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Yannu Zheng and Olof Ejermo

Abstract

Using a new database that matches patent applications by Swedish residents with demographic information from 1985 to 2007, we examine differences in inventive performance by individuals of foreign and domestic origins, in terms of quantity (probability of patenting, total number of patents per inventor) and quality (forward citations, probability of grant) of patents. We further compare adult and child immigrants with their Swedish-born counterparts. Holding other variables constant, we find that the immigrants are generally less likely to patent than the Swedish-born. Nonetheless, the general group of immigrant inventors, including those who migrated as adults, perform as well as the native inventors and therefore seem more positively selected. Compared with the Swedish-born, the immigrants who migrated as children are disadvantaged in both quantity and quality of patents, which may be linked to a lack of Sweden-specific human capital. Whether education was received in Sweden does not seem to make a difference for the immigrants who migrated as adults. In summary, this study provides an initial impression of the inventive performance, contribution, and challenges of distinct groups of immigrants who have differing characteristics and backgrounds.

JEL codes: J15, J24, N30, O31

Keywords: immigrants, inventors, children, adults

1 Introduction

Augmenting the number of highly skilled immigrants can boost workforce diversity, idea development, innovation, productivity, and ultimately economic growth (Goldin et al. 2011; Ozgen et al. 2013; Paserman 2013; Nathan 2014a; Parrotta et al. 2014). In recent years, scholars and policymakers have paid increasing attention to the contribution of the foreign-born to technological development and innovation in their host countries (e.g. Stephan and Levin 2001; Hunt and Gauthier-Loiselle 2010; No and Walsh 2010; Hunt 2011). Most of these studies are based on survey data or case studies from the United States (e.g. No and Walsh 2010; Hunt 2011), but little evidence has been collected for European countries, which differ substantially from the United States, particularly in the origin of immigrants.[1] Unlike the United States, which attracts highly skilled emigrants from different origins (Franzoni et al. 2012), European nations mainly receive highly skilled migrants from neighbouring countries (Breschi et al. 2014).[2]

The US studies indicate that the most innovative and dynamic high-tech industries, such as software, computer science and engineering, have high concentrations of talented immigrants (Goldin et al. 2011), and that these individuals make significant contributions to advancing technology and boosting innovation (Kerr 2010; Hunt and Gauthier-Loiselle, 2010; No and Walsh 2010; Hunt 2011). Sweden shares similarities with the US in certain respects: it has a comparable and increasing proportion of immigrants[3] (Ekberg 2011) as well as a good reputation for openness, advanced technology, and strong innovation capability (OECD

[1]The US immigrants originate mainly from South and East Asian countries as well as Latin America (Pew Research Center 2014). The origins of European immigrants vary substantially between countries (Eurostat 2011).

[2]This may be a result of geographic, linguistic, and cultural proximity as well as established institutional regimes, such as those existing in the Nordic countries and the European Union/European Economic Area (EU/EEA), where free movement of member citizens is allowed between member countries but movement of non-member citizens is restricted (Koslowski 1998). Citizens from other Nordic countries are allowed to live and work freely in Sweden because of the agreements signed between the Nordic countries in 1954 (Stalker 2002). Free mobility has also been allowed for individuals from other EU/EEA countries, since the EEA treaty in 1994 and Sweden's entry into the EU in 1995 (Westin 2000; Cerna 2009).

[3]From 1960 to 2013, the proportion of foreign-born residents increased from 4.0% to 15.9% (Statistics Sweden 2014a).

2008). Sweden, however, not only possesses positive traits similar to the US but also has specific conditions which may negatively affect innovation. For instance, the migration policies in Sweden, historically targeted at refugees, asylum seekers, and tied movers (family-reunification policy) – groups that are usually less educated and skilled (Scott 1999; Bevelander 2000) – can lead to a more negative selection with respect to the skills needed for innovation.

In this paper, we aim to obtain a better understanding of the effect of positive and negative migrant selection on inventive performance through the study of different migration groups in Sweden, which has not been studied before. The results of this study may broaden the understanding of immigration's effects on inventive capability and better characterize the situation of European countries in this respect.

Our study is the first to compare the differences in the inventive performance of immigrants who moved as children (raised in Sweden, migrated under the age of 18) and adults with that of the Swedish-born. Those who migrated as children can differ significantly from both adult migrants and the natives in terms of migrant selection and upbringing experiences. While immigrants who migrated as adults may to some extent be (self-)selected, the children usually do not positively self-select but mainly follow their parents. They may also suffer from a double burden of adaption. First, they usually have to reconcile their home environment with the different culture and language of the host society. Second, they have to attain a Swedish education aligned with the values and educational objectives of the host society (Westin 2003). Immigrants who migrated as adults, on the other hand, may have a direct disadvantage in invention if they are refugees or tied movers, as is the frequent case in Sweden. In some cases, however, they may be more positively selected, for instance if they were hand-picked to work on inventions in one of Sweden's multinational and technologically advanced enterprises.

We also examine the effect of education on inventive performance in two ways. First, for immigrants who migrated as children and obtained an education in Sweden, we examine whether their performance is affected by school performance, measured as final secondary school grade average (high school GPA), which is used as an indicator of ability. Second, for immigrants who migrated as adults, we examine differences in inventive performance between those educated in Sweden and those educated abroad. This distinction is relevant because it may pick up differences in the quality of education, the transferability of education acquired abroad to the Swedish context, and country-specific human capital obtained in the destination country (Chiswick and Miller 1994).

Our investigation uses a unique data set that contains almost all records of inventors with a Swedish address (i.e. both Swedish-born and foreign-born inventors residing in Sweden at the time of filing) found in European Patent Office (EPO) applications from 1985 to 2007. The social security number (SSN)[4], which is identified for the vast majority of these inventors (Ejermo 2011; Jung and Ejermo 2014), allows us to link them to demographic and education information housed at Statistics Sweden.

We examine two dimensions of inventive performance: (a) inventive productivity, indicated by the probability of patenting and the total number of patents attributed to each inventor; and (b) the quality of the patents, indicated by the number of forward citations (NFC) to the patents and the probability of the patent applications being granted.

As this is mainly a descriptive paper, no causal links for the difference between immigrants and natives in inventive performance are explored here. Even so, this study makes several important contributions to our knowledge. First, our results show that there are no general positive 'migrant effects' on invention in Sweden, in contrast to the results found

[4]The Swedish social security number is a unique identification number for each resident in Sweden, including foreigners with a valid residence permit for at least one year. Therefore, foreign-born inventors who reside in Sweden for less than one year have no Swedish SSN.

for the US and the UK (No and Walsh 2010; Hunt 2011; Nathan 2014b).[5] Instead, the immigrants are found to be less likely to patent than the Swedish-born, though the difference is quite small. This difference is greater for the immigrants born in or after 1961 (>=1961) and primarily for those who migrated as adults, which is a reflection of how the distinctive geography, institutional regimes, migration history, and selection of immigrants affect the overall inventive activity of the immigrants in Sweden. Second, this is the first study to compare the inventive performance of the immigrants who migrated as children, those who migrated as adults, and the native born. For those who are inventors, the general group of immigrants, including those who migrated as adults, perform as well as those of the Swedish-born and therefore seem to be more positively selected. However, the immigrants who migrated as children generally perform more poorly than the natives in both the quantity and quality of patents. Their poorer inventive performance may be linked to a lack of Sweden-specific human capital; poorer high school performance explains a minor part of their lower probability of patenting. Third, we also contribute to the literature on whether obtaining an education in the host country is a factor in the immigrants' inventive performance. Looking at the immigrants who migrated as adults, we find that those who were educated in Sweden and those educated abroad have similar inventive performance. In summary, this study provides an initial impression of the inventive performance and contribution of, as well as challenges for, distinct groups of immigrants who have differing characteristics and backgrounds.

The paper is structured as follows: Section 2 summarizes the existing literature on the importance and contribution of foreign-born inventors to their destination countries and the factors that affect their inventive performance. Section 3 discusses the theoretical background used to formulate our hypotheses. Section 4 presents the databases and descriptive statistics.

[5]The comparison of inventive performance between the immigrants and natives in our study sometimes differs from earlier studies. We compare the foreign-born (first-generation immigrants) and the native-born, the same type of comparison as in Hunt and Gauthier-Loiselle (2010), Hunt (2011), and No and Walsh (2010). In e.g. Kerr (2008a) and Nathan (2014b), the comparison is made between the ethnic inventor communities following name-based approaches, where minority ethnic inventors also include second and third-generation immigrants.

Section 5 contains the methodology and the factors that influence inventive performance. Section 6 reports the results of the empirical analysis. The final section concludes the study with a discussion of the results.

2 Literature review

In recent years, more and more researchers have begun to explore the contribution of highly skilled immigrants to invention and innovation in their host country. Extant studies have largely focused on the US. For example, Wadhwa (2009) finds that foreign nationals living in the US contribute to a great many of its international patent applications. No and Walsh (2010) find that according to a national survey of the 'triadic' patents of more than 1,900 US-based inventors, almost 30% of the leading inventors in the US are non-US-born, a significant overrepresentation compared with the total foreign-born population (about 11%) and the foreign-born proportion of the college-educated science and engineering (S&E) workforce (about 22%). Kerr (2008a) indicates that there is a growing contribution by ethnic minorities to US domestic patents. Immigrants of Chinese and Indian ethnicity especially have become an integral part of US invention in high-tech sectors. Similarly, Stephan and Levin (2001) reveal that a disproportionate number of highly cited patents (the top 3.5% from the period 1980–1991) in the life sciences were contributed by the foreign-born (17.6%) and foreign-educated (baccalaureate degree) immigrants (11.1%). Chellaraj et al. (2008) find that the presence of foreign graduate students (immigrants with student visas) has a significant and positive effect on both future patent applications and future patent grants awarded to American universities and firms. The presence of skilled immigrants also has a positive, but smaller, impact on patenting. A study by No and Walsh (2010) shows that foreign-born individuals are more likely to invent than the US-born. After controlling for technology class, education, and time spent on inventing, though, this difference disappears. Nevertheless, the quality of patents filed by leading inventors born outside the US is higher on average. Hunt and Gauthier-Loiselle (2010) and Hunt (2011) also indicate that immigrants in the US generally perform better than the US-born when it comes to patenting, largely because they are more highly educated and more likely to study S&E.

Research on the impact of immigrants on innovation activity in non-US countries is very sparse. We are aware of only a few studies on immigration and patenting outcomes outside the US; these include two regional-level studies by Niebuhr (2010) (German regions) and Ozgen et al. (2012) (across 12 EU countries), as well as some pilot studies based on individual data. For instance, Nathan (2014b), analyzing new UK patent data, finds that increased diversity of inventor communities can help promote individual patenting and suggests that high-patenting minority ethnic inventors, especially patenting ‘stars’ of East Asian origin, drive overall patenting rates. Based on patents filed with the EPO, preliminary results by Breschi et al. (2014) indicate that immigrant inventors contribute significantly to innovation not only in the US but also in selected European countries. Some studies based on the Global Science (GlobSci) survey of 16 countries have also investigated the relationship between migration and scientific performance (Franzoni et al. 2012, 2014; Van Noorden 2012).

In summary, as shown in almost all of the literature, immigrants seem to make a significant and positive contribution to innovation in their destination country, and their positive self-selection is usually considered the basis for their superior performance (Chiswick 1978; Borjas 1987; Wadhwa et al. 2007; No and Walsh 2010; Hunt 2011; Nathan 2014b).

3 Hypotheses

3.1 Positive and negative forces of immigration and their impact on invention

Inventive performance depends not only on demographic or formal human capital characteristics such as gender, age, and education (Hunt 2011; Jung and Ejermo 2014), but also on informal and largely unmeasured assets such as language skills, culture, institutional familiarity, and social networks (Agrawal et al. 2008; Nathan 2014b). A lack of these informal qualities may hamper an individual's development. For instance, patents with more inventors (indicative of larger networks) have been found to be of higher quality (Ejermo and Jung 2011), and inventing teams may stretch across different regions (Ejermo and Karlsson 2006). Thus, inventive activity requires cooperation and network relationships across individuals as well as across organizations. However, immigrants tend to be disadvantaged with respect to these human capital resources, which are country specific in many cases. Language barriers, discriminatory attitudes towards immigrants, limited social networks, and unfamiliarity with the host country's culture and institutions might decrease inventive activity in immigrants (Nathan 2014b).

From an economic perspective, migration is an investment with associated costs and benefits for the individual (Sjaastad 1962; Lee 1966; Becker 1975; Borjas 1987; Nathan 2014a, b). The potential migrant who decides to move does so if the benefits of moving exceed the costs (Borjas 1987; Bevelander 2000). Such immigrants are therefore positively self-selected compared with non-migrants in their country of origin, and may perform better than the average comparable native population in their destination country (Borjas 1987). However, Borjas (1987, 1991) maintains that immigrants can be negatively self-selected under some conditions, where people with below-average earnings and productivity in their home country are more likely to migrate. This occurs if the income distribution in the home country is more unequal than that in the destination country. Compared with the majority of other countries, incomes are much more evenly distributed in Sweden. For example, in 2000, the Gini index[6] in Sweden was the lowest of 47 reporting countries in that year (World Bank 2014). It follows that Sweden is a very attractive destination country for relatively *unskilled* persons from other countries, inducing negative self-selection. In addition, equal and relatively low payment (compared with other developed countries) for highly skilled workers, as well as relatively high marginal income taxes[7] (Quirico 2012), may make Sweden less attractive to highly skilled immigrants.

Furthermore, the migration policy of a prospective destination country may sway the selection of immigrants (Belot and Hatton 2012). Tied movers, who migrate for family reasons, and refugees or asylum seekers, who may be politically oppressed, are not primarily selected for their skill advantages. They may therefore be negatively selected with respect to their abilities to engage in inventive activity, at least compared with immigrants picked for a specific job. Such a skill bias seems to characterize the situation in Sweden (Scott 1999; Bevelander 2000). Since 1968, except for the free migration of immigrants from the other Nordic countries, which has been extended to the other EU/EEA countries since 1995 as well, immigration policy in Sweden for other countries has principally been focused on immigrants who migrate as refugees or for reasons of family reunification, with the result that the opportunity to migrate to Sweden is skewed towards low rather than high-skilled immigrants from those counties. Clearly, such a negative selection mechanism, and its implications for skill and education levels, may also reduce the average inventive capability of Sweden's immigrant population.

Considering immigrants' disadvantage in terms of Sweden-specific human capital and the negative selection mechanism (the Sweden-specific economic feature and migration policy) applied in Sweden, as discussed above, we formulate

[6]The Gini index measures the income distribution of a nation's residents. A Gini index of 0 represents perfect equality, while an index of 100 implies perfect inequality.
[7]Sweden's highest marginal rates of personal income tax ranked fourth (after Aruba, Curaçao, and Denmark) and second (after Aruba) in the world in 2005 and 2010, respectively (see KPMG 2012).

Hypothesis 1. On average, the immigrants to Sweden are less likely to become inventors than the Swedish-born.

3.2 Inventors' inventive performance

Although Sweden faces challenges in attracting highly skilled immigrants,[8] many still find it an appealing destination country for several reasons. First, in general Sweden has shown an impressive economic performance since the Second World War, and has enjoyed relatively low unemployment rates compared with other developed countries, especially before 1992 (OECD 2014). Since the mid-1970s, the Swedish economy has experienced a structural change in which it has gradually shifted from heavy industry to a service economy with investment in new branches of production and innovation (Scott 1999; Bevelander 2000; Schön 2010). This transformation has increased the need for highly skilled workers (Edin and Topel 1997; Cerna 2012), providing job opportunities for skilled immigrants. Second, Sweden stands out as one of the most humanitarian, egalitarian, and democratic countries in the world (Eger 2010), and furthermore offers generous welfare benefits, devoting around 30% of its GDP to social expenditures (Eger 2010; Giulietti and Wahba 2013; OECD 2015). The Swedish social welfare system may be an important positive factor in the choice of destination country for immigrants, including the highly skilled ones, who want to minimize the risks of migration. Residents in Sweden can enjoy a high standard of living, a good work-life balance, universal health care, free education,[9] and generous parental and unemployment benefits (Eger 2010). Third, Sweden offers a very friendly environment and a high degree of

[8]For example, among the Swedish population aged 25 to 64 in 2006, 13% of people engaged in science and technology in Sweden were foreign-born, compared with 16% of total immigrants in the Swedish population (OECD 2008; Statistics Sweden 2014a, b).
[9]Sweden introduced undergraduate and master's programs tuition fees for students from non-EU/EEA/Switzerland countries in in August 2011.

legal equality to immigrants – the best among eight European countries in a recent assessment (Koopmans 2010). Fourth, developed links between Sweden and other European countries (especially other Nordic countries), such as fewer linguistic and cultural obstacles, networks based on a shared history, and free mobility of institutional regimes, as well as short physical distances, play important roles in migration (Belot and Ederveen 2012) and help attract highly skilled immigrants to Sweden.

Highly skilled immigrants may be much more positively self-selected compared with other immigrants, as they are usually more rational in their decision to migrate (Peixoto 1999). They may even be more skilled than the natives if judged by formal human capital indicators like level of education, an important reason for the better patenting performance of immigrants in the US (Hunt 2011). On the other hand, since the economic structural transformation that has taken place in Sweden, and the resulting rising demand for informal qualifications, highly skilled immigrants can also be somewhat disadvantaged in comparison with the past (Klinthäll 2003). For example, the disadvantage of foreign-born inventors regarding informal qualifications, for instance a social network in the destination country, may impede their development (Agrawal et al. 2006; Kerr 2008a). Therefore, considering both the advantages and disadvantages of foreign-born inventors, most of whom can be considered and defined as a subgroup of highly skilled immigrants,[10] we expect that

Hypothesis 2. Among inventors, the immigrants to Sweden perform as well as the Swedish-born in invention, in terms of both quantity and quality of patents.

3.3 Differences between immigrants who migrated as children and adults

[10]In our data, 80% of the identified foreign-born inventors have a long or PhD education and 20% have a short education (see definitions of "education level" in Table 3). The corresponding figures for the identified Swedish-born inventors are 70% and 30%, respectively.

Some immigrants come to Sweden as children[11] and some as adults. These two groups can have different characteristics and expectations of inventive performance compared with natives. The following hypotheses (3–7) could therefore be seen as qualifications of Hypothesis 1 and Hypothesis 2.

3.3.1 Immigrants who migrated as children

Immigrants who migrated as children can be considered a special group for several reasons.

First, in contrast to adult immigrants, who may be (self-)selected, children who migrate to Sweden are not usually positively self-selected based on their knowledge, ability, or skills, but generally follow their parents as tied immigrants.

Second, they may suffer a double burden during their youth. On the one hand, they inherit characteristics from their parents and tend to be raised in families with languages, cultures, and social networks that differ from the native families and host society. This may lead to a smaller social network, discrimination, and cultural and linguistic shocks that result in difficulties integrating into Swedish society. On the other hand, they usually attend schools organized in accordance with the values and educational objectives of the host society (Westin 2003). Schooling can help the immigrant children improve their Swedish language skills, interact with native residents, acquire a wider social network, and gain Sweden-specific human capital. Notwithstanding, the language problem, culture shock, conflicting values between family and school, and social marginalization may impede their school performance, damage their self-confidence (Westin 2003) and hamper their development as innovative individuals.

Third, the advantage of foreign-born children in having characteristics of both immigrants and natives can also become a disadvantage, because these may create difficulties in defining

[11] Among the general population of immigrants in Sweden in 2000, 10.7% were younger than 18. The corresponding figures were 9.1% in 2007 and 9.9% in 2013 (Statistics Sweden 2014b).

their social role among foreigners and natives and thus establishing well-developed social networks, which is important for inventive performance (Owen-Smith and Powell 2003; Kerr 2008a). Several studies suggest that knowledge flows, such as those that stem from patent citations, follow social networks (Agrawal et al. 2006; Kerr 2008a), which may be channeled partially through ethnic networks (Agrawal et al. 2008). Thus, if immigrants raised in Sweden find it difficult to define their social role, resulting in a lack of good social networks with both co-ethnic people and natives, their inventive performance may be affected.

Based on these disadvantages with respect to the acquisition of human capital for the immigrants who migrated as children, our next hypothesis becomes

Hypothesis 3. Immigrants who migrated as children perform more poorly in invention than natives, both in quantity and quality of patents.

A person's school performance may also affect his/her inventive performance. It is reasonable to assume that those with better school performance have better knowledge and ability, and then are able to have better inventive performance. For immigrants who migrated as children and obtained a high school education in Sweden, their high school GPA, which is used as a proxy for ability, can possibly be observed in our data. However, a high school GPA can only indicate part of a lack of formal human capital. Sweden-specific human capital, such as social networks, which immigrants who migrated as children may be lacking, is not necessarily reflected in grades. Thus, even after controlling for grades, we still expect immigrants who migrated as children to suffer from a poorer inventive performance compared with their Swedish-born counterparts. We therefore formulate:

Hypothesis 4. Immigrants who migrated as children are expected to perform worse than the Swedish-born in invention even after controlling for school performance.

3.3.2 Immigrants who migrated as adults

Adult immigrants are more likely to be (self-)selected than young immigrants. Nonetheless, from 1968 and onwards, migration policy in Sweden has favoured refugees, asylum seekers, and tied movers, so that many of those who migrated as adults are less educated and skilled (Scott 1999; Bevelander 2000). Hence the average level of the human capital for immigrants who migrated as adults in Sweden has been decreasing (Bevelander 2000). Because of the date limitations in the available immigration data,[12] in looking at immigrants who migrated as adults we only include those born in or after 1961. We formulate

Hypothesis 5. Immigrants who migrated to Sweden as adults are less likely to become inventors compared with the Swedish-born.

On the other hand, the situation may well be different for inventors who migrated as adults. In this subgroup we are more likely to encounter a positively (self-)selected type of immigrant rather than, for example, refugee immigrants, as invention is a knowledge-intensive activity in which mainly highly skilled individuals participate. Therefore, the level and quality of invention contributed by inventors who migrated as adults may be equal to or even better than those of natives.

[12] Data on the date of immigration on the individual level is only available from 1961 onwards. For those born before 1961, our data on date of immigration may be not their first entry date. To ensure that the date of immigration is the first entry date for immigrants, which can be used to identify their age of immigration correctly, we only keep immigrants who were born in or after 1961 when we study those who migrated as children and adults in Model 4 and Model 5.

Hypothesis 6. Inventors who migrate as adults perform at an equal level or even better in invention than natives.

The inventive performance of immigrants may be affected by whether they have obtained an education in the host country or abroad. First, the quality of education can vary across countries and further affect individual knowledge, skills, and ability. Compared with many other countries, the quality of education in Sweden, especially that of university education, is relatively high: five universities in Sweden rank among the top 200 universities in the world (Ranking Web of Universities 2014). Second, it is difficult to fully transfer immigrants' education acquired abroad to the Swedish context. Third, immigrants who obtain an education in the destination country are more likely to acquire host country-specific human capital to augment the skills they bring with them (Chiswick and Miller 1994), and this may enhance their individual inventive performance. We will examine the effects of education on immigrants who migrated as adults and expect the following result:

Hypothesis 7. Among immigrants who migrated as adults, those with a Swedish education perform better in invention than those without a Swedish education.

4 Data and descriptive statistics

4.1 Summary of data

We use to good advantage a unique database that combines demographic information with patent applications filed with the EPO by Swedish residents from 1985 to 2007 (Jung and Ejermo 2014). The base data set contains information on inventors and inventions extracted from the Worldwide Patent Statistics (PATSTAT) database[13] provided by the EPO. The EPO

[13]This material uses patents and inventors from the April 2010 version, later supplemented and updated with information from the April 2011 version.

was selected as the source of patent information for several reasons. First, it is one of the most frequently used filing offices for inventors in Sweden, along with the Swedish Patent and Registration Office (PRV) and the United States Patent and Trademark Office (USPTO) Fig. 1 shows that there is an artificial downward trend forming at the PRV, but a growing trend for patent applications to the EPO by Swedish residents in the past two decades. Second, as EPO patents cover protection in multiple European countries and impose substantial filing costs on an applicant, the projected returns (either strategic or sales) for a patent need to be higher and of better average quality than, for example, those filed only with the PRV. Third, EPO patents are highly useful for the identification of inventors, since they provide inventors' street addresses, while USPTO records only indicate names and cities. Full addresses have been essential for reaching a high match precision.

Insert Fig. 1 here

In total, our database comprises 39,600 Swedish patent applications and 73,356 patent–inventor combinations[14] filed from 1985 to 2007. In brief, the matching was done in two stages. First, after cleaning the data, the inventor's SSN was added by a commercial company according to his/her name and address.[15] Eventually, 66% of the records were thus matched or could be determined from matches found by the company. Nevertheless, the match rate was much higher for later patenting years. In order to go further, all remaining inventors were

[14]Patent–inventor combination means each inventor in a patent is listed as one observation with demographic and patent information for that application year. For example, if one patent has three inventors, then there are three observations of patent–inventor combinations. If one inventor contributed to N patents, then he/she is shown N times and contributes to N observations.
[15]The commercial company holds all addresses of Swedish residents for the past three years. As the establishment of our database was in 2011, only the inventors whose addresses in the patent file are the same as they had between 2009 and 2011 can be matched.

searched for in a complete address directory of the whole Swedish population in 1990.[16] This raised the match ratio substantially to 79.3%, especially for the 1980s and 1990s, and removed most of the differences in matching over time (Jung and Ejermo 2014). Appendix A reports on our investigations to verify that the 20.7% unidentified inventors were not subject to bias with respect to immigrant or native background.

Next, inventor records were sent to Statistics Sweden, who subsequently matched them with detailed population directory data using the unique SSN provided.[17] In this way we gained access to demographic information for inventors, which was combined with patent information to constitute our rich database. In addition, the inventors were matched with the *entire* Swedish population by the unique SSN.

The data used in this paper has several advantages over survey data, case studies, and data that uses name-matching techniques for the ethnic identification of inventors (e.g. Kerr 2008b; No and Walsh 2010; Hunt 2011; Breschi 2014; Nathan 2014b). First, our data comprises almost all patent applications filed with the EPO by inventors in Sweden from 1985 to 2007, which greatly reduces the risk of selection bias and allows us to track inventors over extended periods of time. Second, the data is complemented with demographic information, which is usually only accessed from complementary survey data but is measured here with very high precision. Third, the data on the *entire* Swedish population is available, which allows us to investigate the inventive activity among the whole population.

We focus on inventors aged 25 to 64 (mean age 43.9);[18] in other words, the working age for the majority of people living in Sweden. People are more likely to work and patent at

[16]In the 1990 directory, the whole Swedish population was included with their addresses and birth dates. The full SSN was derived by checking birth date accordance with existing matches and by contact with the Swedish tax authority.
[17]Statistics Sweden has very detailed information that includes demographic and education information for all residents in Sweden from 1985 onwards. Any resident living in Sweden for more than one year has an SSN. If the SSN in Statistics Sweden can be matched with the SSN identified by the commercial company for the inventors, then the inventor’s detailed personal information can be matched.
[18]Inventors younger than 25 are excluded from our data as their contribution to Swedish invention is negligible. Those aged 16 to 24 only contributed 0.29% of identified patent–inventor combinations that were contributed by

these ages, which makes our sample more coherent. Finally, we use the 76.5% of inventor–patent combinations where inventors are identified[19] (see Table 1). Among the identified inventors, 10.9% or 2,176 individuals are foreign-born and are attributed with 11.6% (by fractional count) of the identified Swedish patent applications.[20] On average, each foreign-born inventor is attributed slightly more patents (by fractional count) than each Swedish-born inventor (1.5 vs. 1.4).

Insert Table 1 here

4.2 Component and growing trends among foreign-born inventors

Of the identified foreign-born inventors (see Table 2), 27.3% of them came from other Nordic countries, 23.3% from EU-15 (excluding Sweden, Denmark, and Finland), 24.3% from the rest of Europe (including the former Soviet Union), 16.3% from Asia, 4.2% from North America[21] or Oceania, and 4.6% from South America or Africa. The proportion of identified inventions (by fractional count) contributed by each group is almost identical.

Insert Table 2 here

Fig. 2 presents the population shares of foreign-born inventors against the shares of their contributions to inventions and the shares of immigrants in the *entire* Swedish population aged 25 to 64. The population shares of foreign-born inventors are between 7.5% and 13.4% from 1985 to 2007. Except for the shares in 1985 and 1986, they are much lower and

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inventors aged 16 to 64, which is less than the contribution by the inventors at any other single age. For example, the corresponding figure for the inventors aged 25 is 0.35%.

[19]Please see Appendix A for the check of unidentified inventors.

[20]Fractional count means each co-patent is counted as a fraction, depending on how many inventors contributed to one patent. For example, if one patent has three co-inventors, then each inventor is attributed 1/3 of the patent.

[21]North America includes Central America and the Caribbean countries. According to data from Statistics Sweden, 66.3% of immigrants from North America were from Canada or the US in 2000 (59.8% in 2008).

more fluctuant than the shares of immigrants in the *entire* Swedish population, which rose stably from 11.0% to 17.0% between 1985 and 2007. In general, the shares of inventions contributed by foreign-born inventors are slightly higher than their population shares over the whole period[22].

Insert Fig. 2 here

The descriptive analyses suggest two key points. First, foreign-born inventors in Sweden appear to be substantially different from foreign-born inventors in American and British populations. Compared with immigrants' shares in the workforce population in the host countries, the minority ethnic inventors in the US and the UK are overrepresented in terms of patents (No and Walsh 2010; Nathan 2014b), while our figures reveal that foreign-born inventors in Sweden are underrepresented. Moreover, in the US, minority ethnic inventor communities are mainly from South and East Asian countries such as China (including Taiwan and Hong Kong) and India (Kerr 2008a, b; Wadhwa 2009; No and Walsh 2010), which are also important regions of origin for foreign-born inventors in the UK (Nathan 2014b). By contrast, the majority of foreign-born inventors in Sweden are from European countries, with other Nordic countries the most important sources of inflow. This reflects how geographic location, migration institutional regime, and migration history in Sweden affect its constituent of foreign-born inventors. Second, foreign-born inventors are on

[22]Fig. 2 shows a temporary decline in the share of immigrants' inventions in 1993 and 1994 and an increase in 1995, after which the trend is steadier. There may be several reasons for this dip and rebound. For example, (a) the economic depression in Sweden at the beginning of the 1990s may have affected immigrants differently (Ekberg 2011); (b) Sweden's entry into the EU may also have led to an increased inflow of skilled migrants from other EU countries from 1995 onwards; (c) labor migration from non-EU/EEA countries tends to be strictly selected in the form of experts and key personnel, who are more likely to participate in invention (Ministry of Justice 2001; Cerna 2009).

average slightly more productive than Swedish-born inventors, in terms of the average number of patents per inventor.

5 Methodology

5.1 Estimated models

We now turn to examining how inventors' backgrounds affect inventive performance in terms of both quantity and quality analysis. For our *quantity* investigations, the unit of analysis is the individual. The level of inventive performance is investigated in two ways. First, we examine the probability of patenting for *all* immigrants compared with *all* natives based on unbalanced panel data for the *entire* Swedish population from 1985 to 2007. Second, among the inventors, we examine the total number of patents attributed to each of them from 1985 to 2007. The *quality* of inventive performance is also measured in two ways for those who are inventors; namely the NFC for each patent and the probability of a patent being granted. In these cases, the unit of analysis is the unique patent–inventor combination.

Each dependent variable is examined in five different models.

In Model 1, we compare the probability of patenting for *all* immigrants with the probability for *all* natives. For the subgroup of immigrants made up of inventors, we compare their contribution to the total number of patents, the NFC received per patent, and the probability of their patents being granted with the corresponding figures for native-born inventors. We use this model to test *Hypotheses 1–2*.

In Model 2, we compare the same indicators for immigrants *raised* in Sweden with those for natives. To do this, we retain only individuals whose high school GPA between 1973 and 1996 are available.[23] We use this model to estimate *Hypothesis 3*. In total, 48.2% of the inventors in Sweden are found to have a high school GPA. Immigrants who have received a

[23]Grade data are complete between 1973 and 1996 but unobserved before 1973 and not comparable with earlier years from 1997 on.

high school education in Sweden are assumed to have been raised in Sweden because the usual graduating age in Sweden is 18–19.[24] Students usually enter secondary school at the age of 16–17.

In Model 3, building on Model 2 for each indicator, we add a variable, high school GPA, as a proxy for ability. We include this variable to represent the otherwise unobservable effect of individual ability,[25] which may correlate with inventive performance. The absence of an individual ability proxy may result in correlation between the explanatory variables and the error term, which leads to potentially biased and inconsistent estimates (Franzoni et al., 2014). High school GPA can be considered a reasonable proxy for ability because those with higher grades are assumed to have higher ability. The unified evaluation standard for high school GPA between 1973 and 1996 in all high schools in Sweden makes it possible to compare different individuals. This model is used to test *Hypothesis 4*.

In Model 4, we compare the same indicators for immigrants raised in Sweden, those who immigrated as adults,[26] and the Swedish-born. We only include individuals born in or after 1961 due to date limitations in the available immigration data. In total, we find that 38.1% of the inventors in Sweden were born in or after 1961. We employ this model to test *Hypothesis 3* and *Hypotheses 5–6*.

In Model 5, building on Model 4, we divide immigrants who migrated as adults into two groups: those who obtained their education in Sweden and those who acquired it abroad. We

[24]We cannot find other higher-quality information to indicate whether immigrants were raised in Sweden for the *entire* population in the whole examined period. We believe it is reasonable to assume those attending high school in Sweden are likely to have been raised in Sweden. Of all inventors in Sweden, 61.5% graduated before the age of 19 and 93.5% before the age of 20. The corresponding figures for foreign-born inventors are 56.2% and 86.4%. Please see footnote 12 for the reason why we do not use data, such as the date of immigration, here to identify whether immigrants have been raised in Sweden or not.

[25]Individual ability could also correlate with the choice to migrate, which may lead to a self-selection problem. To test for endogeneity caused by self-selection, we use the variable *child_migrant* (migration occurred as children) as the instrument variable for *foreign born* (omit: Swedish born), a strategy similar to the one used by Franzoni et al. (2014). According to the ivpoisson control-function model and generalized method of moments (GMM) on total number of patents and NFC to patents (see dependent variables below), we find that the variable *foreign born* is not endogenous.

[26]Of those born in or after 1961, 71.4% of foreign-born inventors and 69.9% (2000) and 71.7% (2007) of all immigrants migrated as adults.

do this to ascertain whether either source of education affects inventive performance. In this model, all the Swedish-born and immigrants who migrated as children are assumed to have been educated in Sweden, regardless of their level of education.[27] Model 5 is used to test *Hypothesis 7*.

Models 1–3 have three submodels each. Each first submodel includes all population/inventors without restricting the sample by birth year. Each second submodel includes only population/inventors born before 1961 (<1961), and each third submodel only includes those born in or after 1961. This age split for the first three models facilitates comparison with Model 4 and Model 5, for which only immigrants born in or after 1961 are available.

Only people with an education level equal to or higher than secondary school, and who were employed, are included in the regressions, as the data on explanatory variables of 'field of study' in Sweden and 'sector of work' (see discussion in Table 3) is only available for this group.[28]

5.2 Dependent variables and estimation methods

5.2.1 Inventive productivity

Probability of patenting. First, we compare the probability of patenting between the *entire* populations of immigrants and the Swedish-born. The dependent variable is set up as a dummy variable, coded as 1 if an individual in Sweden has at least one patent application in

[27]Among the identified inventors born in or after 1961, we find that 97.2% of the Swedish-born and 93.5% of immigrants who migrated as children have received an education in Sweden at secondary school or higher levels according to their study records in Statistics Sweden; 26.2% of immigrants who migrated as adults obtained an education in Sweden.

[28]Among the identified inventors, only 3.8% have an education at primary school level. Of these, 91.5% are Swedish-born and 8.5% are foreign-born. The distribution is similar for inventors who have an education level equal to or higher than secondary school, 89.4% and 10.6%, respectively. Only 3.6% of the identified inventors are unemployed. Of these, 75.9% are Swedish-born and 24.1% are foreign-born. The distribution among employed inventors is 89.6% and 10.4%, respectively.

year t and 0 otherwise. Random-effects probit regressions with observed information matrix (oim) standard errors are applied in the analysis[29, 30] (Gibbons and Hedeker 1994).

Total number of patents attributed to each inventor. Among inventors who attributed with at least one patent application, we consider the total number of patent applications by each inventor to examine differences in patent productivity between the foreign-born and native-born. The number of patents per inventor is widely overdispersed: more than half (53.6%) of the inventors have only one patent application, and the standard deviation (4.1) of the total number of patents per inventor is larger than the mean value (2.8). Therefore, we apply negative binomial models with robust standard errors rather than Poisson models (Cameron and Trivedi 2010) for the analysis.

5.2.2 Quality of patents

It is difficult to assess the value of patents, since the value distribution is highly skewed (Harhoff et al. 2003; Acemoglu et al. 2014). Numerous researchers have approximated patent value with various indicators, such as market value of patents, NFC, patent scope, opposition procedure, family size[31], number of claims, renewal data, and the probability that a patent application is granted (e.g. Trajtenberg 1990; Lerner 1994; Lanjouw et al. 1996; Harhoff et al. 2003). In this paper, we use the NFC and probability of a patent application being granted as our dependent variables to measure the quality of patents.

NFC received by each patent. We use NFC as one of our indicators of patent quality because virtually all studies on patent value have demonstrated that it has a significant and positive

[29]When the dependent variable is a dummy variable (probability of patenting and probability of a patent application being granted) and both probit and logit model are applicable, or when the dependent variable is count data (total number of patents per inventor and NFC received by each patent) and any of the negative binomial, Poisson, and zero inflow models are applicable, we always choose the model which has the higher log pseudolikelihood, smaller Akaike's information criterion (AIC), and Schwarz's Bayesian information criterion (BIC) after comparison.

[30]This method is appropriate because it takes into account that the probability of patenting for an individual is a series of correlated binary outcomes, in which a person who patented previously is also more likely to patent later on.

[31]Roughly: number of countries of patent protection (see Martínez, 2011).

correlation with the value of a patent (e.g. Harhoff et al. 2003; Hall et al. 2005; Gambardella et al. 2008). Although these studies admit that the relationship is quite noisy (Harhoff et al. 1999) and the best possible approximation of patent value is unlikely to be obtained by using forward citation counts alone (Gambardella et al. 2008), NFC retains its role as the most common indicator and is even considered the strongest predictor of patent value compared with other indicators (Lanjouw and Schankerman 1999; Sapsalis et al. 2006). Moreover, it is also considered a proxy for effective use or importance of a patent to new inventions (Sapsalis et al. 2006).

The NFC is calculated within a five-year interval after filing the original patent or one of its family members, using the International Patent Documentation Center (INPADOC) extended family size definition (Martínez 2011). Again, negative binomial models are preferred because the NFC is both count data and highly overdispersed (zero citations: 50.2%, standard deviation: 2.8, mean: 1.4). Since 46.4% of inventors have patented more than one invention, we employ negative binomial regression models with clustered robust standard errors to control for intra-inventor correlation.

Probability of a patent application being granted. The granting of a patent application is interpreted as a signal of the invention’s value. Granted patents are likely to have a higher value than rejected or withdrawn patents for two related reasons. The one is related to the technological value and the granting process.[32] The other is related to the legal rights conferred to the patentee, in which the grant provides an exclusive right to the exploitation of the invention, leading to a potentially higher return than generated by a non-protected invention (i.e. the grant generates value) (Guellec and van Pottelsberghe de la Potterie 2000, 2002).

[32]Three main criteria must be fulfilled during the search and examination procedures for a patent application to be granted: the invention must (a) be novel in terms of the published state of the art (new), (b) be industrially applicable (useful), and (c) exhibit a sufficient “inventive step” (be non-obvious).

Patent grant years are observed from 1987 to 2011.[33] On average, it takes 5.1 years for a patent to be granted, with a minimum of 0.9 years, a maximum of 19.6 years, and a standard deviation of 1.9 years in our data. Of all patent applications, 55% are granted within 5 years and 90% within 7.7 years. A dummy variable is used, coded as 1 if a patent application is granted and 0 otherwise. Logit models with robust standard errors are used to investigate the probability of a patent application being granted.

The logit model is written as follows:

$$P(grant = 1) = e^{X\beta}/(1 + e^{X\beta}) \tag{2}$$

where P is the probability of a patent application being granted, X is a vector of explanatory variables, and β is a vector of estimated model parameters.

5.3 Independent variables

Foreign born is our main variable of interest for each dependent variable. We compare the inventive performance of different groups of foreign born with the corresponding groups of Swedish born (reference groups). The dummy variable here is assumed to capture a mixture of observed and unobserved effects of foreign born in the models.

We include the following control variables for each estimated dependent variable: *highest education level* at the time of the examined year, *high school GPA*, *field of study*, *age and age^2*, *gender*, *firm size*, *sector of work*, and *region of work*. We also include *technology classes* when we examine the total number of patents for each inventor, the NFC for patents, and the probability of a patent application being granted, as they are likely to be influenced by the number of patents in different technology sectors. *Application year* and *number of inventors*, which are related to patent quality, are only included when we examine the NFC

[33] As our data were collected in early 2011, the information on grants in 2011 is incomplete. There are only 171 observations in 2011 compared with 2,216 in 2010.

for patents and the probability of a patent being granted. An overview of the reasons for including these control variables is given in Table 3.

Insert Table 3 here

6 Empirical results

After including control variables, the random-effects probit regressions in Model 1, Table 4, show that the immigrants in Sweden are significantly less likely to patent than the Swedish-born, for those born both before and in or after 1961, which strongly supports *Hypothesis 1*. Model 1.1 shows that an immigrant has a 0.0003% ($p < 0.01$) lower probability of patenting than a Swedish-born. This means that, holding other variables constant, the probability of observing an inventor drops by about 0.5% (=1– (0.000579 – 0.000003)/0.000579, 0.000579 is the average share of Swedish-born inventors in the Swedish-born population sample used in Model 1.1) if the individual is foreign-born. Compared with their Swedish-born counterparts, immigrants born in or after 1961 are even less likely to patent (–0.0005%, $p <$ 0.01, Model 1.3) than those born before 1961 (–0.0002%, $p < 0.01$, Model 1.2). This could be the result of two underlying factors. First, the negative selection of immigrants became a more dominant feature from the 1970s onwards, when migration policy increasingly favoured refugees and asylum seekers over relatively skilled labour (Scott 1999; Bevelander 2000). Second, Sweden's economic structural transition into postindustrial society (Schön 2010) raised the requirement for Sweden-specific skills, such as the ability to speak and write Swedish and other cognitive abilities, which could decrease immigrants' chances to participate in inventive activity.

Generally, the total number (Model 1 in Table 5) and quality of patents (Model 1 in Table 6–7) filed by foreign-born inventors, both those born before and in or after 1961, do not differ significantly from those of Swedish-born inventors, except for the finding that the patents of foreign-born inventors born before 1961 are less likely to be granted ($p < 0.1$, Model 1.2 in Table 7). This means that *Hypothesis 2* is broadly supported. It is therefore quite possible that the selection mechanism works in two ways. Seen as a whole, immigrants may be negatively selected in terms of invention. However, the selected group that does invent is more positively selected and similar to corresponding groups in, for example, the US.

Broadly speaking, immigrants raised in Sweden perform more poorly in invention than natives, both in quantity and quality of patents (Model 2 in Table 4–7), which supports *Hypothesis 3*. Nonetheless, those born before and in or after 1961 perform differently depending on the dimension considered when compared with their Swedish-born counterparts. Immigrants raised in Sweden, especially those born before 1961, are less likely to patent than the Swedish-born (Model 2, Table 4). Conditional on being inventors (Model 2.1 in Table 5–7), immigrants raised in Sweden also file fewer patents per inventor (especially those born before 1961, Model 2.2 in Table 5), have lower quality of patents as indicated by NFC (especially those born in or after 1961, Model 2.3 in Table 6), and are granted fewer patents (both born before and in or after 1961, Model 2 in Table 7). Results in Table 4 and Table 5 show that immigrants born in or after 1961 and who migrated as children (a) are generally as likely to patent as the Swedish-born (Model 3.3 and Model 4), (b) perform relatively better than immigrants born before 1961 (compare Model 2.2 with Model 2.3), and (c) are more likely to patent (Model 4 in Table 4)[34] and file a total number of patents per inventor (Model 4 in Table 5) similar to those who migrated as adults. This may be attributed to the integration policy in Sweden. Since 1975 the policy has aimed for better integration of immigrants into Swedish society through improvement of their Sweden-specific human

[34]Compared with Model 2.3, the significance of the results in Model 4 and Model 5 for immigrants who were born in or after 1961 and raised in Sweden is different. The reason is that in Model 2.3 we only include individuals with a recorded high school GPA between 1973 and 1996, while in Models 4 and 5 we also include individuals without a recorded GPA.

capital, which in turn promotes their ability to invent. Immigrants enjoy the same social and educational rights as natives without restriction, and the government and society pay more attention to their education and growth, such as providing intensive training courses in Swedish (Westin 2003). It is more likely for immigrants raised in Sweden and born in or after 1961 to benefit from this policy than those born before 1961 or who migrated as adults, because of their age and immigration background. However, in contrast to foreign-born inventors born before 1961, the NFC for patents filed by those born in or after 1961 is lower than that of their Swedish-born counterparts. This may be because the establishment and accumulation of social networks through which patent citations flow (Agrawal et al. 2006; Kerr 2008a) are more limited for young immigrants.

Generally speaking, after controlling for high school GPA, the results in Model 2 for each indicator persist (Model 3, Table 4–7), although the significance of the lower probability of patenting for immigrants raised in Sweden declines (Model 3.1 and Model 3.2, Table 4) or even disappears (Model 3.3, Table 4). This means that the poorer performance of immigrants raised in Sweden cannot be well explained by their grades, and that other unexplained human capital, such as social networks or unmeasured abilities, could be the main explanatory factor. This aligns with *Hypothesis 4*.

Model 4 in Table 4 shows that immigrants born in or after 1961, who migrated as adults, are less likely to patent than the Swedish-born, which confirms *Hypothesis 5*. However, as shown in Model 4 in Table 5–7, conditional on being inventors, their total number of patents per inventor and NFC is similar to that of natives, and their patents are more likely to be granted, which supports *Hypothesis 6*. This suggests that inventors who migrated as adults could be a more positively selected group.

However, contrary to the expectations of *Hypothesis 7*, whether education was obtained in Sweden or abroad has no significant effect on inventive performance for immigrants who migrated as adults (Model 5, Table 4–7). This suggests that high school education in Sweden is not an important factor for this group. It is reasonable to believe that adult immigrants who have a foreign education and are active in invention are relatively skilled. The ability to obtain Sweden-specific human capital may therefore not be as important a factor for these two groups of immigrants.

6.2 Control variables

The control variables largely confirm our expectations. Education level has mainly a significant positive effect on inventive performance: the higher a person’s education level, the more productive he/she is in invention, and the greater the NFC received for a patent he/she files. However, the quality of patents is not higher for inventors with a PhD education compared with those with a long education. This may be because inventors with a PhD education are more likely to invent as an adjunct to scientific work, but their inventions are less likely to be granted patents. In the event of being granted patents they would be less likely to be cited.

High school GPA has a significantly positive effect on the productivity of individuals in invention and the NFC a patent receives. However, it has no significant effect on the probability of a patent being granted.

Individuals who studied in different fields perform differently in invention. Those who studied engineering, manufacturing, and construction are significantly more likely to patent, and their patents are more likely to be granted, than those who studied in any other field. However, the patents of those who studied in the fields of science, mathematics, and computing or health and welfare are more likely to be cited than those who studied engineering, manufacturing and construction.

As we expected, a curvilinear relationship is found for age and age squared, and the effect differs when comparing quantity and quality. We find that the higher the age of an individual, the higher his/her cumulative productivity in invention. However, we also find that the higher the age of the inventor, the lower the NFC to his/her patents. Generally, age does not significantly affect the probability of a patent being granted.

Women are significantly less productive in invention than men, and their patents are also significantly less likely to be granted than those of men. Still, no significant difference is found when we investigate the NFC.

Generally, individuals working in smaller firms are less productive in invention than employees in larger firms. This result is similar to the probability of their patents being granted. However, the patents of inventors from small or large firms receive a higher NFC than the patents of inventors from medium-sized firms.

Individuals who work in non-industry sectors are significantly less likely to patent than those who work in industry sectors. In addition, individuals who work in the public service sector file fewer patents per inventor and have lower-quality patents. This most likely reflects the lesser tendency of public employees to work in commercial activities. The results are similar for individuals who work in agriculture, hunting, forestry, and fishing, except that the NFC for their patents is not significantly different from that of inventors who work in industry sectors. Inventors who work in private services perform similarly to or even better than those working in industry sectors with regard to the number of patents per inventor and quality of patents.

Generally, individuals who work in metro regions perform better in inventive activity than those who work in rural regions, both in quantity and quality of invention. Individuals who work in urban regions are more likely to patent, and their patents have a higher NFC, but they have no advantage in the number of patents per inventor and the probability of patents being granted compared with individuals who work in rural regions. As is well established in the literature, the results generally reflect that better opportunities for innovation exist in large regions (e.g. Orlando and Verba 2005).

Insert Table 4–7 here

7 Discussion and conclusion

The results of this paper show that holding other variables constant, immigrants in Sweden are, in general, significantly less likely to patent than the Swedish-born, though the difference is quite small. This difference is greater for immigrants born in or after 1961, and is mainly because of those who migrated as adults. This can be related to immigrants' lack of Sweden-specific human capital and the negative selection mechanism (Sweden-specific economic features and migration policy) applied in Sweden. On the other hand, conditional on being inventors, the immigrants at large, including those who migrated as adults, perform as well as natives and therefore seem to be more positively selected. Immigrants who migrated as children normally perform more poorly than the Swedish-born, in terms of both quantity and quality of patents. However, those born before and in or after 1961 can perform differently when different dimensions are considered. The worse inventive performance of immigrants raised in Sweden may be attributed to their lack of Sweden-specific human capital. However, whether education was obtained in Sweden or not seems to have no significant effect for immigrants who migrated as adults.

In contrast to most prior studies, especially those in the US, which show that immigrants tend to outperform in invention and innovation compared with natives (e.g. Chellaraj et al. 2008; No and Walsh 2010; Hunt 2011), we find that immigrants in Sweden do not outperform the Swedish-born when it comes to invention. The difference in inventive performance between immigrants in Sweden and those in other developed countries, especially the US, may be attributed to several factors.

First, as discussed in section 3.1, the high and evenly distributed income in Sweden, compared with many other countries in the world, makes it attractive for unskilled persons from other countries, and may favour a negative selection of immigrants. In addition, wages for highly skilled workers in Sweden are relatively low compared with other developed countries, such as the US and the UK, as a result of Sweden's even income distribution and high marginal taxes (Quirico 2012). This makes it more difficult for Sweden to attract highly skilled immigrants.

Second, except for the other Nordic countries since 1968, as well as the other EU countries since 1995, migration policies in Sweden have favoured refugees, asylum seekers, and tied movers. This may have swayed the selection of immigrants in Sweden towards low-skilled rather than high-skilled immigrants. In addition, and in contrast to the strict selection of highly skilled immigrants in the US (e.g. the H-1B visa[35]) and the UK (e.g. the 'Highly Skilled Migrant Programme', a points-based system for attracting the 'best and brightest' talent in the world) (Cerna 2011), the free migration between the Nordic and other EU/EEA countries leads to less positively selected immigrants.

Third, the origin of immigrants in Sweden and the US differs. There is no doubt that the US is one of the most attractive countries for the best talent; it is the dominant destination for highly skilled emigrants in most countries (Franzoni et al. 2012). In contrast, the majority of highly skilled immigrants in Sweden are refugees, asylum seekers, or tied movers when they arrive (Gaillard 2002).

Fourth, the relative inventive performance of natives and immigrants differs between countries like the US and Sweden, which may be due to the relative quality and skills of

[35]H-1B is a type of temporary work visa in the US given to people in specialty occupations with at least a bachelor's degree (or equivalent).

natives and immigrants. For example, the average quality of US-born individuals choosing to get doctorates in S&E has declined, as bright native students more often choose lucrative careers in business, law, and medicine (Stephan and Levin 2001). However, in Sweden, many natives still choose to study S&E. For instance, in 2010/2011, 75% of the Swedish-born PhDs under the age of 65 graduated in the S&E field, while the corresponding figure for foreign-born PhDs was 80% (Statistics Sweden 2013).

Finally, language is less of an obstacle for immigrants in the US and UK than for immigrants to Sweden, as English is much more widely used in the world than Swedish.

The Swedish government has realized that there is a shortage of skilled labour. Recently, Swedish policies put into effect a more positive selection that may help to improve Sweden's competitive advantage in technology and innovation (Mahroum 2001; Shachar 2006; Sveriges Riksdag 2014). Since 2001, Sweden has provided tax exemptions on the first 25% of income for up to five years for foreign nationals who work in highly skilled occupations (Mahroum 2001; Forskarskattenämnden 2013). Notwithstanding, Sweden could still do much more if it wants to attract and retain more highly skilled immigrants and improve its inventive performance. For example, (a) making it easier for highly skilled immigrants from non-EU/EEA countries and their families to settle in Sweden; (b) developing programs such as a skill-based points system like those in Canada and Australia to actively and broadly attract and select highly skilled immigrants; (c) expanding preferential policies to skilled adult migrants. The government also needs to do more for immigrants who migrated as children to help them improve their human capital accumulation, including offering more effective education and integration policies. Our results may well be applicable to other countries, suggesting the need in Sweden and elsewhere to improve on immigrants' host-country specific skills by e.g. building stronger ties between ethnic groups and domestic communities.

This study certainly makes contributions to the literature, but there are limitations which call for further research. First, we need to better understand what drives our research results. Causal effects on the difference in inventive performance between immigrants (including those who migrated as adults and children) and natives are not explored in this paper. Second, despite the richness of our data, we do not consider the commercialization of patents or other activities such as publication because of limited available data. Moreover, we cannot rule out the possibility that there may be biases in that 20.7% of the inventors, who cannot be identified as either immigrant or native. The tests based on name inspections of inventors (see Appendix A) suggest no indication of such biases, even though these tests also capture second and third-generation immigrants. Third, the effect of parental background on immigrants is not investigated here because such data are not available. Finally, for reasons of space, we do not compare the intra-group differences among the foreign-born by country of origin, the impact of the motivation to immigrate (e.g. those who migrated as labour-migrants, tied movers, students, refugees), the effect of changes in migration policy (e.g. those of 1968 and 1995) and economy (e.g. 1991), or the influence of diversity and networks on invention. We plan to explore these dimensions in future research.

Tables

Table 1 Number and share (%) of identified inventors in Sweden aged 25–64 and patent applications they contributed to, 1985–2007

	Foreign born	Swedish born	Total	Unidentified/ Excluded by age[a]	Total
Total no. of patent–inventor combinations	6,457	49,745	56,102	17,254	73,356
Share of all combinations	8.8%	67.7%	76.5%	23.5%	100%
Share of all identified combinations	11.5%	88.5%	100%	-	-
No. of identified inventors	2,176	17,839	20,015	-	-
Share of all identified inventors	10.9%	89.1%	100%		
No. of identified applications (fractional count)	3,254	24,853	28,107	-	-
Share of all applications	11.6%	88.4%	100%		
Average no. of patents contributed to	1.5	1.4	1.4	-	-

Source: Statistics Sweden and CIRCLE data on inventors

[a] 'Unidentified/excluded by age' includes 15,183 (20.7%) unidentified patent–inventor combinations and 2,071 (2.8%) combinations where inventor's age is less than 25, more than 64, or unknown.

Table 2 Number and share (%) of foreign-born inventors aged 25–64 and inventions they contributed to (fractional count) by region of origin, 1985–2007

Region of origin	No. of inventors	Share (%) of inventors (1)	No. of inventions	Share (%) of inventions (2)	Gap = (2) − (1) (%)
Other Nordic countries	595	27.3	854	26.2	−1.1
EU-15 excl. SE, DK, and FI	507	23.3	783	24.1	0.8
Rest of Europe[a]	528	24.3	825	25.3	1.1
Asia	354	16.3	526	16.2	−0.1
North America + Oceania	92	4.2	151	4.6	0.4
South America + Africa[b]	100	4.6	116	3.6	−1.0
Total	2,176	100	3,255	100	

Source: Statistics Sweden and CIRCLE data on inventors

[a] Includes the former Soviet Union.

[b] Includes one inventor whose region of origin is unknown and who filed 1.7 inventions by fractional count.

Table 3 Control variables: rationale for inclusion and categorization

Control variable	Rationale	Categories
Highest education level at the time of the examined year	Studies indicate that better patenting performance of immigrants to the US can largely be attributed to their higher education levels (Hunt and Gauthier-Loiselle 2010; No and Walsh 2010; Hunt 2011).	Three education levels: (a) less than three years of post-secondary education[a] (short education); (b) at least three years of post-secondary education but below PhD level (long education, reference group); (c) any PhD education (also unfinished)
High school GPA	Grades are used as a proxy and a control for individual ability. Used to check the robustness of our results compared with leaving it out.	Continuous variable
Field of study	Earlier studies suggest that the type of education is an important factor for the patenting performance of immigrants in the US (Hunt and Gauthier-Loiselle 2010; Hunt 2011).	Four categories: (a) engineering, manufacturing, and construction (the reference category); (b) science, mathematics, and computing; (c) health and welfare; (d) other fields
Age and age^2	Inventive productivity varies with the age of individuals and has a curvilinear relationship (Mariani and Romanelli 2006; Jones 2010; Jung and Ejermo 2014; Simonton 2000). These variables also reflect variations in patent productivity and quality related to birth cohort and how recently a person acquired education.	Discrete data
Gender	There are well-documented gender differences in patenting performance (e.g. Ding et al. 2006; Azoulay et al. 2007), which can be attributed to personal characteristics, structural positions, organizational reasons, and marital status (Xie and Shauman 1998). Women are less likely to patent than men (Azoulay et al. 2007; Huang et al. 2011) because of e.g. their lower probability of holding an S&E degree (Garant et al. 2012) or a preference for devoting more time to family and children than men. Whittington and Smith-Doerr (2005), however, find that the patents filed by women have equal or better citation rates than patents filed by men.	Dummy variable: (a) male (reference group); (b) female
Firm size	Small firms may be more constrained in their propensity to patent and thus might focus only on the most valuable inventions (No and Walsh 2010). Large firms are more likely to patent and can also be expected to produce higher-quality patents, as they usually have more ample resources for invention and can afford to hire employees with greater innovation skills.	Three categories: (a) small firms, coded 1 for 1–99 employees, 0 otherwise); (b) medium firms (reference category, coded 1 for 100–499 employees, 0 otherwise; (c) large firms, coded 1 for 500 employees or

Control variable	Rationale	Categories
		more, 0 otherwise.
Sector of work	Inventive activity can vary across different sectors. Patenting activity can be higher in manufacturing sectors than agriculture and service sectors (Nathan 2014b). Employees in the public service sector may perform more poorly than employees in other sectors as their work rarely involves competing for technology in markets.	Four categories following Swedish Standard Industrial Classification (SNI92, see Appendix B): (a) agriculture, hunting, forestry and fishing; (b) industry (reference category); (c) private service; (d) public service.
Region of work[b]	Larger cities often offer agglomeration economies stemming from thick markets, knowledge spillovers, openness, job opportunities, and cultural diversity. This leads to more developed markets, specialized inputs, and other resources used in innovation, as well as greater opportunities for innovators to learn from one another, than smaller cities (Orlando and Verba 2005).	Three categories[c]: (a) metro regions; (b) urban areas; (c) rural regions (reference group).
Technology classes	In some technology classes, inventions are more likely to be applied for as patents (No and Walsh 2010). Moreover, technologies with many patents are likely to have a higher NFC than those with fewer patents (No and Walsh 2010; Ejermo and Kander 2011). Meanwhile, technological convergence – that is, the blurring of boundaries across technological fields – may increase the probability of a patent being granted (Guellec et al. 2002).	Five categories (Schmoch 2008): (a) electrical engineering (reference group); (b) instruments; (c) chemistry; (d) mechanical engineering; (e) other fields.
Application year	(a) We include them to control for differences in citation behaviour over time and possible differences in the accumulation of citations over time (Sapsalis et al. 2006), although this is largely dealt with by counting citations within five years after application. (b) We also include them when we examine the probability of a patent being granted, as patents are not granted immediately after being filed.	23 time dummy variables
Number of inventors	To some extent, this controls for the level of resources devoted to the research project leading up to a patent, which should therefore affect the quality of a patent (Sapsalis et al. 2006).	Discrete data

[a] This includes secondary education and less than three years of post-secondary education. Education levels are grouped according to the International Standard Classification of Education 97 (ISCED 97).

[b] We have also run regressions using regional fixed effects dividing Sweden into five regions: (a) Stockholm, (b) around Stockholm (including the provinces of Uppsala, Södermanlands, and Västmanlands), (c) Västra Götalands, (d) Skåne, and (e) other regions. We find no substantial differences from the reported results.

[c] The definition of metro/urban/rural regions is from the Swedish Board of Agriculture. Storstadsområden (e.g. Stockholm, Malmö, and Gothenburg) are metro regions, Stadsområden (other cities in Sweden, e.g. Linköping) are urban areas, and Landsbygd (small towns and villages) are rural regions.

Table 4 Random-effects probit regression on the probability of patenting for immigrants among the *entire* population aged 25–64, 1985–2007

	1			2			3			4	5
	1.1	1.2	1.3	2.1	2.2	2.3	3.1	3.2	3.3	4	5
	All	All_be61	All_af61	Chi_all	Chi_be61	Chi_af61	Chi_all_2	Chi_be61_2	Chi_af61_2	Adu_chi_af61	Edu_SE
Foreign born (omit: Swedish born)											
All foreign born	−0.000003***	−0.000002***	−0.000005***								
	(0.000000)	(0.000000)	(0.000001)								
Migrated as children				−0.000003***	−0.000006**	−0.000002*	−0.000002*	−0.000006*	−0.000001	−0.000002	−0.000002
				(0.000001)	(0.000003)	(0.000001)	(0.000001)	(0.000003)	(0.000001)	(0.000001)	(0.000001)
Migrated as adults										−0.000007***	
										(0.000001)	
Migrated as adults											−0.000006***
and edu. in Sweden											(0.000001)
Migrated as adults											−0.000008***
and edu. abroad											(0.000001)
Education level (omit: long education)											
Short education	−0.000011***	−0.000009***	−0.000012***	−0.000020***	−0.000028***	−0.000016***	−0.000012***	−0.000021***	−0.000009***	−0.000013***	−0.000013***
	(0.000001)	(0.000001)	(0.000001)	(0.000002)	(0.000003)	(0.000002)	(0.000001)	(0.000002)	(0.000001)	(0.000001)	(0.000001)
PhD	0.000444***	0.000388***	0.000419***	0.000572***	0.000741***	0.000464***	0.000278***	0.000447***	0.000199***	0.000432***	0.000431***
	(0.000023)	(0.000026)	(0.000037)	(0.000042)	(0.000085)	(0.000044)	(0.000022)	(0.000055)	(0.000021)	(0.000038)	(0.000038)
High school GPA							0.000000***	0.000000***	0.000000***		
							(0.000000)	(0.000000)	(0.000000)		
Field of study (omit: engineering, manufacturing, and construction)											
Science, mathematics,	−0.000007***	−0.000004***	−0.000008***	−0.000011***	−0.000011***	−0.000010***	−0.000011***	−0.000010***	−0.000010***	−0.000008***	−0.000008***
and computing	(0.000000)	(0.000001)	(0.000001)	(0.000000)	(0.000002)	(0.000001)	(0.000001)	(0.000002)	(0.000001)	(0.000001)	(0.000001)
Health and welfare	−0.000010***	−0.000007***	−0.000011***	−0.000015***	−0.000018***	−0.000013***	−0.000017***	−0.000020***	−0.000014***	−0.000011***	−0.000011***
	(0.000000)	(0.000000)	(0.000001)	(0.000001)	(0.000002)	(0.000001)	(0.000001)	(0.000002)	(0.000001)	(0.000001)	(0.000001)
Other fields	−0.000011***	−0.000009***	−0.000012***	−0.000017***	−0.000022***	−0.000014***	−0.000019***	−0.000024***	−0.000015***	−0.000012***	−0.000012***
	(0.000001)	(0.000001)	(0.000001)	(0.000001)	(0.000002)	(0.000001)	(0.000001)	(0.000002)	(0.000001)	(0.000001)	(0.000001)
Age	0.000002***	0.000002***	0.000007***	0.000007***	0.000008***	0.000009***	0.000008***	0.000009***	0.000011***	0.000007***	0.000007***
	(0.000000)	(0.000000)	(0.000001)	(0.000000)	(0.000001)	(0.000001)	(0.000000)	(0.000001)	(0.000001)	(0.000001)	(0.000001)
Age^2	−0.000000***	−0.000000***	−0.000000***	−0.000000***	−0.000000***	−0.000000***	−0.000000***	−0.000000***	−0.000000***	−0.000000***	−0.000000***
	(0.000000)	(0.000000)	(0.000000)	(0.000000)	(0.000000)	(0.000000)	(0.000000)	(0.000000)	(0.000000)	(0.000000)	(0.000000)
Gender (omit: male)	−0.000013***	−0.000013***	−0.000014***	−0.000020***	−0.000029***	−0.000017***	−0.000025***	−0.000035***	−0.000021***	−0.000014***	−0.000014***
	(0.000001)	(0.000001)	(0.000001)	(0.000001)	(0.000003)	(0.000001)	(0.000002)	(0.000003)	(0.000002)	(0.000001)	(0.000001)
Firm size (omit: medium (100–499 employees)											
Small (1–99 employees)	−0.000001***	−0.000001***	−0.000001***	−0.000002***	−0.000004***	−0.000001***	−0.000002***	−0.000004***	−0.000001***	−0.000001***	−0.000001***
	(0.000000)	(0.000000)	(0.000000)	(0.000000)	(0.000001)	(0.000000)	(0.000000)	(0.000001)	(0.000000)	(0.000000)	(0.000000)
Large (500+ employees)	0.000001***	−0.000000	0.000003***	0.000003***	0.000000	0.000004***	0.000003***	0.000000	0.000004***	0.000003***	0.000003***
	(0.000000)	(0.000000)	(0.000000)	(0.000000)	(0.000001)	(0.000001)	(0.000001)	(0.000001)	(0.000001)	(0.000000)	(0.000000)
Sector of work (omit: industry)											
Agriculture, hunting,	−0.000014***	−0.000014***	−0.000011***	−0.000019***	−0.000031***	−0.000015***	−0.000023***	−0.000035***	−0.000017***	−0.000011***	−0.000011***
forestry, and fishing	(0.000001)	(0.000001)	(0.000002)	(0.000001)	(0.000003)	(0.000002)	(0.000002)	(0.000004)	(0.000002)	(0.000002)	(0.000002)
Private service	−0.000010***	−0.000010***	−0.000009***	−0.000014***	−0.000022***	−0.000011***	−0.000016***	−0.000025***	−0.000013***	−0.000009***	−0.000009***
	(0.000001)	(0.000001)	(0.000001)	(0.000000)	(0.000002)	(0.000001)	(0.000001)	(0.000003)	(0.000001)	(0.000001)	(0.000001)
Public service	−0.000015***	−0.000015***	−0.000014***	−0.000021***	−0.000032***	−0.000017***	−0.000025***	−0.000037***	−0.000020***	−0.000015***	−0.000015***
	(0.000001)	(0.000001)	(0.000001)	(0.000001)	(0.000003)	(0.000001)	(0.000002)	(0.000004)	(0.000002)	(0.000001)	(0.000001)
Region of work (omit: rural regions)											
Metro regions	0.000004***	0.000003***	0.000006***	0.000008***	0.000009***	0.000007***	0.000008***	0.000009***	0.000007***	0.000006***	0.000006***
	(0.000000)	(0.000000)	(0.000001)	(0.000001)	(0.000001)	(0.000001)	(0.000001)	(0.000001)	(0.000001)	(0.000001)	(0.000001)

Urban areas	0.000001***	0.000001***	0.000001***	0.000002***	0.000002**	0.000002***	0.000002***	0.000002**	0.000002***	0.000001***	0.000001***
	(0.000000)	(0.000000)	(0.000000)	(0.000000)	(0.000001)	(0.000000)	(0.000000)	(0.000001)	(0.000000)	(0.000000)	(0.000000)
No. of observations	60,722,211	39,909,384	20,812,827	25,438,112	8,931,753	16,506,359	25,438,112	8,931,753	16,506,359	20,789,157	20,789,157
No. of individuals	4,790,529	2,603,142	2,187,456	1,843,162	443,248	1,399,917	1,843,162	443,248	1,399,917	2,185,171	2,185,171
Wald chi^2	28,779	17,572	12,134	16,058	5,884	10,590	15,931	5,888	10,394	12,128	12,128
Log likelihood	-185,198	-119,191	-65,139	-89,044	-32,712	-56,093	-88,449	-32,555	-55,690	-65,035	-65,034
Pseudo R^2	0.198	0.212	0.171	0.183	0.192	0.176	0.181	0.190	0.174	0.172	0.172

Robust standard errors in parentheses. *** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$.

Source: Statistics Sweden and CIRCLE data on inventors

Notes: Marginal effects are reported.

Sensitivity of quadrature approximation has been checked for each regression by quadchk and the results are reliable, as the largest relative difference for each variable is smaller or around 0.01% when we use intpoints (32).

Pseudo R^2=1–Log likelihood (full model)/Log likelihood (constant-only model).

Model 1 was run on the entire populations. Models 2 and 3 were only run on the population whose high school GPA between 1973 and 1996 was available. In each submodel of Model 1–3, we compare all populations, those born before and in or after 1961. Models 4 and 5 was only run on the population born in or after 1961.

Table 5 Negative binomial regressions on total number of patents per inventor aged 25–64, 1985–2007

	1			2			3			4	5
	1.1	1.2	1.3	2.1	2.2	2.3	3.1	3.2	3.3	4	5
	All	All_be61	All_af61	Chi_all	Chi_be61	Chi_af61	Chi_all_2	Chi_be61_2	Chi_af61_2	Adu_chi_af61	Edu_SE
Foreign born (omit: Swedish born)											
All foreign born	−0.045	−0.070	−0.042								
	(0.033)	(0.044)	(0.046)								
Migrated as children				−0.128**	−0.357***	−0.053	−0.113*	−0.340***	−0.039	−0.081	−0.081
				(0.060)	(0.093)	(0.070)	(0.059)	(0.092)	(0.069)	(0.065)	(0.065)
Migrated as adults										−0.027	
										(0.057)	
Migrated as adults and edu. in SE											−0.021
											(0.073)
Migrated as adults and edu. abroad											−0.032
											(0.081)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Constant	−0.529***	−1.603***	−0.931	−1.707***	−4.959***	−0.822	−2.509***	−5.495***	−1.486*	−0.923	−0.924
	(0.191)	(0.457)	(0.609)	(0.376)	(0.943)	(0.754)	(0.394)	(0.979)	(0.761)	(0.609)	(0.609)
No. of observations	16,471	9,399	7,072	8,918	2,876	6,042	8,918	2,876	6,042	7,072	7,072
Wald chi^2	1,802	1,280	1,071	1,077	640	871	1,156	651	886	1,071	1,073
Log pseudolikelihood	-35,208	-20,499	-14,435	-18,797	-6,200	-12,467	-18,745	-6,192	-12,430	-14,435	-14,435
Pseudo R^2	0.038	0.039	0.052	0.044	0.051	0.049	0.046	0.053	0.052	0.052	0.052

Robust standard errors in parentheses. *** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$.

Source: Statistics Sweden and CIRCLE data on inventors

Notes: Coefficient results are reported.

The results for control variables are omitted to save space. The control variables included here are three dummies for education level, high school GPA (only included in Model 3), four dummies for field of study, age, age^2, gender, three dummies for firm size, four dummies for sector of work, three dummies for region of work, and five dummies for technology field.

Pseudo R^2=1–Log likelihood (full model)/Log likelihood (constant-only model).

Model 1 was run on all inventors. Models 2 and 3 were only run on inventors whose high school GPA between 1973 and 1996 was available. In each submodel of Model 1–3 we compare all inventors, those born before and in or after 1961. Models 4 and 5 were only run on inventors born in or after 1961. It is the same for Table 6 and Table 7.

Table 6 Negative binomial regressions on number of forward citations for foreign-born inventors aged 25–64, 1985–2007

	1			2			3			4	5
	1.1	1.2	1.3	2.1	2.2	2.3	3.1	3.2	3.3	4	5
	All	All_be61	All_af61	Chi_all	Chi_be61	Chi_af61	Chi_all_2	Chi_be61_2	Chi_af61_2	Adu_chi_af61	Edu_SE
Foreign born (omit: Swedish born)											
All foreign born	−0.035	−0.024	−0.034								
	(0.051)	(0.068)	(0.068)								
Migrated as children				−0.251***	−0.202	−0.262***	−0.243***	−0.200	−0.248***	−0.251***	−0.251***
				(0.077)	(0.151)	(0.087)	(0.076)	(0.149)	(0.086)	(0.084)	(0.084)
Migrated as adults										0.032	
										(0.079)	
Migrated as adults and edu. in SE											0.049
											(0.107)
Migrated as adults and edu. abroad											0.016
											(0.108)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Constant	0.955***	−0.185	1.449	1.050*	−2.989**	1.923*	0.493	−3.242**	1.315	2.620***	2.614***
	(0.283)	(0.483)	(0.891)	(0.570)	(1.411)	(1.023)	(0.564)	(1.461)	(1.003)	(0.848)	(0.847)
No. of observations	49,949	30,231	19,718	26,356	9,144	17,212	26,356	9,144	17,212	19,718	19,718
No. of inventors	16,752	9,630	7,122	8,993	2,909	6,084	8,993	2,909	6,084	7,122	7,122
Wald chi^2	3,179	1,520	1,993	2,137	722	1,797	2,167	728	1,829	2,006	2,047
Log pseudolikelihood	-78,135	-47,515	-30,490	-41,677	-14,726	-26,889	-41,661	-14,725	-26,873	-30,485	-30,485
Pseudo R^2	0.039	0.032	0.054	0.046	0.034	0.054	0.046	0.034	0.055	0.054	0.054

Robust standard errors in parentheses. *** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$.

Source: Statistics Sweden and CIRCLE data on inventors

Notes: Coefficient results are reported.

The results for control variables are omitted to save space. The control variables included here are three dummies for education level, high school GPA (only included in Model 3), four dummies for field of study, age, age^2, gender, three dummies for firm size, four dummies for sector of work, three dummies for region of work, five dummies for technology field, number of inventors, and dummies for application year.

Pseudo R^2=1–Log likelihood (full model)/Log likelihood (constant-only model).

The results for the foreign-born are robust if using data from 1985–2004, 1985–2005, and 1985–2006.

Table 7 Logit regressions on the probability of a patent application being granted for foreign-born inventors aged 25–64, 1985–2007

	1			2			3			4	5
	1.1	1.2	1.3	2.1	2.2	2.3	3.1	3.2	3.3	4	5
	All	All_be61	All_af61	Chi_all	Chi_be61	Chi_af61	Chi_all_2	Chi_be61_2	Chi_af61_2	Adu_chi_af61	Edu_SE
Foreign born (omit: Swedish born)											
All foreign born	−0.008	−0.021*	0.015								
	(0.009)	(0.011)	(0.015)								
Migrated as children				−0.094***	−0.100***	−0.092***	−0.095***	−0.099***	−0.093***	−0.084***	−0.084***
				(0.022)	(0.037)	(0.026)	(0.022)	(0.037)	(0.026)	(0.025)	(0.025)
Migrated as adults										0.049***	
										(0.016)	
Migrated as adults and edu. in SE											0.042*
											(0.024)
Migrated as adults and edu. abroad											0.054**
											(0.021)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
No. of observations	49,949	30,231	19,715	26,356	9,144	17,209	26,356	9,144	17,209	19,715	19,715
No. of observations granted	25,665	17,642	8,023	12,110	4,931	7,179	12,110	4,931	7,179	8,020	8,020
No. of inventors	16,752	9,630	7,122	8,993	2,909	6,084	8,993	2,909	6,084	7,122	7,122
Wald chi^2	5,802	3,082	2,403	3,268	1,237	2,099	3,272	1,239	2,107	2,402	2,402
Log pseudolikelihood	−28,797	−17,582	−11,152	−15,066	−5,278	−9,751	−15,066	−5,277	−9,750	−11,136	−11,136
Pseudo R^2	0.168	0.144	0.163	0.171	0.164	0.166	0.171	0.164	0.166	0.164	0.164

Robust standard errors in parentheses. *** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$.

Source: Statistics Sweden and CIRCLE data on inventors

Notes: Marginal effects are reported.

The results for control variables are omitted to save space. The control variables included here are the same as those in Table 6.

The results for the foreign-born are robust if using data from 1985–2004, 1985–2005, and 1985–2006, except for those in Model 1.1 (all foreign born) and Model 5 (migrated as adults and educated in SE).

Figures

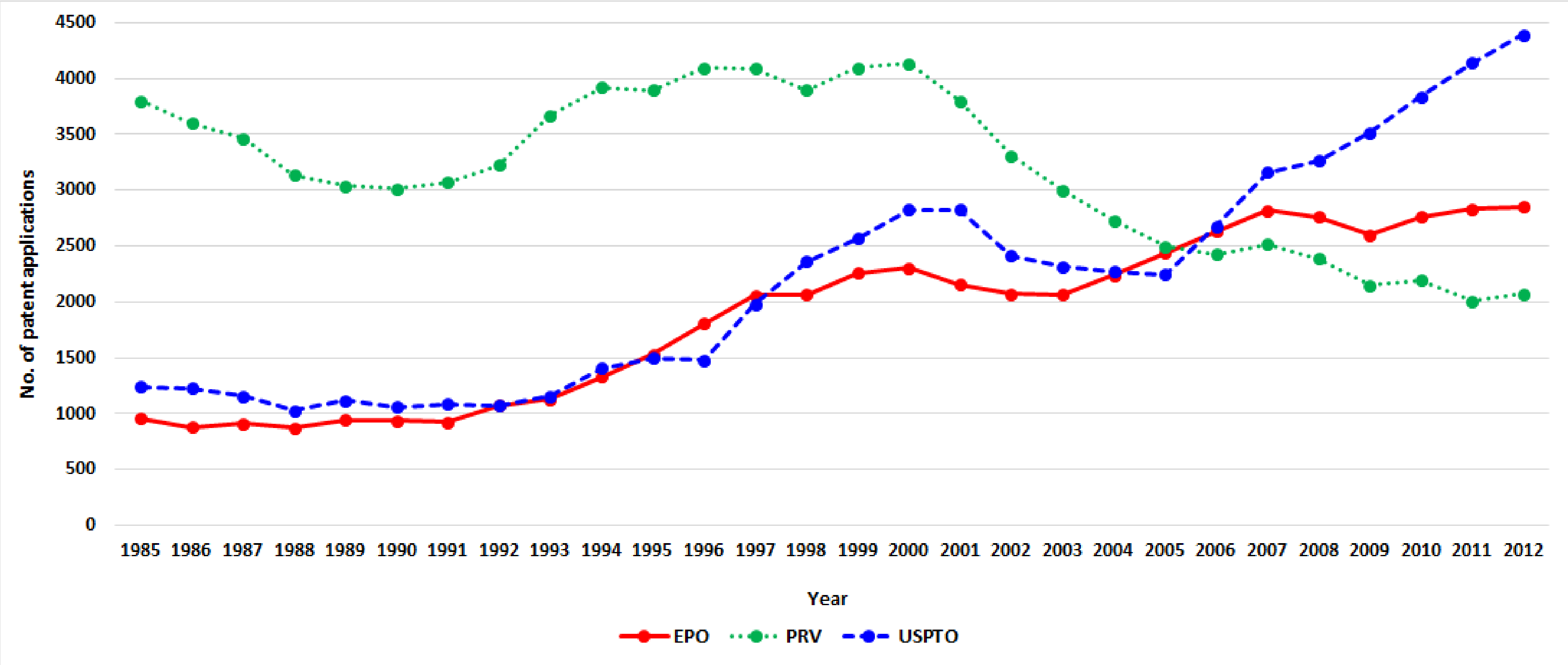

Fig. 1: Number of patent applications by Swedish residents in EPO, PRV, and USPTO
Sources: EPO (2014), PRV (2014), USPTO (2014)
Note: Number of patent applications in EPO is calculated by inventor's country of residence; in PRV it is calculated by the applications that have at least one applicant residing in Sweden; in USPTO it is calculated by the residence of the first-named inventor.

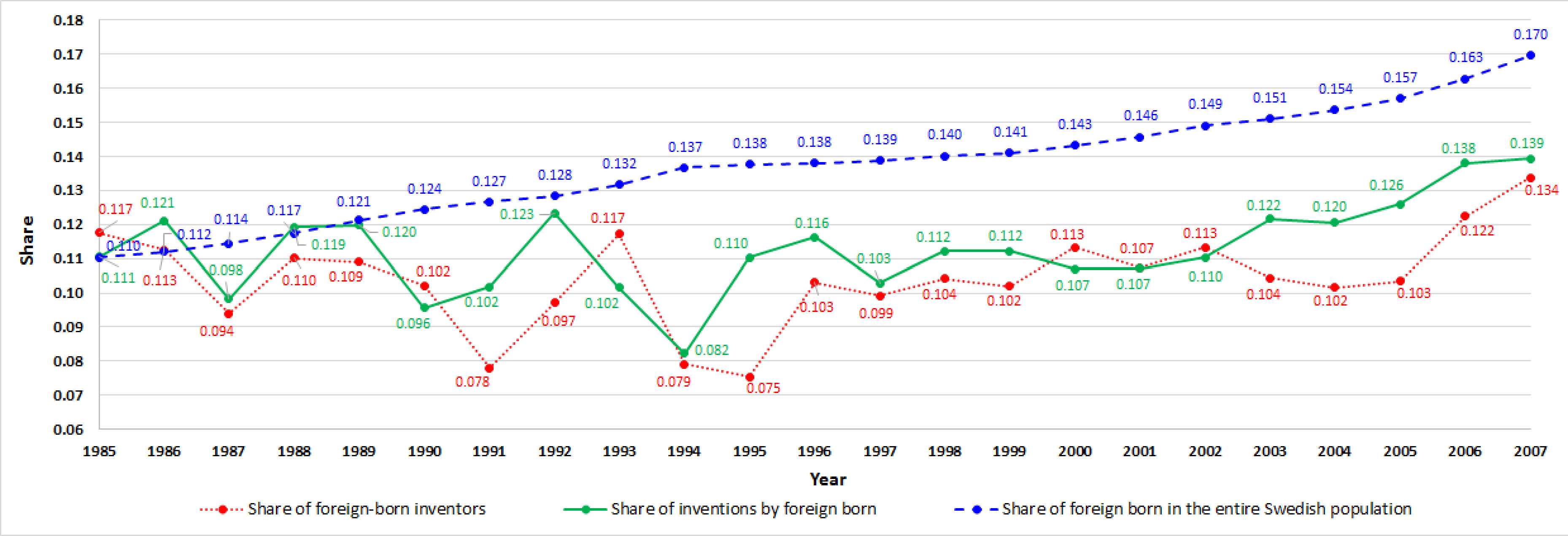

Fig. 2 Share of foreign-born inventors, their contribution of inventions (fractional count), and foreign born in the entire Swedish population aged 25–64, for each year 1985–2007
Source: Statistics Sweden and CIRCLE data on inventors

Appendices

Appendix A. Selection bias of unidentified inventors

As 20.7% of the patent–inventor combinations are still unidentified, one might suspect it to be more difficult to find the SSN of foreign-born inventors in Sweden, as they are likely to be more mobile and less ‘sticky’ in the registers. Thus, we initially looked for sample selection bias as to whether foreign-born inventors might be overrepresented among unidentified inventors by randomly choosing 15% of unidentified combinations per year from 1985 to 2007. Eyeballing inventors’ names, we found 17.6% to have names that could be characterized as ‘foreign’, which is slightly higher than the share of inventions by identified foreign-born inventors (11.5%). This may be because some foreign-born inventors had resided in Sweden for less than one year and thus had no Swedish SSN. Also, our classification of names as ‘foreign’ may be overstated, as many individuals (including inventors) are second and third-generation immigrants (see Fig. C in Appendix C) who are likely to have ‘foreign’ names but were born in Sweden.

We also used the Onomap software[36] to classify inventors’ surname-forename combinations as Swedish or non-Swedish. Among the unidentified inventors, Onomap matched 96.9% of the names (3.1% are unclassified), and among the matched names 51.2% were found to be Swedish. To examine whether Onomap’s result was robust or not, we also used Onomap to classify identified inventors. Among the identified inventors, Onomap matched 96.2% of the names, of which 49.0% were Swedish names. This proportion is much lower than that of the identified Swedish-born inventors in terms of our data (89.1%). Several reasons may account for it. First, we used ‘United Kingdom’ as the origin country of our data, as the other countries in Onomap are not currently working. Thus we found quite a high percentage of inventors with English/Scottish/Welsh/Irish names (14.4% and 11.6% among

[36]See Nathan (2014b) for a detailed introduction to the Onomap system.

unidentified and identified inventors, respectively). Second, many Swedes have names popular in other Nordic countries and Germany, which makes it difficult to differentiate origin among these countries. Third, as mentioned above, many Swedish natives have foreign names. Nevertheless, Onomap shows that among identified and unidentified samples, the proportion of inventors with Swedish names is roughly similar.

Both the eyeballing of inventors' names and the Onomap test cannot directly identify the share of "foreign-born inventors" as in our identified data, since they only show the share of minority ethnic inventors, which can also capture second and third-generation immigrants. Nevertheless, both tests show that it seems unlikely that there is any large sample selection issue in our data with respect to foreign participation.

Appendix B.

Sector of work by SNI 1992

i) Agriculture, hunting, forestry and hunting

A Agriculture, hunting, and forestry: 01–02

B Fishing: 05

ii) Industry

C Mining and quarrying: 10–14

D Manufacturing: 15–37

E Electricity, gas, and water supply: 40–41

F Construction: 45

iii)Private service

G Wholesale and retail trade; repair of motor vehicles, motorcycles, and personal and household goods: 50–52

H Hotels and restaurants: 55

I Transport, storage, and communication: 60–64

J Financial intermediation: 65–67

K Real estate, renting, and business activities: 70–74

P Activities of households: 95

iv) Public service

L Public administration and defense; compulsory social security: 75

M Education: 80

N Health and social work: 85

O Other community, social, and personal service activities: 90–93

Q Extra-territorial organizations and bodies: 99

Appendix C.

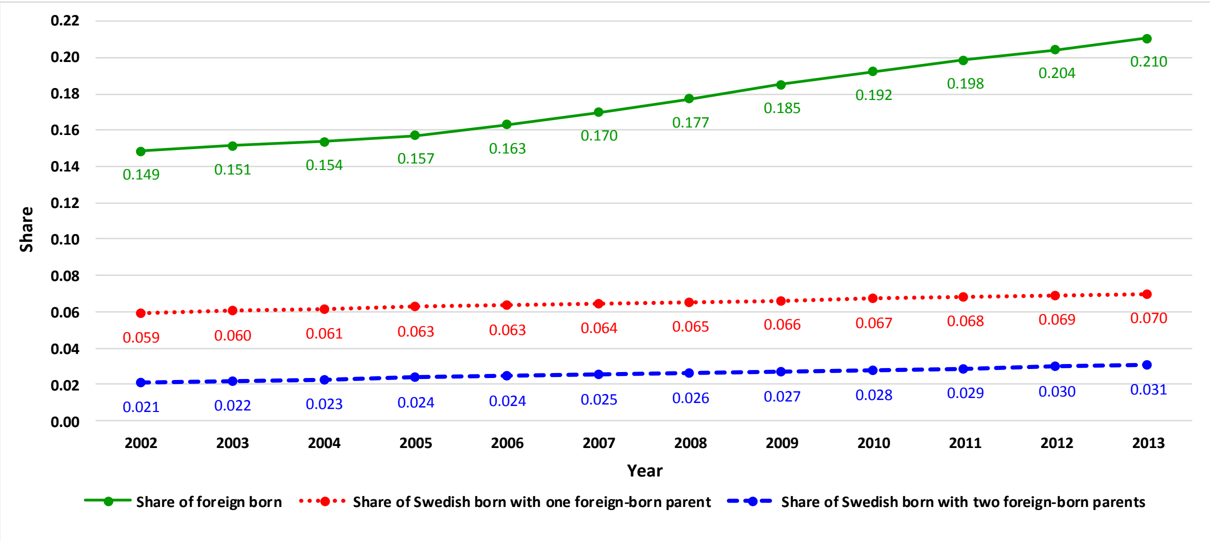

Fig. C: Share of foreign born, Swedish born with one foreign-born parent, and Swedish born with two foreign-born parents among Swedish population aged 25–64, for each year 2002–2013
Sources: Statistics Sweden

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