s more than thirty million people migrated to the US in search for a better life. In today's USA, more than one hundred million people descend from those waves of immigrants (Bandiera et al. 2013). The causes and economic impact of mass migration in the US economy have already received a good deal of attention in the literature (Hatton and Williamson, 1998). More recently, also due to the backlash against immigrants in the US, this topic has regained popularity among scholars, who initiated a new research line on the economic impact of historical migration in the US (Abramitzky et al., 2014; Hatton and Ward, 2018; Rodríguez-Pose and von Berlepsch 2014; Sequeira, et al. 2017; Tabellini, 2018). However, as noted by Abramitzky and Boustan (2017), very few of these works have focused on the link between migration and innovation (Akcigit et al. 2017a; Moser et al. 2014).

More in general, despite the huge policy and economic relevance of the phenomenon, relatively few studies have explored this nexus also for present-day immigration, as pointed out by recent literature reviews on the topic (Kerr, 2013; Breschi et al. 2015; Lissoni, 2018). This link is an important one though, as many of today's and past most innovative US companies as well as scientific and technological discoveries can be traced back to foreign born entrepreneurs and scientists (Wadhwa et al. 2007; Stephan, 2001; Hughes, 2004).

For the US case, figures clearly show that patenting as well as scientific publishing of immigrants workers has been growing steadily overtime (Hunt, 2011; Kerr, 2007; Kerr and Lincoln, 2010). The evidence is mixed instead when it comes to measuring the net impact of immigration (Kerr, 2013). For example, some studies analyzing labour market outcomes tend to highlight the potential crowding-out effect of immigration (Borjas and Doran, 2012). Others instead show that immigration has no effect (Kerr and Lincoln, 2010), or positive effects on incumbents (Hunt and Gauthier-Loiselle, 2010). A related stream of work has investigated the spillovers effect of immigration on natives by looking at specific historical events. For example, Moser at al. (2014) found that German-Jewish scientists escaping Nazi-Germany in 1930s brought new ideas to the US scientific community that eventually contributed to emergence of new subfields in chemistry, to which also US scientists contributed to. Ganguli (2015) showed that Russian scientists who migrated to the US after the collapse of USSR in 1991 were cited by US scientists much more than those who did not migrated, suggesting that migration favoured knowledge spillovers. Overall, it seems that more empirical evidence is needed.

We contribute to this stream of literature by looking at a crucial event in American history, the age of mass migration, which started in the mid-nineteen century and ended in the mid-nineteen twenties. We exploit variation in patenting across US cities and technological classes to investigate the city-level impact of immigrants' patenting. To do so, we draw on an original dataset of immigrant inventors with detailed information on the location of inventors, patents' technological classes, and country of origin during the period 1870-1924[1]. With this information we are able to test both the direct contribution of immigrant inventors to the creation of new knowledge in the US, as well as their indirect contribution via knowledge spillovers. While previous studies have been limited in scope, as they investigate either specific group of immigrants (e.g. Germans, Russian) or one scientific fields

[1] There is no an exact periodisation of the age of mass migration, which usually starts in either 1850 or 1870 and it ends in 1914, with the outburst of WWI. We focus on a slightly different period (1870-1925) as we analyse inventive activity in the US with patent document. For the US the 1924 is when immigration quotas were raised and mass immigration came to an end; 1870 is also when a sufficient number of patent are available.

(e.g. chemistry), our analysis is more comprehensive, as it covers all immigrant groups and technological fields in which immigrant patented after entering the US.

From a theoretical point of view, our study draws primarily upon the geography of innovation literature. A vast bulk of studies has shown that tacit knowledge, being embodied in individuals, requires physical and social proximity for its transfer (Boschma, 2005; Breschi and Lissoni, 2001). Mobile inventors and scientists, including migrants, can be then regarded as important carriers of tacit knowledge (Breschi and Lissoni, 2009; Ganguli, 2015). Cities that are attracting these highly skilled people will show higher rate of innovativeness and long-term resilience, as they will be able to access non-redundant and novel knowledge (Boschma, 2015). We can argue that high skilled immigrants affect the innovation performance of cities in the receiving country through two main channels: on the one side their contribution is direct, as they generate new technological knowledge, e.g. in the form of patents; on the other side they facilitate the circulation of knowledge they brought with them from their home country, so they generate international knowledge spillovers. In this work, we are empirically testing the economic relevance of the knowledge generation and diffusion channels.

The paper is structured as follows. In section 1, we present some contextual background information about the age of mass migration. We focus on how immigrants related to invention and patenting in the US. Section 2 presents a concise review of the main findings of the literature for the US case. Section 3 sketches our conceptual framework, which is the basis for the empirical analysis. In section 4 the dataset is presented with a brief description of the data. Section 4 is dedicated to present our empirical strategy, while section 5 shows the main results. Section 6 concludes with some discussion of the contribution of our work and its possible extensions.

2. The Age of Mass Migration in the US: immigration, invention and patenting

More than 30 million people migrated to the US from all around the world between the 1830s and 1920s (Hutton and Williamson, 1998). A large majority consisted of Europeans from different geographical origins who entered US in large consecutives waves. The first wave gathered up strength through the 1830s and 1840s, bringing mainly northern Europeans from Ireland, Germany and England and picked in 1850. In this year ten percent of the US population was foreign born. A second wave reached its peak in 1880, and was made up mainly of Germans and Scandinavians. At this time about 90% of foreign born immigrants came from Northern and Western Europe, while Southern and Eastern Europeans represented less than 5%. After the 1880s the trend was reversed, a large wave of Italians and Eastern Europeans moved to the US, they reached a share as big as 40% of foreign born by the turn of the century (Abramitzy and Boustan 2017). Overall, in 1870 the share of the foreign born population rose up to 14% and remained stable around this level until 1920. The arrival of immigrants came to an abrupt halt in 1914 because of the outbreak of world war. However, as soon as the war was over, immigration flows increased again. In the next decade of 1920s, finally the Age of Mass Migration came to an end when in 1924 the US Congress passed a law that introduced country-specific quotas[2].

[2] The reform of the immigration policy was widely and publicly debated in the US for long time before the 1924 reform. In 1907 the US Congress established a commission to investigate the socio-economic impact of immigrants. The Immigration Commission recommended the introduction of restrictions. In 1917 the Congress approved the introduction of a literacy test for all immigrants. However, this did not limit significantly the arrival of immigrants. Additional restrictions were imposed in 1921 (Goldin, 1994). The quota system was meant to reduce the inflow of migrants primarily from Southern European countries, for example the flow of immigrants from Italy halved, moving from above 1 million in the 1910-19 decade, to a 528,000 in the 1920-

Along with the millions of immigrants entering the US during these six decades, in the order of thousands were or became inventors and patentees. Between 1870 and 1925, immigrants were (as they are today) disproportionally represented among inventors. According to Khan (2005: 214) foreign-born inventors accounted for 21% of all patentees and represented an even higher share of the great inventors (i.e. 23%), which are those individuals who made relevant technological discoveries. Recent estimates by Akcigit et al. (2017a) suggest similar figures. Although they may appear at first surprising, especially if contrasted with the typical immigrant profile of that time, these numbers are much less so if one considers how the inventive activity was organised in the late nineteen century, in particular in the US context.

Inventive activity before the early twentieth century was primarily an individual endeavour, which required relatively little capital (Hughes, 2004). Inventions were obtained by people active in a specific trade, so trial and error as well fortunate accidents were not unusual ways to come up with smart solutions that fixed specific technical problems (Sokoloff and Khan, 1990; Hughes, 2004). Formal training was not a necessary condition to carry out inventive activity. Even among the most prolific inventors many had little formal education, including Edison or the Wright Brothers. Overall, about forty percent of foreign-born inventors and about 25% of natives did not have formal education (Khan, 2005).

Another important aspect to take into account is that the US patent system, differently from the British or French ones, had very low entry barriers. Registering a patent in the US was affordable and relatively cheap compared to Britain: about 3-4 US dollars in the former against 500 in the latter. Moreover, technological invention was given a central stage in the US social and economic life, to the extent that patenting was mentioned in the US Constitution and accordingly promoted and enforced. An additional feature of the US patent system favoured particularly the participation of disadvantageous groups, as it required that a patent would be granted to the true and first inventor worldwide. This contrasted with England and other European countries, where a patent could be granted also to imported foreign inventions. This latter practice clearly favoured wealthy traders and companies who could afford purchasing technology abroad and patent them domestically (Sokoloff and Khan, 1990). As result, the barriers to patenting were particularly low in the US, which also favoured immigrants. As Khan (2005) states "the notion of patenting and inventive activity as means of achieving eminence, especially for disadvantage groups, is borne out by the experience of foreign-born inventors" (p.2014).

Having said that, we have to acknowledge that immigrant inventors in the age of mass migration showed different biographies and backgrounds. We can distinguish between three broad categories. A first group includes those who arrived to the US during their childhood: they were trained and raised in the US. Perhaps the most prominent example is given by Elihu Thomson, who is regarded one of the greatest American inventors. A second category includes unskilled immigrants with humble origins who came to the US with limited resources. A prominent example is John F. O'Connor, who moved to the US as a child from Ireland. He started working at the age of fifteen, while taking correspondence courses at night. For long he was employed at a railroad company and through on the job learning and trials and errors he was able to invent testing devices and other inventions for railroad draft gearing (Khan, 2005: p.209; McFadyen, 1936). He eventually became one of the most prolific patentees of his time. Another illustrative example in this same group is given by Jan Earnest Matzeliger; one of the first black inventors, who came to Lynn, Massachusetts from Dutch Guiana, to

1929. On the contrary, the system favoured immigrants from Northern Europe, whose flows were largely unaffected.

work in a shoe factory. Mr. Matzeliger patented a shoe-lasting machine in 1883 which revolutionized shoe manufacturing in the US (Khan, 2005: 215). A third category refers to foreign-born inventors who were already trained before moving to the US. Nikola Tesla is perhaps the most well-known example in this group. With his inventions he gave key contributions to the nascent US electrical industry, besides many other related fields. He emigrated to the US with little money in his pocket, though over time he built a reputation of prolific inventor, which allowed him to work with and sell patents to the high tech companies of his time (e.g. Edison, Westinghouse Electric and General Electric). To the same category belongs Charles Steinmetz, a key figure of the General Electric research laboratories. With a background in mathematics and engineering he flew from Europe to the USA because persecuted at home for his socialist ideas. Steinmetz was trained in Europe where he studied at the university in Breslau and at the Polytechnic Institute in Zurich. Steinmetz was a prolific inventor, however, besides that, one of his greatest contributions, along with other German physicists and mathematicians that moved to US in that period, is perhaps to have helped American engineers to adopt a scientific method to tackle technological problems-solving activities (Hughes, 2004).

Our attention will focus on this latter group of inventors: skilled immigrants who arrived in the US already with a baggage of relevant working or intellectual experience. Because already trained, the contribution of these immigrants to the US inventiveness was twofold, they brought knowledge from their home country to the US, and at the same time they directly contributed to the generation of new knowledge while working and researching. We will test empirically if via these two mechanisms immigrant inventors contributed to American inventiveness.

3. Literature background

3.1 STEM migration and innovation

In the last few decades the international migration of high skill workers has increased dramatically (World Bank, 2018; Oecd, 2008). Despite the shire size of the phenomenon and the obvious policy relevance, there is relatively little scholarly work investigating the link between migration and innovation. In particular, little attention has been paid to the impact of Science, Technology, Engineering, and Mathematics (STEM) immigration on destination countries[3]. In more recent times, a stream of literature crossing different fields has started producing evidence, along with useful dataset, which has begun to answer important research questions on this topic (for a review see among others Kerr, 2013; Lissoni, 2018; Breschi et al. 2015).

A good deal of these studies provide evidence on the US case, which is also the focus on our work, and shows that the contribution of STEM immigrants to innovative activity is substantial and growing overtime. For example, looking at patent applications Kerr (2007) and Kerr and Lincoln (2010) have found that inventors of Indian and Chinese ethnic origins have increased their share of patenting moving from less than 2% to 6% and 9% respectively. Hunt and Gauthier-Loiselle (2010) find that 6.2% of STEM immigrants have been granted a patent relative to 4.9% of US natives. Besides measuring the magnitude of the impact, a number of studies have investigated the mechanisms through which immigrants affect the innovation output in the destination country. For the US, it has been shown that the apparent advantage of immigrants over natives in patenting is due to the self-selection of immigrants in STEM fields of study (Hunt and Gauthier-Loiselle, 2010). After controlling for the level of education, this advantage partly disappears and, example among engineering workers, natives over-perform immigrants (Hunt, 2011).

[3] A long tradition in development economics and migration studies has studied the impact of migration from the perspective of sending countries, in particular focusing on the consequences of the so called “brain drain” phenomenon (for a review see Docquier and Rapoport, 2012).

A great deal of attention has been devoted to measure the labour market impact of skilled immigrants. The main issue at stake in this debate is whether the arrival of foreign STEM workers displaces native workers or not. It has been noted that the positive effect of immigration, for example in terms of higher patenting, could be outweighed by the negative impact on natives, so the net effect of immigration would be null or even negative. Empirical evidence is mixed for the US case (Kerr, 2013). Some studies suggest a positive effect. For example, Hunt and Gauthier-Loiselle, (2010) investigate the long term effect of immigration on patenting using US immigrant college graduates data. They find substantial crowding-in effect, showing that one percentage increase in this population increases patents per capita by about 15%. Kerr and Lincoln (2010) carry out an analysis of the H-1B Visa programme, which is used by knowledge workers entering the US. They exploit the large fluctuation in this programme to identify the causal effect of ethnic knowledge workers on the patenting activity of natives. Different from other studies, this analysis is conducted at city level. Findings show some weak crowding-in effect. Overall, they found that the overall invention activity in the US has raised thanks to ethnic inventors, primarily Chinese and Indian.

Other studies instead found a negative effect. In particular Borjas and Doran's (2012) work on the influx of Russian mathematicians in the US after the collapse of Soviet Union suggest a strong crowding-out effect. They show that Russian mathematicians displaced natives in the fields in which they were active forcing them to move into different ones. This strong impact may possibly be also explained by the rigidity with the limited growth in this field, which makes demand curve rigid (Kerr, 2013). This outcome is in line with the evidence on national skills groups which finds strong crowding-out effects of natives (Borjas, 2003). On the same case, but focusing on a broader set of scientific fields, Ganguli (2015) shows instead that Russian scientists migrating to the US after the collapse of Soviet Union brought with them valuable knowledge used by natives, though differences across fields are relevant.

Historical quantitative studies that link migration and innovation are instead rather limited, also because of lack of data. We review those focused on the US case in the next section.

3.2 Migration and Innovation in age of mass migration

The economic consequences of immigration in the Age of Mass Migration have been explored at length (Hatton and Williamson 1998). The literature has primarily investigated the degree of assimilation of immigrants into the USA economy; the selection of immigrants as compared with residents; and the impact on the economic outcomes in the destination country, in particular on the labour market. As contemporary studies on migration and innovation are limited, likewise historical works on this topic are scarce. Nevertheless, the interest is growing, as witnessed by several unpublished manuscript and working papers just realised in the last couple of years (Abramitzy and Boustan, 2017).

A recent work on high skilled immigrants with an historical perspective is Moser, Voena and Waldinger (2014), although it does not specifically focus on the Age of Mass Migration. They investigate the impact of Jewish scientists who fled Nazi Germany after 1933. Findings suggest that German scientists made a crucial contribution to the development of new technological fields in chemistry in the US. In doing that however, the inflow of German Jewish scientists did not displace natives. On the contrary, their evidence suggests a strong crowding-in effect, with US natives patenting in fields in which they were not active before the German Jewish arrival.

Closely related to our work is Akcigit, Grisby and Nicholas (2017a), which analyses the long term impact of immigrants on innovation in the US. While Moser at al.'s (2014) study focuses on a single field of science (i.e. chemistry) and on single immigrant group (i.e. Germans), the work of Akcigit et al (2017a) has the merit to expand the analysis to the universe of immigrants that patented in the US over the period 1880-1940. Their empirical work draws on an original dataset the authors themselves built by matching US patent historical records with Federal Census data (Akcigit et al. 2017b). They find that in the period 1880-1940 immigrant inventors represented a 19.6% share of total US inventors. Immigrant inventors were strongly clustered in space, and tended to locate where immigrants lived in, like New York, while they were barely present in Southern States. To measure the impact of immigrant inventors, they construct an indicator of foreign expertise, which measures the fields of knowledge in which the country of origin of immigrant inventors was active, and use it to predict the change in patenting in the US as whole during the period 1940-2000. Findings show that the technological fields where immigrants were most active developed at faster pace in the long run (1940-2000).

Our work relates to this latter stream of historical studies of immigration. Different from them, our main aim is to understand the geographical distribution of innovative activities in the US. To this end we carry out a fine grained city-level analysis, which investigates the contemporary impact of immigrant patenting on US patenting. We ground our empirical analysis in the literature of geography of innovation and build our claim based on a number of well-established theoretical arguments and stylised facts in this literature as discussed in conceptual framework section below.

4. Conceptual framework

Different streams of literature in economics, geography, development and population studies among others provide theoretical arguments that explain how high skilled migration impact on either sending or receiving countries (Breschi et al. 2015; Lissoni, 2018). However, there is no established theoretical framework that links high-skilled migration to innovation. In what follows we sketch a simple framework which serves to guide us in this complex set of processes. In doing so we primarily draw on concepts developed in the literature of geography of innovation (Audretsch and Feldman, 1996; Breschi and Lissoni, 2001 and 2009). We believe that some well-grounded stylised facts and theoretical arguments in this literature can help explaining why immigration affects innovation activity in the receiving countries.

As to begin with, an important theoretical claim is that variety (e.g. technological, organisational) is a fundamental feature to explain the dynamics of economic systems (Dosi and Nelson, 1994). A dynamic innovation system, either local or national, needs to be fed continuously with new knowledge in order to keep a certain degree of internal heterogeneity. Even small variations in knowledge bases (or product specifications) in a local economy (e.g. cities, industrial cluster, regional economy) can be sufficient to generate enough variety which triggers innovation (Maskell, 2001). A compelling question is how the system can be fed and by whom.

A second stylised fact is that technological development is path dependent (Dosi, 1997). From a geographical perspective this means that cities and regional economies have a tendency to overspecialise in narrowly defined technologies or industries, which further implies that agglomeration economies can get locked in outdated technological or industry specialisations because of the presence of network externalities in the form of irreversible investment, technological complementarities or economies of scale (Martin and Sunley, 2006). Such a decrease in knowledge variety on the one side raises the cognitive proximity across local actors, and it is well known that too much proximity limits the opportunities of interaction and knowledge exchanges among local actors on the one side (Boschma, 2005); on the other side time it hampers local actors in recognizing that changes, threats or opportunities are out there, so these actors get trapped in once successful routines (Martin and Sunley, 2007). The process of de-locking builds on the ability of local agents to develop new growth paths (Boschma, 2015). It has been well documented that the rise and fall of industries as well as the success and decline of cities are linked to their ability to generate new ideas (Grabher, 1993). This can happen via an endogenous process of knowledge creation and recombination (Hassink, 2005), for example by bridging unconnected knowledge networks (Glucker 2007). However, this endogenous process is often obstructed by incumbents and coalitions of actors with vested interests in the established industry (Grabher, 1993). If they favour change, it is along pre-existing technological trajectories (i.e. adaptation), which can reinforce existing specialisations and further reduces the resilience of the system (Boschma 2015).

Third, it is well grounded in the literature that economic systems escape lock-in and decline by tapping into external knowledge, which increases the variety in the system. A prominent strand of literature in geography of innovation has shown that external networks can feed local economies with new ideas (Breschi and Lenzi, 2015; Morrison et al. 2013). They bring complementary assets and technologies, as well access to non-redundant knowledge. These external connections can operate via different channels (e.g. multinationals subsidiaries, R&D international networks; strategic partnerships), of which professional communities of knowledge migrants is a prominent one (Saxenian 2007). All these connections allow local economies to access external non-redundant knowledge which can be re-combined with local tacit knowledge.

Fourth, it can be claimed that migration can be a rather effective international knowledge channel for knowledge transfer. Knowledge does not circulate well due to its tacitness (Audretsch and Feldman, 1994), so, its transfer is facilitated by the colocation of those who contributed to its production. Mobility represents then a key mechanism of knowledge diffusion (Breschi and Lissoni, 2009), and high-skilled immigrants can be regarded as one of the possible carriers of new knowledge. They bring with them the tacit component of knowledge, which is the most needed for its assimilation and diffusion.

Bringing together the above arguments, we can argue that high-skilled immigrants represent *external* actors that carry with them *new* knowledge from their country of origin. Such knowledge can increase the knowledge *variety* of the local economic system in the receiving country. Immigrants on the one side contribute to expand the local knowledge portfolio by bringing with them their pre-exiting knowledge, and on the other side they recombine this knowledge with the local one in novel ways, so generating new knowledge at destination. In such a way they help the receiving regions to augment their innovative potential and likewise reduce the risk of lock-in.

Based on the above discussion, in the empirical sections that follows we will test whether immigrant inventors contribute to the generation of knowledge at destination, and if this occurs also via the diffusion of knowledge from their home country.

5. Data

To carry out the analysis we constructed a new dataset that identifies migrants in historical patent documents of the United States Patent and Trademark Office (USPTO). These documents provide information about the nationality of the patentee, disclosing the place she was born. Patent document number 381,968 in Figure C1 (see Appendix C) below provides a clear example. This patent shows an invention granted in May 1888 to Nikola Tesla, the Serbian[4] great inventor. As it can be read from the abstract (highlighted in the text), Tesla comes from Austria-Hungary and resides in New York. These two pieces of information are what is needed in order to classify this inventor as an immigrant. Tesla arrived to the United States in 1884 from Europe after having studied in Graz (Austria) and started working almost immediately at Edison's premises. Shortly after he left Edison after disagreements and begun his career as independent inventor, which brought him fame and recognition, though did not made him rich. He can be regarded has one of the greatest immigrant inventor, because of his contribution to AC electricity transmission and in many other technological fields.

Our main task consisted in identifying all potential patent documents that belonged to immigrants. In our study an immigrant inventor is an individual from a country different from the US who resides in the US as reported in the patent document of Tesla above. Manually scanning all documents for foreign applicants would render the task unfeasible. However, one can rely on an automated algorithm to first identify potential candidates and later evaluate manually the accuracy of the procedure. Following this line of work, we trained an algorithm to identify patents who can be attributed to an immigrant inventor based on the vocabulary (and its location) in those patents. Words such "a subject of", "a citizen of", or "kingdom" are usually associated with the description of the location of foreign inventors in patents. These should appear in combination with words such as "residing in", which indicate where the inventor is located in the US. This algorithm works well especially when these words are located near the title of the patent or the inventor name. The algorithm used at this stage is analogous to the one described in Petralia, Balland and Rigby (2016).

Two important problems may arise when it comes to the correct (unbiased) identification of all immigrants. First, that such an algorithm may commit errors and identifies as immigrants those who are not. Second, that it will be excluding the patents of immigrants that have obtained already the US citizenship. We address the first issue by using a semiautomated procedure to check all patent documents that were identified as immigrant patents. The automatic identification of possible candidates reduced the scope of the manual search drastically.

After identifying manually all true migrants, we text-mined all patents in the period 1840-1940 to check if the identified immigrants appeared in other patents. This allowed us to collect patents of migrants who had already obtained the citizenship or that were not captured by the automated algorithm. This resulted in a final database containing 55,096 patents. In our analysis we make use of a restricted timeframe including the years 1870-1925, which reduces the number of patents to 51,436[5].

The second source of data comes from the Histpat dataset in Petralia et al. (2016), which provides county-level information on the location of the inventor(s) and/or assignee(s) for most patents granted since 1836. With this information we could track the diffusion of the inventions of immigrants (and of the rest of the inventors) in space (within the US)[6].

Additional information was extracted from the US decennial Census in order to construct the control variables used in the empirical analysis. In particular we retrieved data on number of inhabitants in counties.

5.1 Descriptive statistics

In what follows we illustrate the main characteristics of our dataset. Figure 1 shows the total number

[4] Serbia was part of the Austrian-Hungary empire at that time.

[5] The years between 1840 and 1880 have been excluded from the analysis because a very limited number of patents are present in the dataset, and even less of immigrants.

[6] This database was built using optically recognized and publicly available patent documents at USPTO, combining text-mining algorithms with a statistical model to identify locations.

of patents of immigrant inventors. We observe a growing trend in patenting which peaks in 1916, possibly capturing the effect of WWI. After that, a new peak is reached in 1926, right after the introduction of immigration quotas, which ended the open door immigration policy in the US.

Figure 1 Yearly Patenting by immigrant inventors (1840-1940)

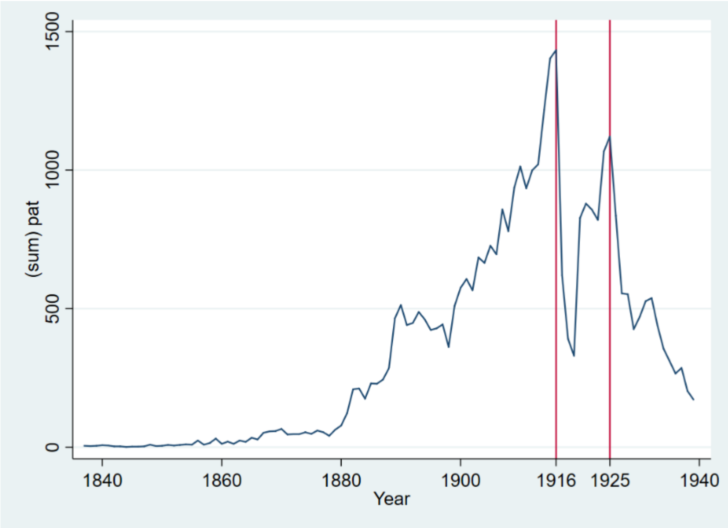

Table 1 Top inventive countries of origin of immigrant inventors

Country	patents	% of the total
Great Britain	17795	46.16
Germany	6188	16.05
Sweden	2753	7.14
Russia	2494	6.47
Austria	1828	4.74
Italy	1420	3.68
Switzerland	1041	2.70
Norway	858	2.23
Denmark	840	2.18
Canada	800	2.08

Table 2 Share immigrants of top ranked inventor cities

City	% of immigrant population	Rank inventors
New York	42,08	1
Chicago	41,82	2
Detroit	36,78	6
San Francisco	35,30	7
Boston	34,8	3
Worcester	31,6	8
Pittsburgh	27,8	5
Philadelphia	26,46	4
Albany	26,13	9
Los Angeles	20,47	10

Table 1 shows the most prolific patenting countries of origin of immigrant inventors. Not surprisingly, this ranking resembles too large extent the distribution of immigrant population in the US, with Great

Britain at the top of the list, followed by Germany. All major European countries which had large flow of emigrants to US are listed, among other Sweden, Italy, Russia and central European countries.[7]

Looking at the geography of invention, Table 2 shows the top destinations of immigrant inventors. As immigrant in general (Abramitzy and Boustan, 2017) also immigrant inventors tended to cluster in space. Not surprisingly, large urban areas are highly represented in this list, with New York and Chicago ranked respectively first and second.

Most inventive states were also those hosting more immigrant inventors, as shown in Table C1 (see Appendix C). The east coast of the US has a prominent position, however a not negligible number of patents appears in the Mid-West, where large communities of German and Scandinavian immigrants were located. Turning our attention to contribution of immigrant inventors, Figure C2 shows the distribution of patens according to the NBER sectors. Immigrant inventors were mainly contributing to mechanical technologies, which were also the dominant sectors of the time. Immigrant inventors contribute with their invention also to the development of emerging fields of that time, like electricity, chemicals and communication. Indeed, as shown in Table C2, they specialized particularly in those emerging technological fields, such electrical, communication and chemical technologies.

Some descriptive statistics of the dataset are presented in Table 3.

Table 3 **Patenting of immigrant inventors**

	Mean	Sd	Min	Max
Patents per city	3.53	7.93	1	258
Patents per technological class	3.10	1.77	1	17.87
Patents per inventor	3.03	8.95	1	537
Patents per decade	4,558.90	6,070.92	0	14,829
Inventors per city	1,322.09	1,586.19	0	3,866
				Total
Number of cities				492
Number of technological classes				379
Number of inventors				18,129
Number of patents				51,436

6. Empirical Strategy

6.1 Knowledge creation at destination

In order to investigate the contribution of immigrant inventors to the creation of new knowledge in the US, we estimate the impact of their patenting activity on US native inventors across US cities. This analysis will help to unravel the potential displacement effect of immigration. The innovation literature suggests that knowledge tends to be sticky, and in particular tacit knowledge diffuse mainly locally (Audretsch and Feldman, 1996). Following this intuition, and in line with others studies (Ganguli, 2015; Kerr and Lincoln, 2010), we take the city as unit of analysis, instead of the state or the US as whole. In particular we use the Core Based Statistical Areas (CBSA), which include counties linked to a relatively large urban area and the surrounding counties that are economically integrated with it. The focus on cities makes sense also because the circulation of knowledge was

[7] Due to the small number of patents, we have grouped some countries, in particular: Great Britain includes also Ireland, Wales, Scotland and England; Austria includes also Hungary, Croatia, Bulgaria and Yugoslavia; Russia includes Ukraine and Latvia.

possibly more geographically bounded back then than today, since markets for technology were geographically segmented (Lamoreaux and Sokoloff, 1999) and transportation and communication networks were incipient.

In line with the economic literature on migration and innovation (see Kerr, 2013), we exploit variation across cities, technological classes and time to identify the effect of immigration on knowledge creation. Our baseline OLS regression model is as follows:

$$lnPat_{nat,\, krt} = \beta_1 lnPat_{mig,krt} + \beta_2 Pop_{rt} + \gamma_t + \varphi_{kr} + \varepsilon_{krt}, \tag{1}$$

where the dependent variable ($lnPat_{nat,\, krt}$) counts the number of patents (in log) of US native inventors in city r and technological class k at time t. The independent variable of interest is the number of patents (in log) by immigrant inventors ($lnPat_{mig,krt}$) in city r and technology class k at time t. The baseline model uses CBSA as geographical unit of analysis. We estimate the same specification also using counties in order to test for the robustness of our results (see Appendix B). The time interval is the decade, this choice is justified by the fact that census data information is decennial. We add φ_{kr} city-technological class specific fixed effects to control for unobservable variation in patenting across regions and technological classes which is constant overtime, and decade fixed effects (γ_t) to control unobservable variation in patenting overtime. A covariate measuring the total number of inhabitants (Pop_{rt}) in a city is added to the baseline model in order to further control for size effects. It is indeed plausible that largest urban agglomerations, which were presumably those with the highest innovative output, attracted more immigrants.

The above specifications however fail to identify the causal effect of immigration on innovation. As widely discussed in the literature of migration (see Borjas, 2003), immigrants do not randomly distribute over space. They may be attracted to specific locations because of unobservable factors. If this unobservable factors are correlated with our output measure (i.e. patenting), an endogeneity problem will emerge. If immigrant inventors were attracted to cities because they could better use their skills and knowledge for some unobservable reason, then the estimate of the $\beta_1$coefficient will be biased, and show an upward bias. Beside endogeneity, also reverse causality could undermine our estimates. It could be indeed argued that natives' inventive activity attracted immigrant inventors to specific locations.

In order to address the above concerns, an instrumental variable strategy is implemented. We build a modified version of the "shift-share" Bartik instrument, which is well grounded in the migration literature (see Card, 2001) and widely applied in the recent literature on immigration and innovation (see Ganguli, 2015; Hunt and Gauthier-Loiselle, 2010). The instrument is usually composed of two parts: the inflow of immigrants from a given country to a destination country (e.g. the shift), and the share of immigrants of that country residing in a specific city in the previous period (e.g. the share). In our case the instrumental variable is constructed as follows:

$$\textstyle\sum_{c=1}^{C} ShareMigrants_{c,r,t-1} MigrantInventors_{c,k,t} \quad , \tag{2}$$

where *ShareMigrants* identifies the lagged distribution of the share of immigrants (i.e. non inventors) from source country c in location r, and *MigrantInventors* is the change in immigrant inventors from country c in technological class k to the US as a whole. The predicted inflow of immigrant inventors into a city is constructed as the weighted average of the national inflow rates from each country, where the weights are given by the initial distribution of non-inventor immigrants. The underlying logic of the instrument is that immigrant inventors settled down in US cities where immigrants of the same ethnicity, but not engaged in inventive activity, were living.

It is important to highlight that immigrants tended to cluster by region in the United States. While on the one side Italians located in urban areas in New York, Pennsylvania and New Jersey, Scandinavians and Germans were the largest immigrant groups in areas like the upper and lower Midwest (Abramitzky and Boustan, 2017). Different immigrant groups were attracted by different cities, so for example Boston or San Francisco hosted large Italian communities, while very few Swedes. In contrast, Swedes were highly represented in Minneapolis, which hosted barely any Italian (Tabellini, 2018).

In order to find some evidence that supports the above argument, we first looked at the clustering of immigrants and compared it with those of immigrant inventors. Table 2 shows in column 1 the top ten destinations of immigrants in the US, and in column 3 how these locations ranked among immigrant inventors. It can be observed that both groups (immigrant inventors and not) had very similar location patterns and clustered in the same top ten destinations.

Looking at some specific ethnic groups with different locational patterns can help to illustrate this point. We know from historical census data that a German belt connected the West and East coasts of the US, with a significant presence of Germans in the Mid-West (Abramavitzy and Boustan, 2017). On the contrary Italians clustered in a few states in the East coast (primarily New York, New Jersey and Pennsylvania). Looking at our inventors' data, we observe that German inventors were much more present in Mid-West States than Italians (e.g. such as Wisconsin Minnesota, Michigan, Ohio and Iowa). This latter ethnic group was instead almost absent in these States. The comparison between Italians and Scandinavian (e.g. Swedes, Danish and Norwegian) further illustrates these different locational patterns. For example, Minnesota, which hosted the highest percentage of the Swedish immigrant population, ranks first also in the number of counties hosting Swedish inventors (43% of the total with at least one Swedish inventor). Italian immigrants, who were barely present in this state, had also a very limited population of inventors: only one county appears to host them. A similar pattern can be observed in other Mid-West states. For example, eighteen counties in Iowa hosted at least one inventor from Germany and fourteen had inventors originated from Sweden, but only two had Italian inventors. In Michigan, thirteen counties hosted German inventors, eighteen had at least one Swede and only four hosted Italians. Overall this evidence seems to further indicate that social networks and ethnicity did play a role in shaping the distribution of inventors across location, as predicted by migration literature. However, immigrant inventors of any ethnicity were highly clustered in some large urban agglomerations such as New York, Detroit or Chicago. As robustness check we estimate all models excluding the top two immigrant destination.

6.2 Knowledge diffusion from origin-to-destination

Besides contributing to knowledge creation in the host country, immigrant inventors brought new knowledge from the countries they originated from to the location they migrated to. We investigate the process of knowledge diffusion by testing the following model:

$$lnPat_{i,kr,t+1} = \beta_1 E_{krt} + \beta_2 Pat_{krt} + \gamma_t + \varphi_{kr} + \varepsilon_{krt}, \quad (3)$$

where $lnPat_{i,krt}$ measures the total (native) number of patents (in log) in city *r* and technological class *k* at time *t*. As in (1) we add φ_{kr} city-technological class specific fixed effects and time fixed effects (γ_t). We add a covariate (Pat_{krt}) that counts the total number of patents in city *r*, technological class k and decade t in order to control for the convergence process. The independent variable E_{krt} is a measure of the expertise of country c from where immigrant inventors originated (Akcigit et al. 2017a).

$$E_{krt} = \sum_{c=1}^{C} \frac{P_{ckt}}{P_{ct}} M_{crt} , \tag{4}$$

where $\frac{P_{ckt}}{P_{ct}}$ is the share of patents in class k of country c, and M_{crt} is the total number of immigrant inventors from country c in region r. As discussed in Akcigit et al. (2017a), the underlying idea is that the share of patents in a technological field captures the specialization of a country in a given technological domain, while the scope of knowledge diffusion depends on the number of immigrant inventors migrating to a US location. Differently from the original indicator in Akcigit et al. (2017a), our measure is constructed at regional level.

We analyse the impact of knowledge diffusion also by looking at the growth of patenting. We estimate the growth of patenting as a function of the expertise of foreign knowledge.

$$\Delta lnPat_{i,kr\{t\to t+1\}} = \beta_1 E_{krt} + \beta_2 Pat_{krt} + \gamma_t + \varphi_{kr} + \varepsilon_{krt} . \tag{5}$$

Where $\Delta lnPat_{i,kr\{t\to t+1\}}$ is the growth rate of total patenting in sector k and location r. $E_{mig,krt}$ is the expertise measure, while γ_t and φ_{kr} are the usual fixed effects as above, and (Pat_{krt}) controls for the stock of previous accumulated knowledge.

It is worth noting that this specification can raise some concerns due to the potential endogeneity of the expertise indicator. As discussed above, immigrant inventors do not distribute randomly across cities, therefore M_{crt} is possibly endogenous. To tackle this issue we build the following instrument:

$$E_{krt}^{IV} = \sum_{c=1}^{C} \frac{P_{ckt}}{P_{ct}} \widetilde{M}_{crt}^{k} , \tag{6}$$

$$\text{where } \widetilde{M}_{crt}^{k} = M_{crt} - M_{crt}^{k} . \tag{7}$$

The instrument E_{krt}^{IV} is exogenous because immigrants from technological class k have been excluded. The instrument is relevant if $corr(\widetilde{M}_{crt}^{k}; M_{crt}^{k})>0$ that is if inventors from country c go to the same location r in the US, because for instance social networks, you can predict the migration of an inventor in class k from inventors in other classes.

7. Empirical results

7.1 Knowledge creation at destination

The results presented in Table 4 refer to equation (1), where patenting in the US is related to patenting of immigrant inventors. Column 1 shows that natives' patenting is positively associated with patenting of immigrant inventors in a given city, technological class and decade. The findings suggest that a ten percent increase in immigrants' patenting leads to about four percent increase in patenting of US natives. After controlling for the total population of the city in Column 2, the effect remains positive and significant and its magnitude only slightly decreases. After excluding New York and Chicago from the analysis, the coefficient estimates become smaller, however they remain positive and highly significant (see Appendix A, Table A1). Our results are in line with other studies (Akcigit, et al. 2017a; Hunt and Gauthier-Hoiselle, 2010; Moser et al., 2014) that find positive crowding-in effects: immigrant inventors do not displace natives, instead results show a positive impact on their productivity.

To the best of our knowledge no other studies have tested this relation for the age of mass migration. For the sake of comparison, the magnitude of our estimates is higher than Kerr and Lincoln (2010), who run a similar city-level analysis and show that a ten percent increase in Indian and Chinese patenting is associated to a 1,4% increase in English patenting in the period 1975-2004. The discrepancy can be attributed to different reasons. The main findings of Kerr and Lincoln refer to Indian and Chinese ethnic migrants. It is interesting to note however that when we sum the contribution of all the ethnic groups included in their extended analysis (i.e. European, Hispanic and Russian), the total effect gets very similar to ours.

Table 4 The relationship between US and immigrant patenting

	OLS		IV	
	Pat_{nat}		Pat_{nat}	1^{st} $stage_{nat}$
VARIABLES	1	2	3	4
$lnPat_{mig}$	0.384***	0.360***	0.846***	
	[0.0483]	[0.0419]	[0.0718]	
lnPop		7.08e-11***	-0	2.59e-10***
		[0]	[0]	[1.59e-11]
Iv				0.158***
				[0.0097]
Observations	8,063	8,063	5,426	5,426
R-squared	0.838	0.839	0.818	

Clustered standard errors in brackets *** p<0.01, ** p<0.05, * p<0.1

In order to give a causal interpretation of our findings, we present the instrumental variable estimates using the instrument in equation (2) (see Table 4). The coefficient estimates of immigrant patenting in columns 3-4 are positive and significant. These findings are also robust to the exclusion of large cities from the analysis (see Appendix A, Table A1). The magnitude of the coefficients of the instrument are twice as much those of the corresponding OLS model in column 2. This is surprising as one would expect a positive bias in the OLS estimates. Similarly to what Ganguli (2015: 279) argues for citations of Soviet scientists' papers, such unexpected finding can be possibly explained by the fact that immigrant inventors contributed more to the inventive activity of cities where they migrated because of social networks rather than in cities where they moved to because hired by local companies. In this latter case, their inventive activity was most likely adding up to an existing stock of knowledge of native inventors, so their overall impact in these cities appear less pronounced. An alternative explanation is that the flow of foreign inventors is measured with an error, and the IV corrects for OLS' attenuation bias.

7.2 Knowledge diffusion from origin to destination

In this section we will present the findings of the impact of knowledge diffusion on US patenting that relates to equation (3). The results in Table 5 show that foreign expertise contributes positively to US patenting at city-field level. An increase in the foreign expertise by one unit is associated with 0.037 percent increase in total patenting. Considering that each city as an average of about 1,300 inventors over the entire period, if this number increases by about 10%, and the share of foreign patent remains constant, we can expect an increase in total patenting by 4,87% (130x0.037) over the entire period. The result is robust to the inclusion of the stock of patenting for a given city, field and decade, as shown in column 2, though it decreases considerable in magnitude from 0.037 to 0.0157. Assuming as above a 10% increase in immigrant inventors, the total patenting will increase by approximately 2% (130x0.0157). In column 1 (Table A2, Appendix A), the same model is tested excluding New York and Chicago: the sign and significance of estimates do not differ from those in column 2, and the magnitude of the estimates only slightly decreases to 0.0135. Given the endogeneity concerns, in column 4 the instrumental variable estimates are shown using the instrument in equation (6). Findings still show a significant and positive effect of foreign expertise on total patenting. The magnitude of the estimates is only slightly higher than to the similar OLS model in column 2 (0.0167 vs 0.0157).

Table 5 The relationship between foreign expertise and US total patenting

	Total $Patents_{t+1}$		
	OLS		IV
VARIABLES	1	2	3
Foreign expertise	0.0307***	0.0157***	0.0167***
	[0.00899]	[0.00471]	[0.00333]
$Patents_t$		0.00343***	0.00342***
		[0.000824]	[0.000484]
Observations	162,007	162,007	121,659
R-squared	0.781	0.782	0.803

Clustered standard errors in brackets *** p<0.01, ** p<0.05, * p<0.1

When total patenting is replaced with patents by US natives, our findings remain qualitatively unchanged. These results suggest that immigrant inventors generate positive externalities that increase the productivity of US inventors (see Table 6)

Table 6 The relationship between foreign expertise and US native patenting

	Native $Patents_{t+1}$		
	OLS		IV
VARIABLES	1	2	3
Foreign expertise	0.0222***	0.0109***	0.0111***
	[0.00670]	[0.00325]	[0.00220]
$Patents_t$		0.00266***	0.00217***
		[0.000754]	[0.000381]
Observations	161,783	161,783	121,436
R-squared	0.787	0.787	0.810

Clustered standard errors in brackets *** p<0.01, ** p<0.05, * p<0.1

Now we turn to the estimates of the speed of diffusion of foreign expertise as in equation (5). The findings are presented in Table 7. In column 1 the estimates of the baseline model show a positive and significant effect of the expertise variable on US patenting growth. The future decennial growth rate in total patenting for a unit increase in foreign expertise is 0.0066%. These findings do not qualitatively change after the inclusion of the patent stock variable, which is negative as expected (see column 2), and after excluding the cities of New York and Chicago from the analysis. The magnitude of the coefficient however increases substantially (0.0132). This is possibly related to the strong correlation between the expertise indicator and the patent stock variable (0.5), which could indicate the presence of some degree of multicollinearity. After running a VIF (Variance Inflation Factor) test for multicollinearity we find a value (1.3) well below the usual tolerance threshold of 10, which suggests the absence of multicollinearity among the independent variables. The estimates in column 2 show that an increase of immigrant inventors by 10% in the expertise indicator is associated to a 1.71% increase in total patenting (130x0.0132). Interesting to note, this effect becomes much stronger when excluding large cities (6 times higher), although smaller urban areas will possibly attract a number of inventors which is well below the average, so the overall effect would be similar. As above, we test an instrumental variable model using the instrument in equation (6). The coefficient estimates reported in column 4 are qualitatively similar to the findings of the corresponding OLS model in column 2.

Table 7 The relationships between foreign expertise and total patent growth

	Total Patent growth		
	OLS		IV
VARIABLES	1	2	3
Foreign expertise	0.00660***	0.0132***	0.0125***
	[0.00169]	[0.00286]	[0.00313]
$Patents_t$		-0.00268***	-0.00303***
		[0.000384]	[0.000782]
Observations	1,881	1,881	1,545
R-squared	0.622	0.632	0.646

Clustered standard errors in brackets *** p<0.01, ** p<0.05, * p<0.1

Conclusion

During the age of mass migration more than thirty millions people migrated to the US. It has been shown that immigrants changed the quantity and composition of the working population and that had a permanent impact on the US economy (Hatton and Williamson, 1998; Sequeira et al. 2017; Rodriguez-Pose and Berlepsch 2014).

Our work investigates the relationship between immigration and invention in the age of mass migration using a novel and original dataset of immigrant inventors. This study contributes to different strands of literature that have focused on either immigration or innovation or both.

We contribute to the recent literature on immigration from an historical perspective (Abramitzky and Boustan, 2017; Akcigit, et al. 2017a; Moser et al. 2014) by providing comprehensive evidence on the impact of immigrant inventors to US inventiveness. In line with these studies we show that immigration had positive effects, increasing US patenting. Our work contributes also to the economics literature studying the displacement effects of high-skilled immigrants (Kerr and Lincoln, 2010; Borjas and Doran, 2012). Our results show that immigrants did not displace US natives, rather we find evidence suggesting that the opposite is true. Our study contributes also to the literature linking migration to knowledge spill-overs by showing that immigrants represent an important channel for knowledge diffusion across space (Ganguli, 2015). Due to its tacitness, knowledge is sticky, so immigrant inventors bring this embodied knowledge across oceans and diffuse it locally. Our results show that the effect of this process at city level is positive.

Our main results suggest that immigrant inventors had a twofold effect on US inventive activity: a direct impact, by patenting their ideas; in addition, they generated positive externalities, which increased the productivity of US native inventors.

These findings are not exempted from potential biases, mainly because of the presence of endogeneity and reverse causality. To reduce these distortions, we implemented an instrumental strategy that is widely used in the literature. However, this approach strongly rests on the assumption that social networks constitute an important driver in the localisation decisions of immigrant inventors. This seems to be plausible on average, but it is perhaps less realistic for the brightest and possibly more productive foreign inventors. Some of these scientists were certainly attracted to and concentrated in a few innovative spots. We are comforted however that once we exclude big inventive cities from the analysis, our findings are still significant and qualitatively unchanged.

There are promising avenues of research that can be further pursued with our data. We have examined the contribution of *all* immigrant inventors without distinguishing by their country of origin. Following the literature on diversity and polarization (Ager & Brückner, 2013), we could argue that the ethnic composition of immigrant inventors in cities could impact on their innovative outputs.

Second, our analysis quantifies the *contemporary* impact of immigrant inventors. Other studies have shown that the immigration had a long lasting effect on the US economy (Sequeira et al. 2017). An interesting question is whether immigrant inventors' contribution to US inventiveness was either short or long term, and whether the long-term effect was more sizable at city vs national level.

Third, our descriptive evidence indicates that the distribution of immigrant inventors' productivity is highly skewed. Important historical studies have investigated the relationship between the US patenting system and the role of *great* inventors (Khan and Sockoloff, 2004). An interesting analsysis is to compare the productivity across these groups and quantify the overall impact of great immigrant inventors.

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Appendix A – Small sample excluding New York and Chicago (Cbsa)

Table A1 The relationship between US and immigrant patenting

	OLS	
VARIABLES	$lnPat_{nat}$	$lnPat_{nat}$
	3	4
$lnPat_{mig}$	0.379***	0.380***
	[0.0455]	[0.0460]
lnPop		-3.98e-10
		[4.11e-10]
IV		
Observations	5,767	5,767
R-squared	0.771	0.771

Clustered standard errors in brackets *** p<0.01, ** p<0.05, * p<0.1

Table A2 The relationships between foreign expertise and patenting

	Total $lnPatent_{t+1}$	Native $lnPatent_{t+1}$	Total lnPatent growth
VARIABLES	1	2	3
Foreign expertise	0.135***	0.112**	0.0801*
	[0.0414]	[0.0434]	[0.0423]
$Patents_t$	0.00509***	0.00454***	-0.00802***
	[0.00118]	[0.00120]	[0.00238]
Observations	158,380	158,238	836
R-squared	0.746	0.750	0.627

Clustered standard errors in brackets *** p<0.01, ** p<0.05, * p<0.1

Appendix B – County level regressions

Table B1 The relationship between US and immigrant patenting

	OLS				IV
	full sample		small sample		
	$lnPat_{nat}$				
VARIABLES	1	2	3	4	5
$lnPat_{mig}$	0.203***	0.201***	0.162***	0.149***	0.168**
	[0.0298]	[0.0335]	[0.0254]	[0.0202]	[0.0733]
lnPop		2.23e-09		8.45e-09	2.76e-09***
		[3.17e-09]		[5.89e-09]	[9.13e-10]
Observations	10,086	10,028	7,845	7,787	6,606
R-squared	0.866	0.867	0.822	0.825	0.881

Clustered standard errors in brackets *** p<0.01, ** p<0.05, * p<0.1

Table B2 The relationships between foreign expertise and total patenting

	Total $\ln Patent_{t+1}$			
	OLS			IV
	full sample		small sample	
VARIABLES	1	2	3	4
Foreign expertise	0.0365***	0.0166**	0.123**	0.0157***
	[0.0112]	[0.00656]	[0.0554]	[0.00562]
$Patents_t$		0.00443***	0.00659***	0.00440***
		[0.000846]	[0.00138]	[0.000642]
Observations	213,521	213,521	209,944	159,198
R-squared	0.752	0.753	0.721	0.776

Clustered standard errors in brackets *** p<0.01, ** p<0.05, * p<0.1

Table B3 The relationships between foreign expertise and native patenting

	Native $\ln Patent_{t+1}$			
	OLS			IV
	full sample		small sample	
VARIABLES	1	2	3	4
Foreign expertise	0.0285***	0.0122**	0.107**	0.0110***
	[0.00946]	[0.00525]	[0.0527]	[0.00393]
$Patents_t$		0.00386***	0.00623***	0.00339***
		[0.000860]	[0.00136]	[0.000549]
Observations	213,207	213,207	209,691	158,918
R-squared	0.755	0.756	0.723	0.780

Clustered standard errors in brackets *** p<0.01, ** p<0.05, * p<0.1

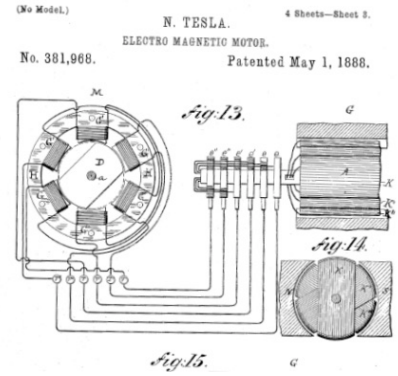
Table B4 The relationships between foreign expertise and patent growth

	Total lnPatent growth			
	OLS			IV
	full sample		Small sample	
VARIABLES	1	2	3	4
Foreign expertise	0.00585**	0.0140***	0.130*	0.0142***
	[0.00281]	[0.00410]	[0.0742]	[0.00400]
$patents_t$		-0.00303***	-0.00575***	-0.00353***
		[0.000514]	[0.00168]	[0.000958]
Observations	1,945	1,945	970	1,594
R-squared	0.642	0.651	0.666	0.658

Clustered standard errors in brackets *** p<0.01, ** p<0.05, * p<0.1

Appendix C – Data

Figure C1 Example of historical patent document



UNITED STATES PATENT OFFICE.

NIKOLA TESLA, OF NEW YORK, N. Y., ASSIGNOR OF ONE-HALF TO CHARLES F. PECK, OF ENGLEWOOD, NEW JERSEY.

ELECTRO-MAGNETIC MOTOR.

SPECIFICATION forming part of Letters Patent No. 381,968, dated May 1, 1888.

Application filed October 12, 1887. Serial No. [illegible]. (No model.)

To all whom it may concern:

Be it known that I, NIKOLA TESLA, from Smiljan Lika, border country of Austria-Hungary, residing at New York, N. Y., have invented certain new and useful Improvements in Electro-Magnetic Motors, of which the following is a specification, reference being had to the drawings accompanying and forming a part of the same.

the system I prefer to connect the motor-circuits directly with those of a suitable alternate-current generator. The practical results of such a system, its economical advantages, and the mode of its construction and operation will be described more in detail by reference to the accompanying diagrams and drawings.

Figures 1 to 8 and 1ᵃ to 8ᵃ, inclusive, are dia-

Table C1 Top inventive US states

State	% immigrants' patents	rank
New York	38,42	1
Pennsylvania	10,32	2
Illinois	9,39	3
Massachusetts	7,95	4
New Jersey	7,34	5
California	4,39	6
Michigan	3,86	7
Ohio	3,72	8
Connecticut	2,38	9
Wisconsin	1,96	10

Figure C2 Patenting of immigrant inventors by NBER sector

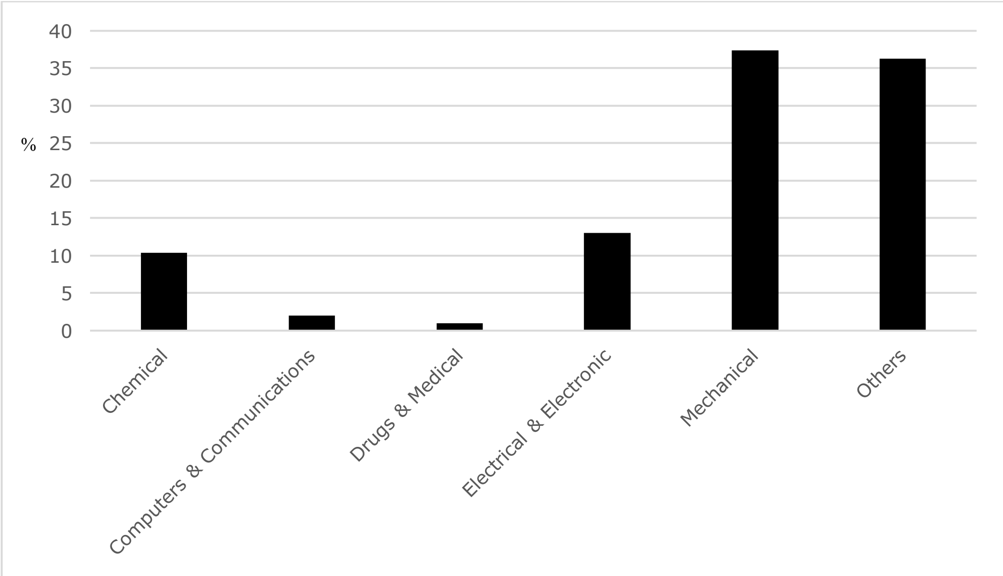


Table C2 Technological specialisation of immigrant inventors patents

Nber classes	Specialization
Electrical & Electronic	1.64
Computers & Communications	1.22
Chemical	1.14
Mechanical	1.09
Drugs & Medical	1.03
Others	0.86