Understanding the Relationship Between Immigration and Innovation: A Systematic Review and Meta-Analysis

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Abstract

The relationship between immigration and innovation has become an urgent topic of discussion in the USA and in the European Union due to the current migration patterns and the crucial role played by innovation as a driver of growth in modern economies. The present study is a systematic review regarding the investigation of the status of the research on immigration, ethnic diversity, and their impact on innovations, especially at the firm's organisational level. With a focus on high-skilled immigrants, a closer examination of the link between migration and economic performance of the private sector has been conducted during the research. The paper will focus on the elements that impact the contributions of migrants towards the total level of innovation of host countries. Cultural diversity, demographic agglomeration forces, and the educational backgrounds of newcomers are identified as drivers of innovation which influence patenting activity. Additionally, the research provides an overview of the positive influence of migration on innovation spillovers, taking into account its ability to isolate the channels concerning education history and labour supply that lead to this beneficial effect. The evidence suggests that immigrants contribute to the overall level of economic growth and innovation in destination countries, as spillovers of entrepreneurial capabilities and scientific and technological knowledge appear to be fundamental to innovation in host countries. Nonetheless, policy-makers are presented with expected outcomes, as well as no evidence to suggest that migration is detrimental to a strong research and development sector.

Introduction

Migration has become a central focus in contemporary public debates and policy-making. In today's rapidly evolving landscape the complex challenges, surrounding migration, hold significant importance. This pertinence extends beyond the scope of traditional diversity discussions and intersects with various aspects of public discourse. As our world grapples with the implications of human mobility, migration takes a central stage. It is a pivotal topic in discussions covering economic, cultural, and social dimensions of migration. These conversations also delve into the intricacies of national identities, security, and policy decisions across various domains. It is evident that migration's impact reaches far and wide shaping contemporary public debates and policies, including those involving nationalist movements. According to the United Nations' analysis of international migrant populations by region, Europe is currently the leading choice for global migrants, housing 87 million individuals and representing 30.9% of the global migrant population (Fig. 1 shows the average share of foreigners across EU countries).

Following closely are the Asian countries with 86 million international migrants (30.5%), while Northern America ranks third, counting 59 million international migrants (20.9%). Africa comes last, with 25 million migrants (9%). Over the past 15 years, Latin America and the Caribbean have undergone a noteworthy surge in international migration, as the numbers of migrants have risen from

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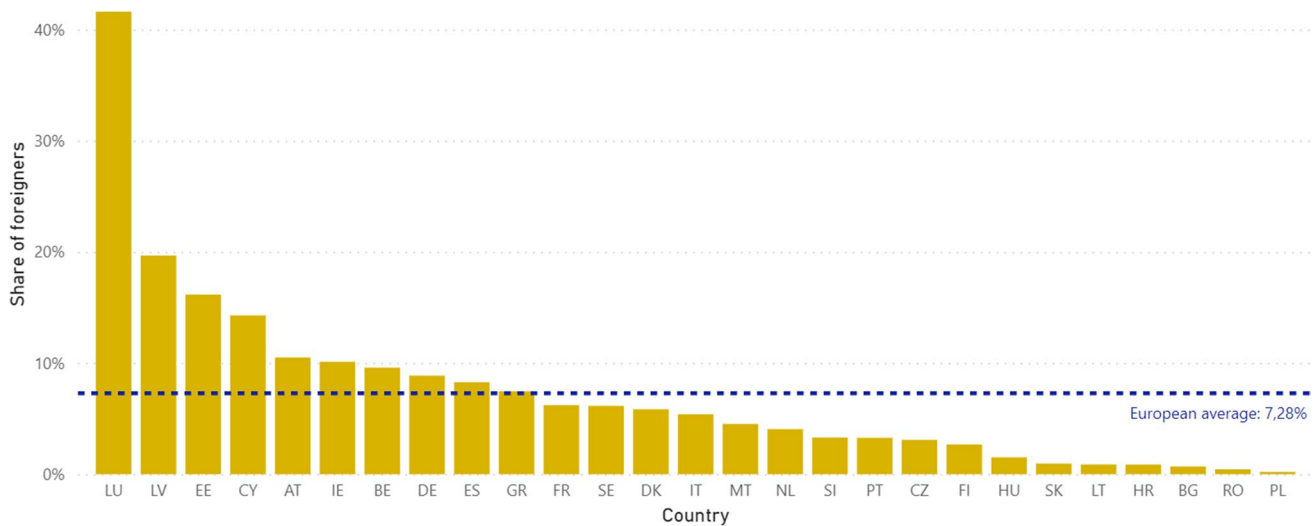3 Department of Mathematics, University of Turin, Turin, Italy

Fig. 1 Average share of foreigners across EU countries (indicated using alpha-2 codes) in the period 1998–2017 (reprocessing of Eurostat data, 2017)

approximately 7 million to 15 million. At present, this area exhibits the highest growth rate of international migrants and accommodates 5.3% of all international migrants. In contrast, Oceania hosts around 9 million or 3.3% of all international migrants (Mcauliffe and Triandafyllidou 2021). The report presents the primary trends of migration, while also exploring their impact on urban settings such as vulnerabilities, growth and development, governance, and so forth. Additionally, it provides recommendations for enhancing urban governance with respect to migration. As economic development depends on innovation, it is crucial to adopt a comprehensive approach to identify the channels through which immigration impacts innovation. It is evident that immigration has a positive impact on innovation, and this should be carefully considered in policy-making. A shift in population is noticeable as a result of immigrants bringing along their knowledge, since it is impacted by non-local information (Maré et al. 2011). It also results in an increase in cultural diversity, leading to wider creativity and a faster development of new ideas, as shown by Ozgen et al. (2011), Romer (1990), and Uppenberg (2009). However, the topic appears to be of recent interest, and mainly confined to research focusing on the USA and the European Union. The topic of immigration is gaining consideration in Australian and New Zealand literature, influenced by its relevance for the Oceanic continent. For example, in their comprehensive studies, Crown et al. (2020) thoroughly examine the impact of foreign-born graduates on innovation within Australia. The literature frequently converges with the specific US admission system, which tends to favour the entrance of high-skilled migrants, and for the specific US migration history, which attracts migrants from a defined set of countries, such as China and India (Lissoni 2018). The present study is

a systematic review regarding the investigation of the status of research in the field of immigration, ethnic diversity, and their impact on innovations, namely, the capability to pioneer inventions in the form of intellectual property rights and patents. In contrast to the usual spatial, chronological, or methodological techniques employed in most literature reviews on the topic, we contend that a thematic approach is optimal for detecting the vital elements that support innovation spillovers. This strategy has significant consequence, owing to its originality and great policy implications. The method enables the identification of areas that should not be prioritised for enhancing innovation via the direct or indirect contributions of migrants. This approach informs policymakers seeking to stimulate national technological development about the particular channels through which migration impacts. Alongside, by recognising that prevalent research on the relationship between immigration and innovation mainly signals the importance of the topic, our approach is aimed at narrowing the considered channels of influence of immigration, limiting to the analysis of labour market effects, including wage differences and the reallocation of human capital. At the same time, by recognising the universal knowledge that migrants import into destination economies as a comparative advantage over natives, the approach we have adopted considers education as a second key factor for an accurate frame of the effects of immigration on innovation. As concerns the general composition of immigration to the developed countries, in spite of our decision to merely focus on high-skilled migrants, we widely acknowledge that large shares of immigrants—either legal or illegal—are classified as unskilled, even though most developed countries have instituted policies to attract skilled migrants. In general, migration, both of skilled and unskilled individuals, is

beneficial for all incomes (high and low) and for all generations (Razin and Sadka 2000). In this regard, Altonji and Card (1991) assumed that the labour market within each city considered in their research consists of skilled and unskilled workers, and that immigration adds workers to both sectors, with additions depending on the nature of immigrant inflows to the considered city. Similarly, Borjas and Katz (2007) referred to the rapidly increasing (legal and illegal) immigrant influx of Mexican workers after 1970 to shed light on the fact that, in general, the economic performance of Mexican immigrants is significantly behind that of other immigrant groups due to skill composition factors and educational attainments. Figure 2 illustrates the educational composition of immigrants across different European Union nations.

Our thematic survey of current state-of-the-art literature proceeds as follows. The first section outlines all the criteria used for article selection. In the second section, our emphasis is on assessing the impact of immigration through an analysis of a country's patent activity and labour market. Lastly, in the third section, we conducted a meta-analysis to combine the results from the studies in order to present a comprehensive overview of the topic. The examination of the relationship between immigration and innovation with a particular focus on the patenting activity, the role of high-skilled migrants as a force of innovation, and their labour market impact on destination countries has been carried out taking into account cultural diversity, demographic forces, and educational attainments, which are undeniably part of the innovation debate. In this regard, the next section will place emphasis on the novel approach used in this article, namely, the review of approximately 50 articles through the identification of search criteria, article evaluation, analysis,

and eventually outcome examination. Specifically, as mentioned above, two-thirds of the papers focus on North America and Europe, as a large percentage of immigration is directed to developed countries.

Systematic Review and Criteria Used to Select the Articles

In operational terms, and with regard to the research question of the present study, a number of previous researches has been identified, leading to a delimitation of the research field. The result of this preliminary selection is a multiple-step analysis of the elected literature described in Fig. 3.

This paper examines how these components, including cultural diversity, demographic agglomeration forces, and the educational attainment of immigrants, affect the patenting activity of firms. In particular, the analysis will focus on the relationship between patenting and the share of high-skilled migrants in the destination countries, which emerges as the main focus of the research. In order to accomplish this, a three-step data collection process involved content analysis, grounded theory, and discourse analysis. In practical terms, keywords have been analysed by relying on specific academic databases, including Scopus, JStor, Google Scholar, EconPapers, ResearchGate, and Iza Migration. In fact, almost 38% of the articles were selected from Google Scholar, while 30% and 15% of the analysed papers were sorted from Econpapers and Jstor, respectively. As concerns keywords, the terms considered included "immigration," "innovation," "patenting," "high-skilled migrants," "economic growth," "productivity," and "meta-analysis." Of the
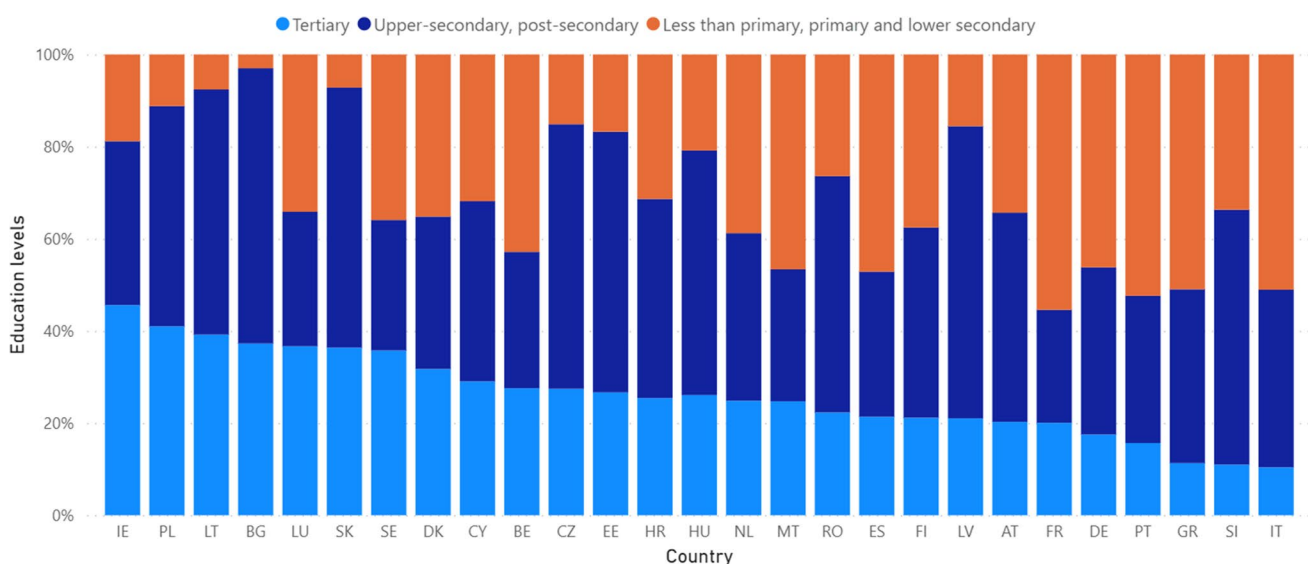

Fig. 2 Average foreigners' education in EU countries in the period 1998–2017 (Eurostat 2017)
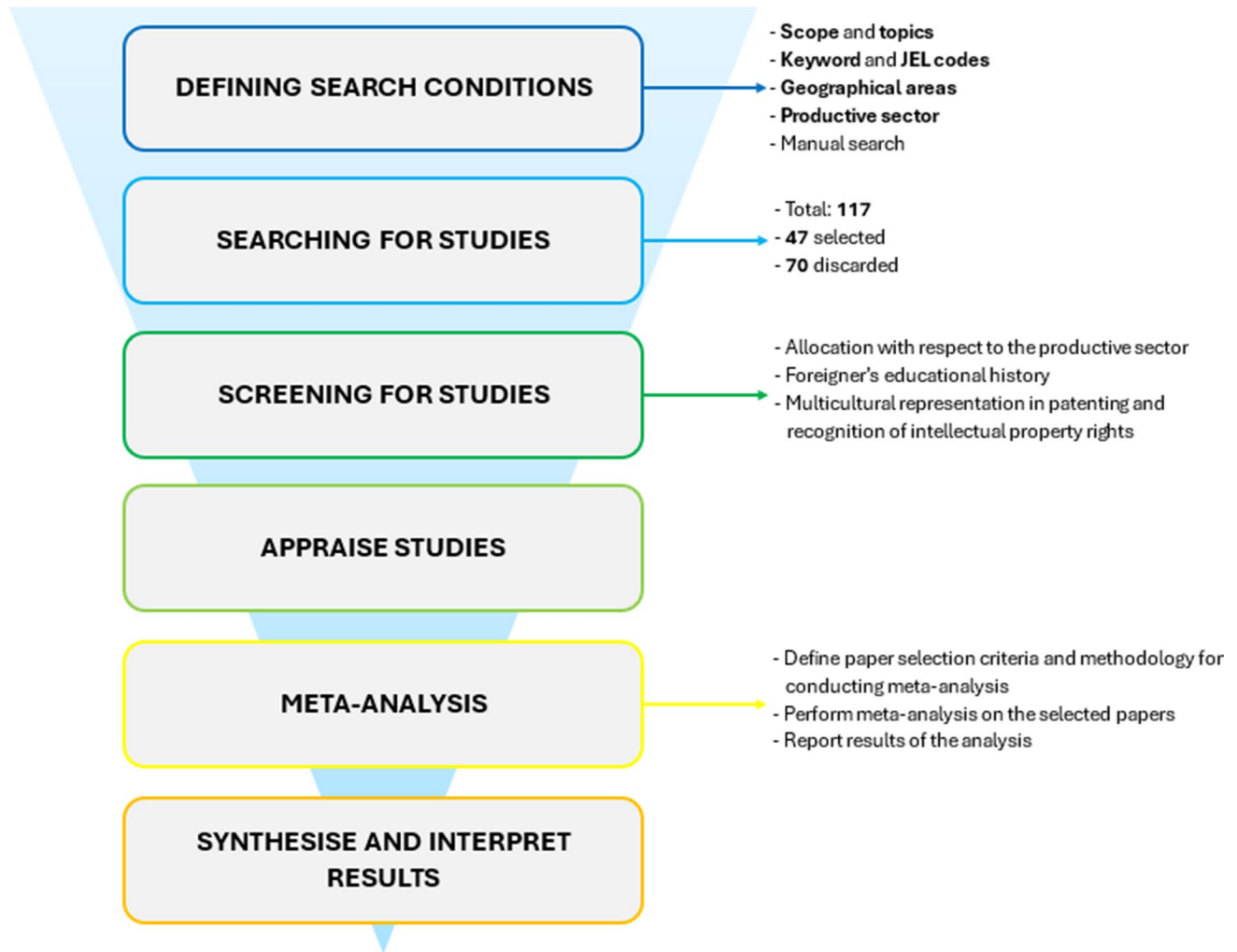
Fig. 3 Methodology overview

articles selected, 40 were analysed, while 70 were discarded due to the incompatibility of the abstract with the scope and purpose of our research question. In addition, seven articles were further added to our selection through a manual search in order to complement and extend the aggregate of data collected through keywords analysis. Specifically, these were studies on the link between immigration and innovation carried out at regional level, precisely in the European Union.[1] A total of 117 articles were therefore included in our database of eligible studies, and 47 were finally examined during the drafting of the article. These articles were subsequently sorted and classified according to the source database, author, year of publication, journal, JEL code, keywords, geographical scope, and other dimensions that we considered relevant for our analysis.

Notably, 89.4% of the selected articles took an empirical approach, while only 10.6% tackled the issue from a theoretical perspective. For the selection of existing literature, attention was also paid to the recurrence of JEL codes, focusing on how often the following codes appear in the selected papers: F22 (international migration), J6 (mobility, unemployment, vacancies, and immigrant workers, more specifically JEL code J61, concerning geographic labour mobility and immigrant workers), and O31 (innovation and invention: processes and incentives). Specifically, the recurrence of the JEL code J61 has been noted. It occurs in 15 out of 47 selected articles amounting to a relative frequency of 16.1%. Significantly, the JEL codes F22 and O31 appear in 11.8% and 9.7% of the studies included in our database, respectively. As illustrated in Fig. 4, the majority of the considered studies has been published between 2000 and 2019, whereas only a limited number of research before 2000 contributed to the state of the art in the field.
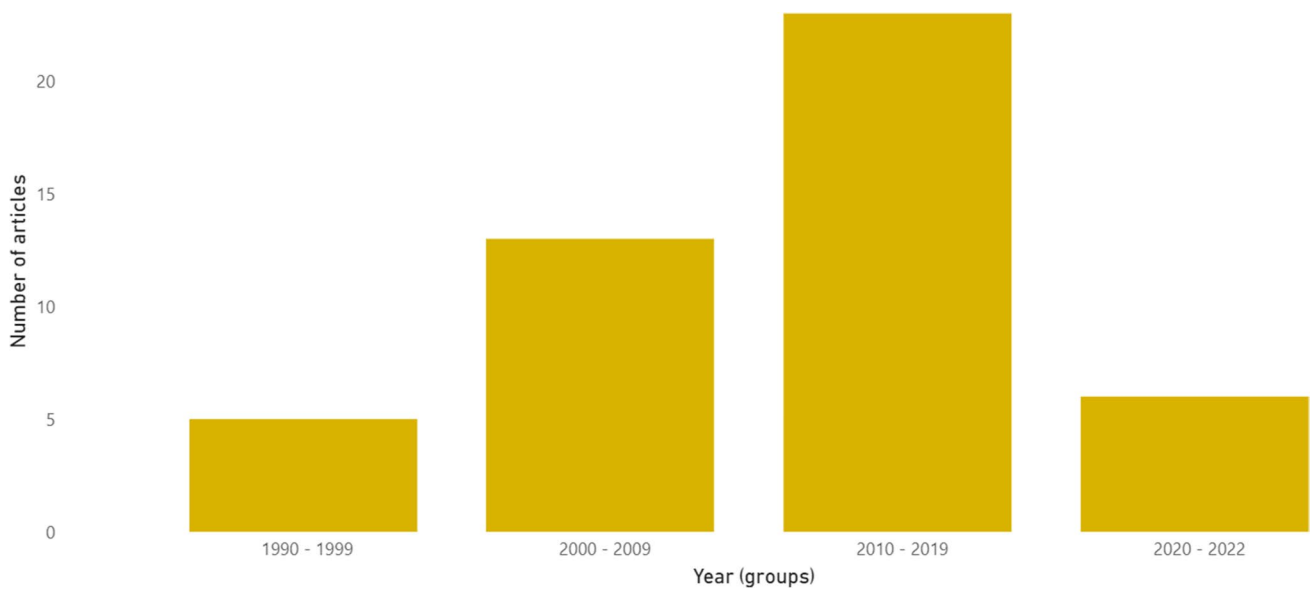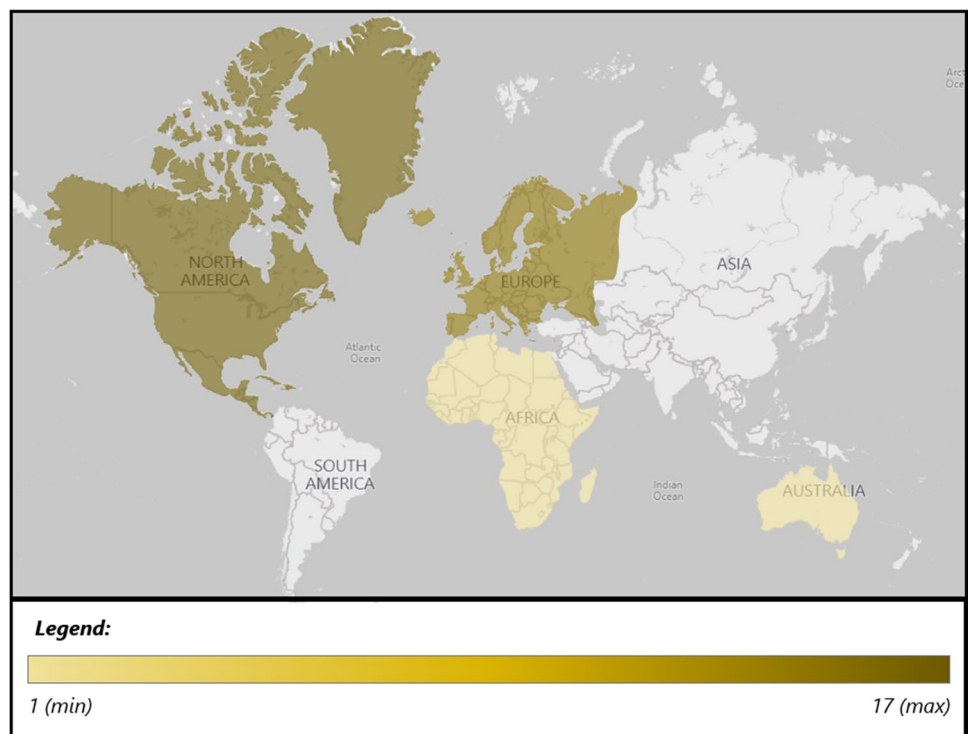
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[1] See, inter alia, Ivlieva (2015), Fassio et al. (2019), Solheim and Fitjar (2018), and Mayda et al. (2022).

Fig. 4 Analysis of selected articles by year of publication (1956–2022)

Fig. 5 Analysis of selected articles by geographical macro-area per continent

Overall, the frequency of articles by year of publication seems to suggest that the examined topic is a relatively recent phenomenon, with a significant prevalence of articles (more than 75% of the total number of papers considered) published between 2007 and 2022. Hence, the data suggests a recent scholarly interest in this specific theme. To conduct this research effectively, we must consider the geographical areas and scope addressed by the selected articles.

By observing the graph above in Fig. 5, it is reasonable to draw the conclusion that, from a geographical perspective, the majority of the studies considered refer to the North American (17 studies) and European (13 studies) continents, followed by Oceania (1) and Africa (1), whereas none of the articles focused on Asia and the rest of the world. This is probably connected to the importance of the topic for those countries which historically represented a gateway for
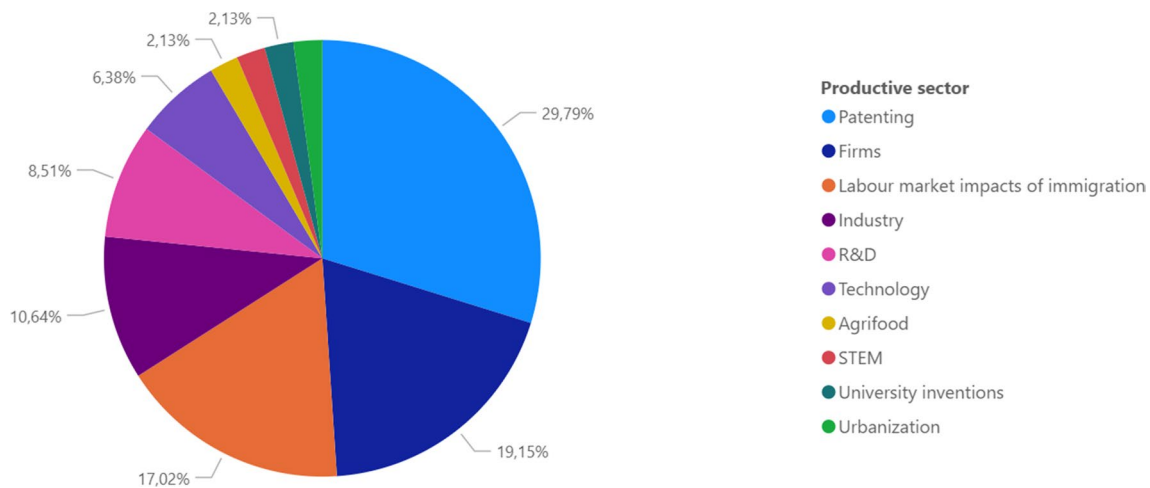
Fig. 6 Analysis of selected articles by production sector

immigration. The remaining nine articles did not focus on a single continent, but referred to the entire world.

For the purpose of our research, it appears to be worthy of note that the vast majority of empirical findings favourably evaluated the impact of educated newcomers on the overall level of innovation, measured in terms of patenting by local firms and economic and income growth. Especially by observing a vast convergence between US and European academic approaches, innovation is intended as the creation of private knowledge and new patent applications. Simultaneously, the consideration of educated migrants resides in the awareness of the role of high-skilled workers in fostering competitiveness and innovation. As a consequence, implications for policymakers concerning the attraction of this specific category of migrants emerge, as skilled professionals could potentially configure themselves as inventors. Empirical findings from Bosetti et al. (2015), among other sources, indicate that a greater presence of skilled migrants is linked to increased knowledge creation. This suggests that policies focused on attracting and utilising skilled migrants in Europe's professional workforce can enhance the EU's competitive edge in innovation. For this reason, attention has been placed on the focus of the selected articles: the productive sector.

Notably, most of the examined papers empirically investigated the contribution of educated and high-skilled immigrants on various sectors of the economy. This research, as shown in Fig. 6, primarily revolved around the patenting sector (30% of the selected papers) and the firms sector (19%). Furthermore, 17% of the studies focused on the effects of immigration on the labour market, while the industry sector received attention in 11% of the studies. Research and development (R&D) was a subject of interest in 9% of the studies, with technology being the focus in 6% of them. The STEM sector, agrifood, university inventions, and urbanisation each

garnered 2% of the research, reflecting a diversified approach to examining the impact of highly educated immigrants across various sectors.

Immigrants' Impact on the Patenting Activity and Labour of Host Countries

It is undoubted that innovation is of central importance in modern economies due to its impact on growth, despite its rather complex and multi-faceted phenomenon and the lack of widely accepted indicators. Indeed, empirical investigation is still prominent to identify the main factors contributing to the spur of innovation and, in turn, economic growth (Bratti and Conti 2018). Therefore, due to the contemporary unprecedented size and scale of migration patterns, the economic literature has seen a new interest in the investigation of the role of immigration on innovation, with a focus on the question as to whether the trans-border movement of skilled labour force has the capacity to (positively or negatively) influence the economic performance of host countries and simultaneously contribute to knowledge spillovers and welfare gains in the long run through increased competitiveness (Maré et al. 2011). As far as innovation is concerned, knowledge creation is widely considered the main process through which immigration potentially influences the economic development of destination countries: by examining the age of mass immigration, Sequeira et al. (2020) found the effects of skilled immigrants on the economies of the host countries to be beneficial both in the short and the long run, by increasing the whole population's welfare and decreasing the level of poverty and unemployment. In this respect, the relationship between immigration and innovation is based on the interaction of numerous variables. Among these, immigration inflows alter the demographic composition of

host countries, thus contributing to the population growth of certain regions. At the same time, an increase in the availability of human capital and labour force may occur (Coppel et al. 2001; Dolado et al. 1994). The former study suggests that the human capital brought by immigrants could cancel the negative effects of population growth, thus leaving room for a positive impact on the long run. Notably, the way in which immigrants decide to allocate is not an independent choice, but appears to be influenced by pre-existing conditions, namely, pull factors that encourage migration, including economic dynamism and the innovativeness of the destination area, along with the ethnic distribution of the foreign communities to which they belong (Mahroum 2000). Burchardi et al. (2020) propose additional allocation considerations, including the underlying link between historical and present migration, the local economy, and ethnic proportions. In light of this, even though immigrants' different backgrounds in terms of their skills, culture, and knowledge, immigration may have the potential to stimulate innovation activities within the local community through interaction.[2] In Nathan's research (2011), it is demonstrated that ethnic inventors hold significance in driving innovation in the UK. In particular, the diversity of inventor communities in terms of ethnicity can yield positive outcomes in terms of innovation productivity. With a focus on knowledge, Jonkers (2011) shed light on the intrinsic entrepreneurial attitude of the category of economic migrants, in order to investigate the possibility of immigration to enable innovation through positive spillovers on the managerial and entrepreneurial skills of native workers. Indeed, the specific category of migrants considered is usually perceived as resourceful and business oriented thanks to a natural opportunity-seeking and risk-taking behaviour. Based on 1940–2000 data concerning skilled immigration to the USA, Hunt and Gauthier-Loiselle (2010) emphasise that knowledge spillovers of high-skilled immigration result on average in a higher number of patent applications per capita, either by a higher education invested through immigration policies or by inspiring natives because of their inventiveness and entrepreneurship.[3] Possibly, immigrant's countries of origin may similarly benefit from relevant sources of wealth in terms of remittances and welfare gains flowing from highly educated migrants after a period of time in foreign countries; remittances could also cover the cost of education and transportation, in addition to aiding the household of origin with humanitarian or insurance purposes (Agarwal and Horowitz 2002).

Nevertheless, in terms of empirical research on the subject, current studies have an inclination to focus on short-term consequences rather than investigating long-term implications. As a result, the topic transpires to be understudied and especially limited on empirical research on North American data, thereby widening the gap between the subject's economic importance and the existing literature.

On the basis of available studies, there is no doubt around the fact that immigrants have proved essential for the leading role of the USA as an innovative and entrepreneurial country, especially after the approval of the Immigration and Naturalization Act in 1965, which altered national immigration policy allowing skilled individuals from all over the world to enter the USA. Markedly, the subsequent visa system was based on a different classifications of incomers, and it replaced the previous national regulation, which banned Asian immigrants from the USA. As a result, immigrants coming from India, Taiwan, China, and South Korea, among others, had the possibility to contribute to the internationalisation of the US technological sector, thus acting in support of the pioneering innovative position of the USA (Puffer et al. 2018). To this respect, a number of academic studies have noted the presence of immigrants among the top performers in the USA. Specifically, 26% of Nobel Prize winners in the decade 1990–2000 were awarded to immigrants (Peri and Sparber 2009), as well as 25% of the founders of US companies supported by public venture between 1990 and 2005 and a quarter of the new high-tech companies with revenues of more than $1 million in 2006 resulted to be born in foreign countries (Hunt and Gauthier-Loiselle 2010). Another conclusion of the previously cited study is the significant effect immigration has on native US citizens in terms of innovation, due to an increase in patent per capita, resulting in positive knowledge spillovers. Conversely, when it comes to the assessment of the impact of immigration on innovation in Europe, empirical evidence results to be restricted. By taking into consideration the Eurozone's structural features and the refugee crisis phenomenon affecting the area for the past decade, it would nonetheless be erroneous to affirm that migration and innovation proceed according to different and separate paths. Specifically, Europe is currently experiencing unprecedented challenges, including ageing population, decreasing birth rates, and existing levels of unemployment (particularly exacerbated by the Covid-19 pandemic), which would eventually affect the pace of growth of European economies and the European labour market in future decades. Therefore, both competition and innovation figure among the top priorities on the agenda of the Member States. All in all, the underlying belief that high-skilled immigrants can be potential drivers of innovation and economic growth in the Member States has led the European Union to launch a set of initiatives aimed at attracting trained and qualified migrants, through the European Council

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[2] An insight into the positive externalities of openness can be found in Roper et al. (2013).

[3] Similar results are found by Akcigit et al. (2017) considering the period 1880 to 2000.

Lisbon Strategy and the Commission Blue Card Directive within the framework of the Global Migration Approach. Most research has primarily focused on the impact of immigration on the economies of either host or home countries, particularly examining the connection between immigrant arrivals and wages. For instance, Borjas and Katz (2007), who concentrated on immigration from Mexico to the USA, found a negative association between low-skilled immigration and the wages of low-skilled workers. Because of the educational gap between natives and immigrants, this effect is also observed among native workers of Mexican descent. This immigration led to a significant wage decrease of approximately 4–5% for relatively low-skilled native workers from 1980 to 2000. Borjas (2003) also observed substantial adverse effects on workers with similar educational backgrounds and experience, resulting in a similar conclusion of reduced income and job opportunities. Conversely, other studies, such as Card (2009), revealed that immigrants are predominantly distributed in the top and bottom of skills distribution, and therefore residual inequality among them is higher than among natives. Therefore, the author concludes that the overall wage inequality within the US economic system appears to be positively related to immigration levels, especially over the long term. However, following Ottaviano and Peri (2008), the impact of immigration on wages differs depending on whether natives and foreign workers are imperfect substitutes or not, reflecting a positive effect on natives' wages and a negative influence on immigrants' salaries. Empirical data suggests a moderate level of competition between natives and immigrants. Although less-skilled natives were displaced from immigrant-intensive industries to some extent during the 1970s and 1980s, there is no consistent or systematic impact on the employment rate of less-skilled natives.[4] Hence, comprehending the skill configuration is the key variable to understand the impact of foreign workers' arrival on domestic outcomes. Assuming that the capital supply has perfect elasticity and immigrants possess the same skill level as natives, the additional workforce can be readily assimilated into the economic system through the mechanism of expansion. However, if the skill distribution of migrants is different and there is no adjustment mechanism, the inflow of foreign-born workers could lead to wage adjustments (Ottaviano and Peri 2008). Indeed, the wage losses of natives are likely to be mitigated depending on immigrants' specialisation, which is generally distinct from natives' in spite of similar education levels. Eventually, the study conducted by Das et al. (2020) considers the

potential effects of migration-driven innovation on unskilled sectors and the consequent reduction of existing wage gaps. What emerges is the fact that other relevant variables—prices, trade, public expenditure, and fiscal balance—are able to affect the economy of host countries despite labour market changes being one of the most relevant channels. A further conclusion of this study reveals that investing primarily in skilled migrants in the R&D sector creates pay discrepancies; to address this, R&D should assist the unskilled workers in the manufacturing industry. In their examination of how immigration promotes innovation, Mazzolari and Neumark (2012) explained that the arrival of immigrants heightens local aggregate demand by increasing import quantities and providing a wider selection of local production, possibly influencing natives' choice of consumption, thus leading to potential welfare gains. However, in the short term, the increased labour supply necessary to sustain such output growth may come from newcomers. Yet, in the long term, further investment is necessary, particularly in technology, to stimulate innovation in both process and product. This, in turn, may enhance firm growth and the creation of start-ups, which typically represent the foundation of innovative activity (Freeman and Soete 1997). Over time, the allure of urban centres may prompt job-seeking immigrants to settle there, leading to population growth, agglomeration, and subsequently, higher levels of innovation. Maré et al.'s study (2011) identifies a divergent pattern. Specifically, after conducting an in-depth analysis of the average levels of innovation and the composition of the labour force in New Zealand, the authors concluded that there is limited evidence to suggest a positive systematic relationship between workforce specifics and innovation. An extensive examination of New Zealand's 2006 Census of Population and Dwellings illustrates a firmly established correlation between innovativeness and firm-level variables. The size of a firm, the inclusion of highly skilled workers, and, specifically, research and development spending appear to be the primary catalysts for implementing new production processes, rather than the proportion of immigrants residing in a given region. Instead, highly skilled migrants primarily contribute to the establishment of novel products and services within the nation. Eventually, it should be noted that income inequality of source and destination countries equally play a role on immigration decisions. In particular, Borjas (1999) acknowledges the fact that migration decisions are mainly motivated by wage differentials. The author seems to be in line with the research of Sir Hicks, who first argued in *The theory of wages* (Hicks 1932) that differences in net economic advantages and, above all, differences in wages are the main causes of migration. In addition, income inequality is characterised as the starting point of all modern studies of migration. More specifically, Borjas (1999) explained that the emigration rate is likely to fall when the

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[4] Further analysis of the skill set of the workforce is presented in Dustmann et al. (2008), where the authors outline a possible theoretical model to explain the impact of immigration on the labour market of host countries and its subsequent effect on native workers.

mean income in the source country rises, when the mean income in the host country falls, and when the time-equivalent migration costs rise.

While not strictly focusing on immigration, Nathan and Lee (2013) propose a different analysis that pivots on cultural diversity to evaluate its impact on innovation, entrepreneurship, and sales strategies. In their study of 7600 firms in London from the 2005–2007 period, they found that diversity positively affects innovation in terms of introduction and commercialisation of new products, increasing the access to international markets and spurs of entrepreneurship. The following findings were obtained by this study: first, the most creative enterprises are those founded by migrants; second, knowledge and diversity are less diffused in specialised industries; and third, businesses are more oriented towards domestic and national markets. Contrasting findings are conversely advanced by Bratti and Conti (2018), whose analysis employs province-level data on total patent applications in Italy from 2002 to 2009. Specifically, the use of an IV estimation approach revealed that the effects of migration on patents depend on migrants' skill levels. For this reason, low-skilled immigrants negatively impact patent applications per million inhabitants, whereas high-skilled migrants have a positive impact; thus, immigration has no influence on the country's innovation as a whole. Against this background, we can argue that various, and at times opposed, results are reached in the literature presented so far. In general, most of the works using micro-level data for wider areas, such as regions NUTS-2 in Europe or states in the USA, highlight a positive effect of immigration on innovation, in particular, on patents. However, no substantial effect is revealed in analyses based on observations from a smaller area, as the impact of migration and diversity relies primarily on the educational achievements of the migrants and their sectors of employment. Two conventional benchmarks are employed within the economic literature in order to measure the level of innovation of a particular economic system, namely, the growth rate of total factor productivity (TFP) and the total number of patent applications. In general, TFP accounts for production advancements deriving from changes in labour quality, which in turn depend on age, education, skills, and provenance: by researching the effects of immigration on innovation in three European nations (the UK, France, and Germany), it was discovered that young educated migrants bring more original ideas than aged and/or low-skilled migrants, although, findings may slightly differ by country (Venturini 2012). Chellaraj et al. (2008) present three clear justifications for utilising patents as the primary indicator in innovation research. First, patents have a close affiliation with the protection of intellectual property and copyrights, and they provide insights into a significant amount of a company's inventive activities. Second, freshly awarded patents reflect the uniqueness of an invention, which is often the outcome of an original and non-trivial method to investigate a certain problem. Third, the high costs associated with patent applications indicate both the financial significance of the technical breakthrough in the field and the company's ability to seek exclusive rights for their idea. Patent applications, whether in a university or non-university context, are growing as a result of international graduate students, who are contributing significantly to scientific advancement. Considering the points mentioned earlier, our focus will be solely on utilising patent applications as a metric for assessing innovation. This will involve the examination of data from various time periods, with a particular emphasis on data related to the USA.

Ozgen et al. (2011) initially identified a set of pivotal factors through which migrants influence patenting activity. These factors encompass the scale and density of the population, the proportion of foreigners in the population, the skill composition of the migrant flow, and the diversity of immigrants. Furthermore, immigrants demonstrated a higher number of patents per capita, with a ratio of 2.0 compared to 0.057 for native-born individuals. In cases involving licensed or commercialised patents with the potential to significantly benefit society, immigrants maintained a slight advantage. However, the percentage of immigrants who successfully commercialised a patent (1.2%) was only marginally higher than that of native-born individuals (0.6%). Kerr and Lincoln (2010) revealed similar trends, indicating a significant increase in the proportion of US patents awarded to Chinese and Indian inventors residing in the USA, reaching 15% of all patents by 2004. Additionally, Wadhwa et al. (2007) observed that 24% of patent applications filed overseas from the USA were made by individuals who were not US citizens, demonstrating a considerable relevance that skilled immigrants hold on USA's prosperity throughout the last decades. In the context of patenting, Winters (2014) found that STEM graduates, whether they are native or foreign born, exert a substantial and statistically significant influence on patent intensity in metropolitan areas. As a result, the greater the number of STEM graduates, the greater the advantages on local and worldwide markets. Additionally, immigrants possessing scientific and engineering degrees have a distinct advantage over natives, especially noticeable in the presence of STEM backgrounds or post-college education (Hunt and Gauthier-Loiselle 2010). Their contribution significantly boosts innovation in the USA, without placing native-born individuals at a disadvantage, rather they assist them by sharing their expertise and entrepreneurship through knowledge spillovers. In fact, immigrants' higher proportion of STEM education helps accelerate innovation (Venturini et al. 2012). Research by Burchardi et al. (2020) indicates that immigration positively influences patenting, with a unitary increase in annual patents per 100,000 inhabitants corresponding to the arrival of 10,000 immigrants
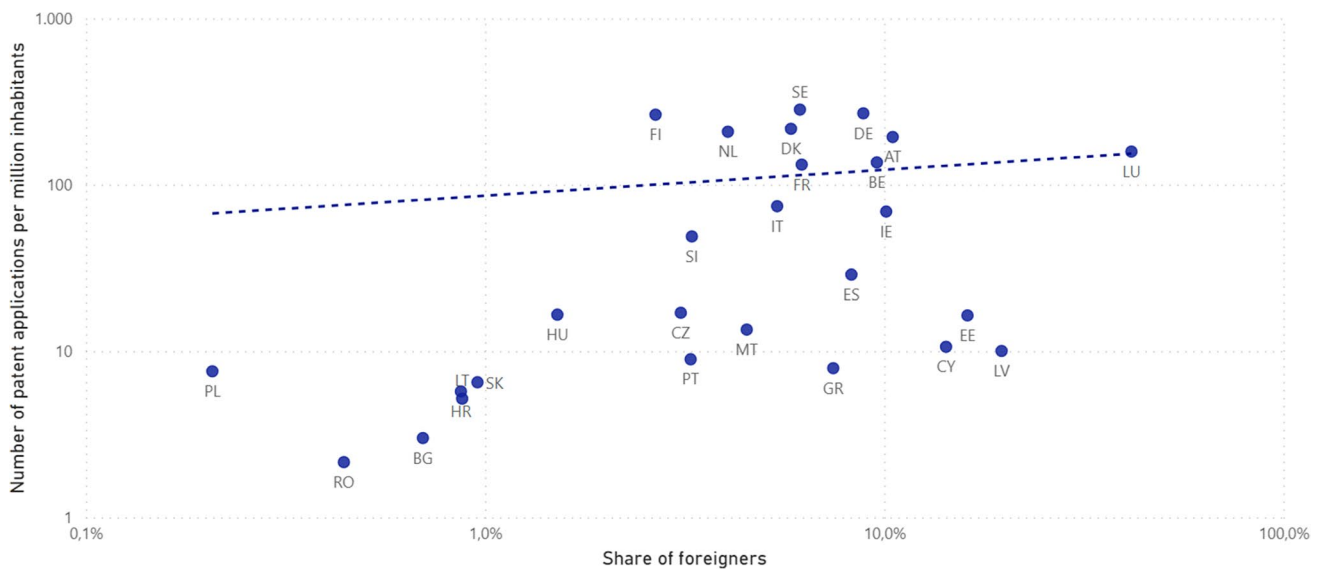
Fig. 7 Relationship between patent applications and average share of foreigners in various European countries during the period 1998 to 2017 (reprocessing of Eurostat data, 2017)

over a 5-year period. Moreover, historical data from the US Patent and Trademark Office from 1860 to 1920 underscore the positive impact of immigration on innovation: non-skilled workers contribute to the labour force, whereas the skilled immigrants spread their knowledge and techniques in order to boost productivity altogether (Sequeira et al. 2020). Sinoi (2019) examines the positive impact of skilled immigrants on innovation (measured by the number of patents), emphasising the need for financial support in Research and Development. To boost knowledge creation and economic growth, the EU should attract skilled migrants and increase investment in R&D. This nexus is reinforced by factors such as financial support for R&D, investment in tertiary education, employment in knowledge-intensive sectors, and the presence of scientists and engineers in the population.

In Fig. 7, a positive correlation between the share of foreigners and patent activity can be observed, also at the European level. Universities also play a role in innovation. Following the Bayh-Dole Act in 1980, which enabled the commercialisation of university research, there has been a significant increase in innovation through the licensing of university-developed inventions, resulting in a technological progress for the USA (Chellaraj et al. 2008). The partnership between the private sector and academia further enhances patenting activity. Industries increasingly outsource research to universities and academic departments, often purchasing intellectual property rights for new inventions developed at universities. Similar studies have taken place in Europe. Ozgen et al. (2011) analysed patent application data across 170 European regions during two time periods (1991–1995 and 2001–2005) at the NUTS 2 level. Their findings suggest that the composition of

immigrants, in terms of education, skills, and cultural diversity, positively influences innovation. The study indicates that diverse urban areas encourage the cross-fertilisation of ideas, leading to heightened innovation. However, it underscores a critical diversity threshold, noting that the positive effects on innovation are evident beyond the first quartile of diversity distribution among NUTS2 regions. Figure 8 illustrates the annual number of patent applications per million inhabitants, featuring data from the top 10 EU countries.

High-skilled immigrants play a crucial role in assessing the impact of immigration on innovation, and their educational background is widely recognised by scholars and theoretical models alike. Indeed, it is indisputable that the influx of highly educated immigrants modifies the composition of the local human capital, positively influencing the generation of innovative concepts (Sinoi 2021). Stephan (2010) observed a significant number of foreign students earning doctorates in the USA, while the percentage of postdoctoral researchers who are US nationals or permanent residents increased modestly. Visa restrictions may have contributed to the decline in temporary resident postdocs during the early 2000s. Another consequence is the large presence of foreign-born people in the academic sector as a result of the visa restrictions on the industry field, which normally offers greater earnings in comparison.

Figure 9 clearly illustrates that foreign scholars have provided a major contributor to the rise in postdoctoral positions. Specifically, from 1985 to 2006, the proportion of postdocs holding temporary resident visas more than tripled, from roughly 7000 in 1985 to over 20,000 in 2006; this represented an increase from 42 to approximately 60%. In contrast, during the same period, the proportion of postdocs
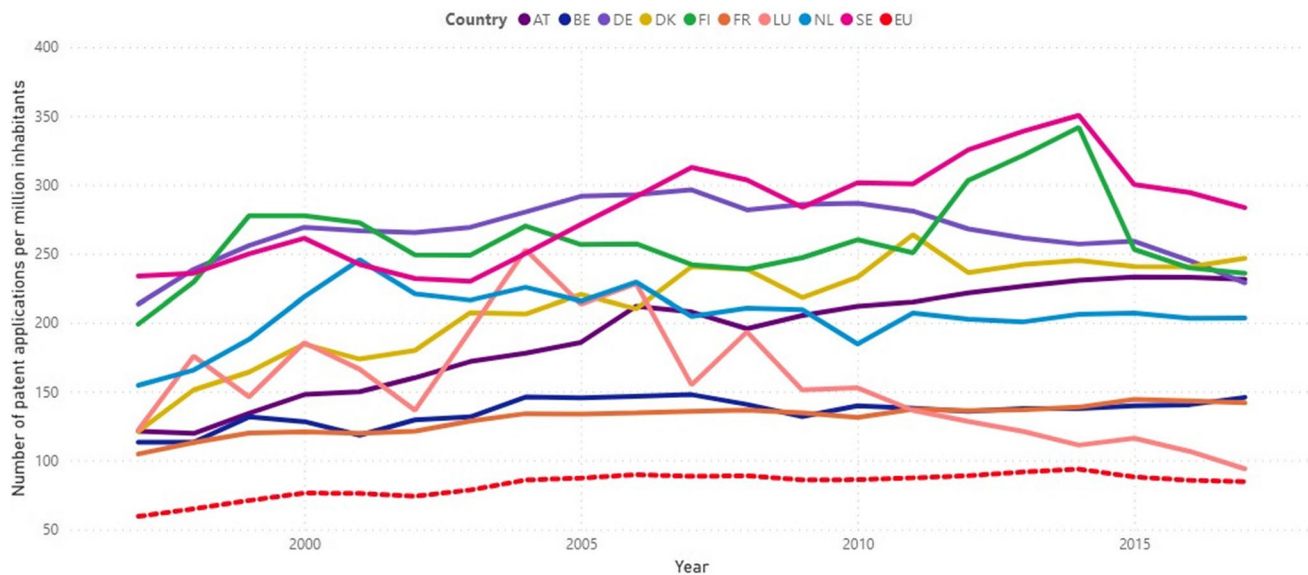
Fig. 8 Number of patent applications (per million inhabitants) per year, including data on the top ten European countries and the EU average

who are US citizens or permanent residents increased by less than half. The decrease in temporary resident postdoctoral researchers observed in the early 2000s may be explained due to stricter visa security measures. In 2001, less than 8% of J-1 visa applications were denied, whereas in 2003, 16% were rejected. Still, drawing the conclusion that inflows of science- and engineering-educated immigrants should be reduced to the subsidisation of natives in the study of STEM disciplines appears to be inappropriate, since natives could potentially have fostered US economic growth in sectors other than science and engineering (Hunt and Gauthier-Loiselle 2010). In a similar vein, immigrants' engagement in STEM fields is not necessarily due to their supposed superiority in these areas compared to natives; rather, it may be attributed to immigrants' inclination to invest in education within these disciplines (Kerr 2013). Additionally, when considering international students and immigrants in general, it is crucial to account for the phenomenon of "homecoming" after studying or working in the USA. Stephan (2010) estimates that approximately 40% of foreign PhD-awarded students leave the USA about a decade after obtaining their degrees.

Meta-analysis

In order to offer a more comprehensive insight into the topic, we decided to employ a meta-analysis, that is, a statistical analysis of a large collection of analysis results from individual studies, for the purpose of integrating their findings (Glass 1976). Due to the large number of topics discussed in this paper, the meta-analysis will have to focus on only one, namely, the impact of immigration on the patenting activity.

In particular, the focal point of the analysis will be the relationship between patent applications and the share of high-skilled migrants in destination countries. From the 47 papers examined, the number of papers of interest was then reduced to 17, i.e., all those that dealt to some degree with the relationship between migration and patenting activity. Of these, however, a further selection had to be made, as many did not provide usable empirical results, others had missing data, and others tested relationships between other variables, such as the share of total immigrants. We have also observed that different articles in literature frequently introduce distinct frameworks. This happens because each study examines different unique relationships and events. As a result, this leads to less consistency across the studies and, consequently, a greater challenge in synthesising their findings. In order to address these challenges, we opted to focus exclusively on research that employed OLS regressions. In these studies, the dependent variable was the number of patent applications (ln), and one of the independent variables in the model was the proportion of high-skilled immigrants. Synthesising regression slopes is challenging for several reasons, and scholars have suggested multiple methods of analysis (Aloe 2015; Becker and Wu 2007). To conduct a meta-analysis of the selected studies, we chose to employ the partial correlation coefficient method, which was also recommended in Aloe and Thompson's (Aloe and Thompson 2013) and Aloe's (2014) works. To create visual representations and conduct the analysis, we used the R metafor package. The sample used has thus been reduced to 13 articles, as reported in Table 1.

Where n_i is the number of observations, b_i the regression coefficients, se_i the standard errors, t_i the t-statistics, and m_i the number of independent variables used in the model.

Fig. 9 Number of postdoctoral researchers in science and engineering employed in academia between 1985 and 2006 (Stephan 2010, p. 98)
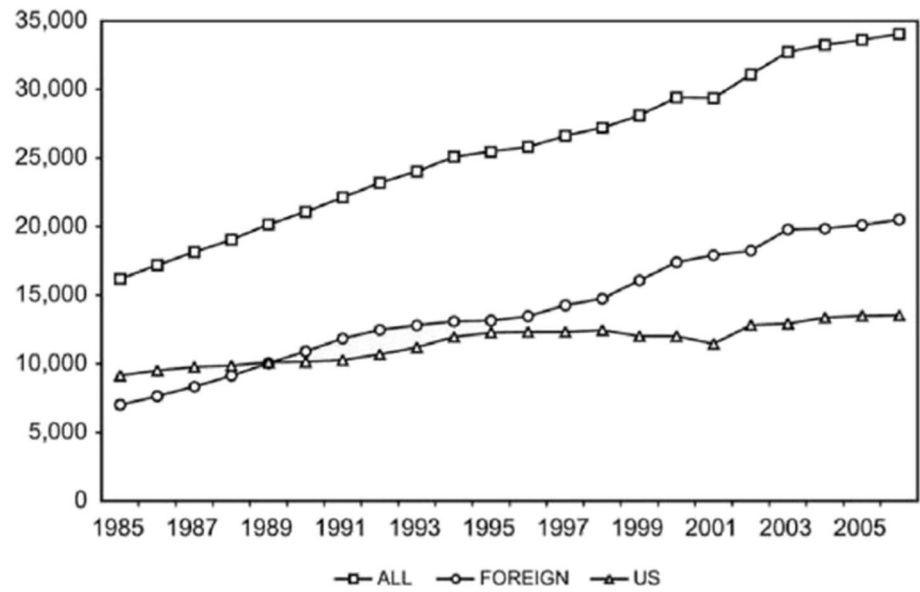

Table 1 Reported results of studies included in the meta-analysis

	Authors	Year	Countries	Dataset	n_i	b_i	se_i	t_i	m_i
1	Akcigit et al.	2017	USA	USPTO	399	0.4610	0.0440	10.4773	1
2	Bosetti et al.	2015	EU	OECD	213	0.0766	0.0276	2.7754	3
3	Bratti et al.	2018	IT	ISTAT	927	0.0720	0.0160	4.5000	1
4	Burchardi et al.	2020	USA	USPTO	18,846	0.1960	0.0970	2.0206	1
5	Chellaraj et al.	2008	USA	USPTO	39	0.1140	0.0567	2.0100	8
6	Crown et al.	2020	AUS	IPGOD	1256	0.0317	0.0118	2.6864	1
7	Fassio et al.	2019	UK, FR, DE	PATSTAT	457	0.0360	0.0210	1.7143	4
8	Kerr et al.	2010	USA	USPTO	3653	0.0740	0.0280	2.6429	1
9	Mayda et al.	2022	FR	ORBIS, INPI	1504	0.1070	0.0200	5.3500	2
10	Nathan	2011	UK	KITESPATASTAT, LFS	89,312	− 0.0100	0.0150	− 0.6667	2
11	Sinoi	2019	EU	EPO, OECD	1040	0.1040	0.0262	3.9700	7
12	Sinoi	2021	EU	EPO	70	1.9960	0.7448	2.6800	5
13	Winters	2014	USA	USPTO	307	24.8020	3.9160	6.3335	1

A random-effects meta-analysis was carried out on the results of the studies in Fig. 10. The collected effect size was found to be statistically significant (p-value < 0.0001 with zero not included within its confidence interval), but of relatively small magnitude.

The weighted mean partial effect size of the 13 effects, calculated using a random effects-model, was 0.159 [95% CI: 0.079, 0.2386]. In this meta-analysis technique, we considered the existing partial correlation between outcome variables and regressors explained above, using the number of predictors in the model as a moderator. The analysis suggests a partial correlation between the high-skilled migrant share and the patenting activity in the destination country, even though it is relatively weak. In the implementation of the meta-analysis, as stated earlier,

several challenges emerged. Assessing the connection between an explanatory and a response variable involves various approaches in the research studies, which are not always readily comparable. In many instances, papers did not provide detailed descriptive statistics of the studied variables, along with lacking crucial measures of variation such as standard errors, or utilising different methods to measure variables and outcomes (Nieminen 2022). The technique of meta-analysis encounters particular limitations when handling multivariable relationships, as the statistical outcomes rely on the inclusion of other variables in the analysis. Further calculations and data transformations are necessary to estimate effect sizes when consolidating these studies (Borenstein et al. 2021). Obtaining a comprehensive overview of the relationships
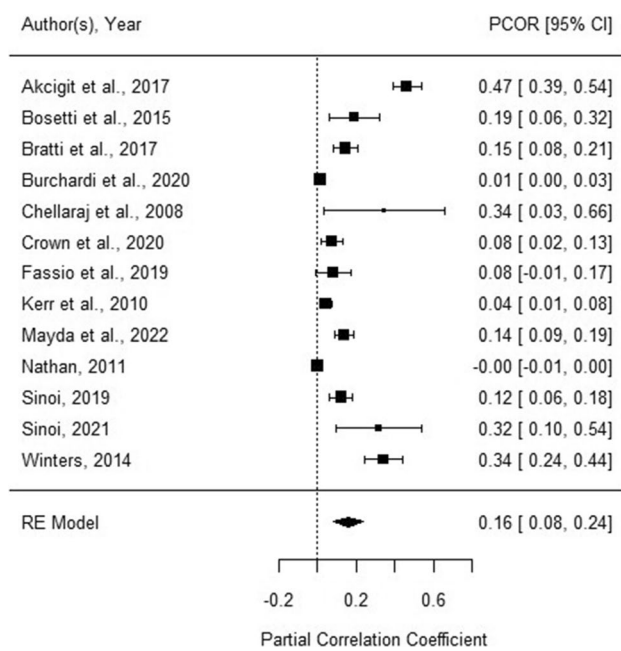
Fig. 10 Patent activity and high-skilled migration association in destination countries is visualised in a forest plot

studied presents a challenge. As such, consistent reporting of results across comparable effect sizes is crucial. Establishing guidelines for this purpose within the scientific community would be advantageous. In particular, the provision of detailed descriptive statistics is critical in studies using multivariate regression techniques. This will aid other academics in the aggregation and meta-analysis of effects, as recommended by Nieminen (2022). In conclusion, this meta-analysis aimed to consolidate the findings from various studies that explored the impact of the proportions of skilled migrants on the innovation of destination countries, assessed through patenting activity. The method used, based on partial correlation coefficients, provides a practical measure of assessing effect size, allowing results from different multivariable studies to be combined. Consequently, we obtained a low effect size, suggesting that the proportion of skilled immigrants alone does not have a significant impact on the patent activity of the destination country.

Conclusion

To conclude, the analysed literature and the employed methodology have demonstrated the importance of the debate on the association between immigration and innovation. Furthermore, the presence of different dimensions of the impact of newcomers on host countries has been identified, such as patenting activity, demographic and agglomeration forces, and labour market influences. The studies considered

have shown that the income inequality between the countries of origin and destination, as well as the immigrant's educational level, also contributes to assessing the impact of immigration on the overall level of innovation and economic growth of host states. Immigrants contribute to economic growth and innovation in destination countries through increased cultural diversity, demographic concentration, and agglomeration in large cities, along with spillovers of entrepreneurial skills and scientific knowledge. However, a debate exists over the impact of immigration on the total number of patents awarded. Several authors have found a positive correlation between immigration and the patenting activity during a specific time period, including university patenting. Conversely, some scholars argue that sustained immigrants' inflows are not necessarily linked to higher innovation outcomes. The results of the meta-analysis confirm that the proportion of skilled immigrants alone does not significantly influence patent activity in the destination country. However, conducting this meta-analysis posed certain difficulties in consolidating results, and we thought it would be beneficial for upcoming research to set standardised research protocols or conduct more extensive studies funded by the government, in order to reduce heterogeneity in outcomes and facilitate the streamline of aggregation. Moreover, the role of education as a driver of innovation remains largely undisputed, since positive spillovers of highly educated human capital are pivotal to spur the development of new ideas. Considering the labour market in destination countries, various immigrant effects emerge. Some studies show little evidence of consistent displacement of low-skilled natives from the industrial sector. It is often argued that investments in R&D are crucial for long-term innovation and output growth. In this context, our review offers important insights for policymakers. Immigrant-driven high-skilled migration might not be the silver bullet for innovation: heavy reliance on them may not be effective, despite their significant positive influence on innovation in the short run. However, this does not support stricter migration policies. In summary, our comprehensive review finds immigration to be an enhancement of diversity with no evidence of a negative impact on a robust R&D sector. Further research is needed to explore diversity's role in firm sizes and education levels, emphasising the importance of balanced approaches.

Author Contribution • Luigi Capoani: Conceptualization; Original Draft; Literature review; Methodology; Supervision.
• Valentina Chabert: Methodology, Investigation; Literature review; Review & Editing.
• Andrea Izzo: Methodology, Data collection, Analysis; Review & Editing.

Declarations

Ethical Approval This article does not contain any studies with human participants performed by the author.

Consent to Participate Not applicable as this study did not involve human participants.

Consent for Publication Not applicable as this study did not involve human participants.

Competing Interests The authors declare no competing interests.

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