The global race for inventors' brains

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Carsten Fink, Ernest Miguélez* & Julio Raffo**

*Economics and Statistics Division – WIPO[1]

{Carsten.Fink, Ernest.Miguelez, Julio.Raffo}@wipo.int

Abstract

The present paper makes two main contributions to the literature on international mobility of skilled labor. First and foremost, we compile and use a new database on international mobility of inventors covering an extensive number of sending and receiving countries for a large period of time (1990-2010). Second, we test the role of immigration policies in receiving countries in selecting the most skilled workers. We start with a typical utility-maximization migration model, augmented to include skill-selective migration policy variables. We also test other hypotheses that have occupied migration economist in recent years, such as the role of income differentials or migration costs. We find our new dataset on migrant inventors suitable to studying the international mobility patterns of high-tech workers, as well as certain evidence of skill-selection on immigration policies. Moreover, we find economic incentives (migration costs) to positively (resp. negatively) affect inventors' migration.

JEL classification: F22, J61, O3, O15

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[1]The views expressed in this article are those of the authors and do not necessarily reflect those of the World Intellectual Property Organization or its member states.

1. Introduction

In the last two decades, governments in high-income countries, increasingly aware of the importance of attracting worldwide skilled labor to tackle skills' shortages and scant entrepreneurial spirit, have introduced a number of selective open immigration policies targeted to increase the inward flows of knowledge workers to their national labor markets. Clear examples of this are the Indian and Chinese IT workers migrating massively to the US under the HB1 visa framework, or the flight of health professional from African countries to high-income, developed economies. Cross-country figures seem to support this extreme. Recent data (United Nations, 2012) show that, by 2010, the estimated migrant population was around 213 million, meaning a 58% increase compared to 1990 figures, thus making international migration a critical pillar of the ongoing process of globalization (Docquier and Rapoport, 2012a). With population figures increasing at a similar pace, the world migration rate has raised from 2.5% to 3.1% during this same period. Strikingly, however, the number of highly educated immigrants living in OECD countries increased by 64% during the 1990s, compared to the 23% increase of low-skilled migrants for the same period.

In consequence, the issue of skilled international migration has driven the attention of academics and policymakers alike, in both sending and receiving countries. In sending economies, the flight of the most skilled individuals is said to have sizeable economic consequences – such as loss of human capital endowments and tax revenues, or gains from remittances and diaspora externalities – which have fuelled the debate in recent years.[2] The impact of skilled immigration on the receiving countries has also been studied. Among others, the effects of skilled immigration on wages (Borjas, 1999, 2003; Ottaviano and Peri, 2012), unemployment (D'Amuri et al., 2010) and innovation (Niebuhr, 2010; Partridge and Furtan, 2008; Hunt, 2011; Hunt and Gauthier-Loiselle, 2010; Stephan and Levin, 2001; Saxenian, 1999) has been extensively discussed in the literature. These contributions have further motivated a number of studies trying to disentangle what country features attract highly skilled workers, from the receiving countries' perspective. Still, this is a somewhat underdeveloped research avenue (Bertoli et al., 2012; Ortega and Peri, forthcoming).

[2] See Docquier and Rapoport (2012a,b) for a review.

This paper builds on and contributes to the existing literature on the skilled workers' international mobility in two main aspects. First, we look at the case of inventors, a class of highly-talented workers among the tertiary educated labor force. As asserted by Docquier and Rapoport (2009), there is considerable heterogeneity among skilled workers which is worth examining. Indeed, previous studies have shown that between 30 to 50 percent of scientists and technologists that were trained in developing countries live in developed ones (Meyer and Brown, 1999; Barré et al., 2004; cited in Lowell et al., 2004). Similarly, Docquier and Rapoport (2012a) report emigration rates of PhD holders and researchers between 2.2 to 5.3 times larger than the average rate for tertiary educated migrants. In contrast, most of the existing studies make use of skilled migration datasets referring to tertiary educated migrants, without further breakdown into specific levels of education or areas of specialization.

Second, we examine the link between selective open immigration policies and immigration flows. Existing literature have looked at the effect of immigration policies on immigrants' skills selectivity, but only under a cross-section framework (Beine et al., 2011; Grogger and Hanson, 2011); while those studies in a longitudinal setting have not differentiated across skills (Mayda, 2010; Ortega and Peri, forthcoming).

With the intention of complementing the abovementioned literature, we focus on the international mobility of high-tech workers by making use of a new longitudinal bilateral worldwide dataset on the international mobility of inventors applying for PCT patents. Following the existing literature (Agrawal et al., 2011; Kerr, 2008; Oettl and Agrawal, 2008), we argue that this new dataset characterize international mobility at the upper tail of the skills' distribution – the so-called 'elite brain drain' – with a unique coverage in terms of country-pairs and time. To advance our results, our analysis shows that inventors' migration data can be reasonably used to study the migratory patterns of highly-skilled workers.

We test the validity of the new dataset in the context of a theoretical model of individual utility-maximization migration choices, augmented to include the demand for foreign and national labor in the receiving countries and skill-selective migration policies. From this theoretical setting, we derive an estimable gravitational model to ascertain the specific role of immigration policies in discriminating between highly skilled workers and the total migrant population. In addition, we test the role of income differentials, the effects of migration costs, and whether income differentials not only affect the inflows of migrants to a given country, but also the mix of the immigrant population to be more skilled.

We find that income maximization strongly drives inventors' mobility, but does not positively shape the educational mix of immigrants. Meanwhile, migration costs and immigration policies positively select inward flows of this highly-skilled class of workers over the general population of migrants.

The rest of the paper is organized as follows: section 2 reviews some relevant previous studies. Section 3 thoroughly describes the database, while section 4 sets the theoretical model and the empirical approach. Section 5 shows our econometric results, and section 6 presents the conclusions.

2. Literature review

The study of the international mobility of skilled labor and the associated brain drain has now a long and established tradition within economics. In the present inquiry we do not attempt to provide an in-depth literature review, for which recent surveys already exist (Docquier and Rapoport, 2012a). Rather, this section summarizes a non-exhaustive, instrumental list of previous contributions that have looked at the international mobility of 'the best and brightest'.

Pioneering contributions to the brain drain literature, back to the 1970s, clearly stress the adverse consequences of the loss of nationally trained human capital ending up working and living abroad (Bhagwati and Hamada, 1974; Grubel and Scott, 1966; Bhagwati and Rodriguez, 1975). Loss of human capital and human capital externalities, tax revenues, innovative competences and absorptive capacity, have been put to the forefront alike to emphasize the negative effects of the brain drain for development. A more positive light is adopted during the 1990s, and several contributions attempt to prove that, under certain circumstances, the emigration of skilled individuals may turn out to be beneficial for the origin country. The idea that emigrants' remittances largely contribute to their origin country GDP growth (Grubel and Scott, 1966; Faini, 2007) or the concept of the brain gain – larger individuals' incentives to invest in human capital formation induced by the prospective to emigrating (Mountford, 1997; Beine et el., 2001), are also underscored and enter the debate.

Rather more nuanced views have developed since then, showing that a positive skilled emigration rate is likely to be beneficial for developing countries (Docquier and Rapoport, 2004). In particular, this literature puts large emphasis on the role of returnees with skills acquired abroad (Rosenzberg, 2008; Mayr and Peri, 2009; Dos Santos and Postel-Vinay, 2004; Gaullé, 2011), as well as diaspora networks fostering international knowledge flows and business networks (Agrawal et al., 2011; Kerr, 2008; Foley and Kerr, 2012; Saxenian, 2002, 2006), trade and capital flows (Gould, 2002; Rauch and Trindade, 2002; Docquier and Lodigliani, 2008; Parsons, 2012), home country institutions, values and norms (Li and McHale, 2009; Spilimbergo, 2009), or even further migration flows (Beine et al., 2011; Pedersen et al., 2008).

Interestingly, empirically-based contributions have only sprung up in recent years. The availability of migration data has made possible this rise of a significant body of empirical work. The pioneering study by Carrington and Detragiache (1998) is the first systematic cross-country attempt to provide a comprehensive dataset on the brain drain and migration flows of the educated workforce. Their study provides 1990 emigration rates for 61 sending countries to OECD destinations. Breakdowns by skills are estimated imputing the schooling levels of US immigrants by origin country in other receiving countries. Docquier and Marfouk (2006) estimate immigrants' stocks in 30 OECD countries for 174 origin countries, for 1990 and 2000. They obtain the count of migrant population over 25 years old, broken down by schooling levels (primary, secondary, and tertiary), and combine their figures with Barro and Lee's (2000) human capital ones, to obtain brain drain rates by education level and country. Docquier and Marfouk's (2006) dataset, together with Docquier et al. (2009) – with a gender breakdown – and Beine et al. (2007) – controlling for age of entry – have been the most comprehensive datasets available to study the abovementioned topics. An enlarged coverage is provided more recently by the OECD, census 2000-2001 data, DIOC-E database, release 3.0 (Dumont et al., 2010), including numerous sending (233) and receiving (100) countries, by gender, age, and educational attainment.

Notwithstanding these exceptional data collection efforts, several remarks are worth mentioning[3]. First, these datasets cover only one single year (or single time spans) or two at

[3] For further details see, for instance, Hanson (2010) or Bertoli et al (2012).

the most (1990 and 2000), preventing any longitudinal analysis. In order to overcome this limitation some studies have made use of longitudinal data from the Continuous Reporting System on Migration (SOPEMI). This is the case of Mayda (2010) and Ortega and Peri (forthcoming), where annual migration flows to OECD destinations from 1980 to 2005 are analyzed. In none of these longitudinal studies the level of skills of the migrant population is taken into account. Second, the distinction into three levels of schooling in the majority of these datasets is rather rough. In particular, tertiary education may include non-university tertiary degrees, undergraduate university degrees, and postgraduate and doctorate degrees, which, on top of that, might not be comparable (in terms of the skills acquired) across different countries. In consequence, migrants' contributions to various economic outcomes in receiving and sending countries are likely to be highly heterogeneous as well.

A plausible alternative approach to overcome these limitations is to look at inventors' migratory background as a proxy for highly skilled labor international mobility. Following this road, Agrawal et al. (2011) use the likely cultural origin of inventors' names in USPTO patents to estimate the size of the Indian diaspora in the US. Afterwards, they test the prevailing source of knowledge for inventors resident in India, that is, the role of the Indian diaspora vis-à-vis the agglomeration of Indian inventors in their origin country. In a broader research agenda, Kerr (2008) estimates the ethnic origin of all USPTO inventors' names, for nine ethnicities: Chinese, English, European, Hispanic, Indian, Japanese, Korean, Russian, and Vietnamese. By means of citation analysis, he confirms that knowledge diffuses internationally through ethnic networks, which also has sizeable effects on home country output (increases around 10 to 30 percentage points). More recently, Foley and Kerr (2012) estimate significant effects of US firms' ethnic innovators in promoting linkages of these firms with the innovators' home countries, in the form of knowledge flows or R&D alliances.

The databases mentioned earlier have also conferred the possibility to address other issues that have occupied migration economist in recent years. For instance, it is now a well-established fact that international migration is severely hampered by restrictive migration policies adopted in destination countries. Some studies have looked at immigration policies' effects on inflows of migrants to receiving countries, generally not broken down by skills, using different proxies for immigration policy and with mixed results (Ortega and Peri, 2009, forthcoming; Mayda, 2010; Karemera et al., 2010; Clark et al., 2007).

It has been also widely reported that all OECD countries tend to facilitate immigration of skilled persons over non-skilled individuals: considerable shortages of skilled labor are foreseen in the coming years and recruiting skilled individuals from abroad seems to be a straightforward answer (Chaloff and Lamaître, 2009). The US HB1 visa framework or the German "Green Card" initiative constitute clear examples of that. Thus, increasingly countries are redefining their immigration policies to make them more skill selective (Bertoli et al., 2012). Accordingly, recent contributions look at the effect of immigration policies, not only on the scale, but also on the skills' selection of immigrants. Bertoli and Fernandez-Huertas Moraga (2012) find that visa requirements by country j to country i, as a rough proxy of bilateral immigration policy, negatively correlate with the level of migration flows (elasticity estimated around 40-47%). Interestingly, they also find the absolute values of the estimated coefficients to be significantly lower for high-skilled than for low-skilled migrants. As they argue, this result is consistent with the idea that low-skilled migrants are more sensitive to changes in the costs of migration (including legal barriers) as compared to skilled migrants.

As will be discussed later on, testing the selection effect of open immigration policies is also a critical aim of our contribution. Different from the former, we use the number of visas a given country reserves for refugees and asylees as a proxy for the skills bias of countries' admission policies. As it has been argued in the literature, less educated workers are more likely to end up migrating as refugees or asylees. Therefore, countries reserving larger shares of visas for refugees or asylees are more likely to receive low-skilled migrants.

In a cross-sectional setting, Grogger and Hanson (2011) find the share of asylum visas to be insignificant to explain the scale of immigration, but significantly negatively correlate with the schooling level of immigrants. On the contrary, they find the Schengen agreement variable to be positively associated with skills' selection of immigrants. In a similar vein, Beine et al. (2011) find that non-selective immigration policies and generous social expenditures lower the educational mix of migrants.

Despite these contributions, further research on the effects of skill-selective migration policies need still to be done. Again, our paper contributes to this literature by estimating the impact of immigration policies on inflows of inventors and comparing the estimated coefficients to the general migrant population.

Finally, other topics have been also addressed. Above all, Borjas (1987), building on Roy (1951), argues that migrants tend to be negatively selected in terms of education, explaining the change of the average skills' level of immigrants in the US over time. Recent empirical studies (Beine et al., 2011; Pedersen et al., 2008; Grogger and Hanson, 2011; Belot and Hatton, 2012; McKenzie and Rapoport, 2010) show that income and income inequality at destination positively affects the selection of high-skilled migrants, whilst larger social expenditure at destination, lower migration costs – physical distance or cultural links – and diaspora networks, negatively affect the selection of skilled inflows of individuals.

3. Research design: A new dataset on migrant inventors

In the present paper, we look at yearly migration data for a large number of sending and receiving countries, focusing on a specific subgroup of highly skilled workers, such as inventors. Following the literature on inventors' mobility (Agrawal et al, 2011; Kerr, 2008; Oettl and Agrawal, 2008; Foley and Kerr, 2012), we assume inventors to be a critical part of the highly skilled labor force. While we acknowledge that inventors constitute a small proportion of the highly-skilled population, it is also true that they have a critical economic significance. In particular, it is undeniable that they are involved in the production of technological innovations and are responsible for the transfer of large shares of knowledge (Breschi and Lenzi, 2010). Applying for patents is a costly and time-consuming process, which is even truer for the case of the PCT patents. PCT patents are more technologically and economically exploitable, suggesting that PCT inventors should be among the most skilled within the educated labor force.

3.1. Data collection

Information on inventors with migratory background is retrieved from patent applications under the PCT treaty (WIPO IPSTATS databases). In particular, we retrieve nationality and residence information of inventors at the time of their application.[4] To the best of our knowledge, PCT patents are the only ones recording this type of information. Behind that is the fact that not all countries are PCT contracting states. However, in order to be allowed to file an international application, the applicant should be either a national or a resident of a contracting state. Providing this information is therefore compulsory for applicants. Yet,

[4] See Miguélez and Fink (2013) for a detailed description of the dataset and data sources.

unfortunately, nationality and residence information is not always available. Aside from several cases where the information is missrecorded, nationality/residence information of inventors is only collected in PCT applications if and only if the inventor declares him/herself also as an applicant.

Luckily, the large majority of PCT inventors are considered also applicants in PCT patents. Behind that is the fact that US patent applications procedures bind the applicant of a patent also to be the inventor. If a given PCT application includes the US as a designated state[5], which is the case for the majority of the applications, inventors must be considered also applicants, and in consequence their nationality and residence information is provided. In reality, the country with a larger share of inventors over applicants-inventors is the US, since a large number of applications have been previously applied for at the USPTO, and therefore they do not need the US to be one of the designated states. As a result of this, the share of inventors' names in patents over the inventors plus applicants-inventors names is around 33% for the case of the US. Similarly, the share of inventors is relatively high for the case of Canada (17%) or the Netherlands (16%), and way lower for the case of other relevant countries such as Germany (3.7%), the UK (5%), France (3.5%), Switzerland (3.2%), China (2.2%) or India (3.4%).

Fortunately for our purposes, PCT regulations where modified in 2004. From that date, all PCT applications automatically include all PCT member states as designated states, which entails that, worldwide speaking, inventors represents a minor share (1% to 7%) in PCT patents, being the applicants-inventors the large majority.

All in all, between 1990 and 2010, the share of inventors' records for which we can retrieve nationality and residence information is pretty high, around 80% of the cases. Admittedly, this coverage is unevenly distributed over time, being around 60-70% during the 1990s, and 70-95% during the 2000s, to which we add all the specific country differences commented above. In any case, we are of the opinion that these drawbacks do not necessarily induce any specific bias in our subsequent estimations, which are at the aggregated pair-wise country level.

[5] Designated states refer to those countries in which applicants wish to have international patent protection.

3.2. Data description

In order to preliminary assess the quality of our constructed dataset we carried out a series of descriptive analysis of the international mobility of inventors, focusing on immigration and emigration rates of selected countries and continents. We summarize here the most relevant findings. Both the descriptive and the econometric analyses are run at the aggregated country level. We treat each record in our patent database ("record" meaning unique combinations of "inventor name" and "application number") as if it were a different individual and we then aggregate by country-pair and year[6] to compute our figures and build our dependent variable.

First and foremost, we find exceptionally high migration rates for our sample of extremely skilled individuals. For instance, data compiled by Docquier and Marfouk (2006) or Beine et al. (2007), among others, show that general migration rates in 2000 for population 25 years old and over were estimated around 1.8%, including 1.1% of immigrants among the unskilled population, 1.8% among population with secondary education, and 5.4% among population with tertiary education, witnessing the selection effect in global migration figures. The positive selection of immigrants (the more skilled are more likely to migrate) and the large heterogeneity among skilled population is markedly evident if one looks at inventors' migration rates: by the year 2000, up to 8.62% of inventors' names in PCT patents have migratory background. Figure 1.a depicts the evolution of the share of inventors' names in PCT patents with migratory background, alongside the same figures broken down by a number of selected receiving countries. As can be observed, the share of worldwide migrant inventors has steadily increased over time. Among the most receiving countries of the world, Canada, Australia and, notably, the US, stand out as being the primary receiving countries, as compared to their resident stock of inventors. Meanwhile, technology leading European countries, such as Germany or France, are lagging behind. Of special interest is the case of the UK, which has experienced a substantial increase in its stock of immigrant inventors' population. On the other side, Japan is, and has been over the years, one of the developed countries with a smaller share of inventors' immigrant population. It is worth mentioning that in unreported results we find Switzerland to have large immigration shares as well, even larger than for the case of the US, for the whole period.

[6] We use the priority date of applications to allocate our individuals in time. By "priority date" we refer to the first year the patent was applied worldwide.

The exceptional performance of the US in attracting talent can be further seen in Figure 1.b, where the same variable is computed for these selected countries, but considering only immigrant inventors coming from non-OECD countries. These figures are intended to show more clearly the South-North brain drain of inventors in the 'global competition for talent'. As can be seen, the general trends for the majority of countries are maintained as compared to Figure 1.a, with the nameable exception of the US, which stands out as the leading country in attracting talent from non-OECD countries, being the difference with the remaining countries way larger than before.

[Figure 1 about here]

Our descriptive analysis of immigrant inventors is comparable to another group of highly-skilled workers, i.e., scientists. In a recent study by Franzoni et al. (2012), 17,182 scientists of 16 countries were surveyed in 2011. According to their results, Switzerland records the largest scientists' immigration rate, around 56%, followed by Canada (47%), Australia (44%) or the US (38%). Spain, Italy, Japan and India appear at the lower end of this list. As shown above, their results are analogous to our inventors' immigration rates for most of these countries.

It is also worth looking at the emigration rates of sending, less developed areas. These rates are calculated as the share of inventors' records nationals of a given country living outside that country, over the number of residents in that country, broken down by world geographical areas. Again, as abovementioned, the share of migrants among the highly skilled (tertiary education and above) accounts for 5.4% in 2000. This figure hides remarkable differences across country-groups: for the high-income countries, the emigration rate was 3.6%, whereas 7.3% for developing countries. The figures were extremely pronounced for the case of small developing islands (42.4%) or least developed countries (13.1%), as extracted from 2000 census data (Docquier and Marfouk, 2006; Docquier et al., 2007).

These differences turn out to be even more marked when looking at inventors' data. The share of inventors' names with migratory background was around 6.98% in the time window 1991-2000, and 9.02% in the time window 2001-2010. However, large differences between high- and medium-/low- income countries coexist. Thus, high-income countries' emigration rates for these two time windows were, respectively, 5.05% and 5.91%. In the meantime, the figures for medium- and low- income countries were, respectively, 40.96% and 36.11%. As it is observed in Figure 2, where the time evolution of emigration rates is shown, both for the whole world and broken down by continents, Africa and Latin America and the Caribbean are greatly contributing to the former figures. Specially striking is the case of Africa, which, departing from already large figures during the nineties, has steadily increased its general emigration rate from 2000 to 2010. Hence, by 2010, around half of the African inventors lived abroad.

[Figure 2 about here]

4. Methods

4.1. Theoretical Model

Demand for skilled labor

Assume that a typical firm of country j uses capital K_j and labor L_j^I to produce Y_j through a Cobb-Douglas production function with constant returns to scale, as:

$$Y_j = z_j K_j^{1-\alpha_j} \left(L_j^I\right)^{\alpha_j} \tag{1}$$

where z_j is the country level of technology. We define L_j^I as the normalized total labor employed in country j – either nationals or foreigners – making α_j the country's average labor elasticity across all nationalities. Thus,

$$L_j^I = \sum_i \theta_{ij} L_{ij} \tag{2}$$

where L_{ij} represents the quantity of country i nationals employed in country j – including $i = j$. θ_{ij} is a moderator parameter and accounts for any potential differences foreign inventors from country i in country j may face with respect to nationals and other foreign nationalities affecting their productivity, which is normalized to one when i=j. θ_{ij} comprises different aspects such as language barriers and similar/dissimilar cultural roots, shared historical ties, proximity to the home-country – family and friends, local networks of co-ethnics – legal barriers and restrictive immigration policies, and the like. In a nutshell, θ_{ij} takes on board all the potential factors that make a given ethnicity more or less productive compared to the national inventors, for a given level of skills.

The representative firm rents capital at rate r_j and hires labor at wage w_{ij}. We allow w_{ij} being different between nationals and foreigners, but also across foreign nationalities, due to the reasons sketched in the previous paragraph – therefore w_{ij} is the equilibrium wage of the ethnicity from country i working in country j, including the case when i=j. Thus, the firm optimizes its profit function (π_j) by hiring labor and capital constrained to the competitive prices of these factors. Given the following firm's objective function

$$\pi_j = Y_j - r_j K_j - w_{ij} L_j = z_j K_j^{1-\alpha_j} \left(\sum_i \theta_{ij} L_{ij} \right)_j^{\alpha_j} - r_j K_j - \sum w_{ij} L_{ij} \ , \tag{3}$$

the first order conditions with respect to labor from country i residing in country j are taken as

$$\frac{\partial \pi_j}{\partial L_{ij}} = z_j K_j^{1-\alpha_j} \alpha_j \left(\sum \theta_{ij} L_{ij} \right)^{\alpha_j - 1} \theta_{ij} - w_{ij} = 0 \tag{4}$$

which can be solved to give country j's total labor demand as

$$L_j^D = \left(\alpha_j z_j \frac{\theta_{ij}}{w_{ij}} \right)^{1/(1-\alpha)} K_j \ , \tag{5}$$

as well as the wage equilibrium received in country j by inventors from country i:

$$w_{ij} = \alpha_j \frac{Y_j}{L_j^I} \theta_{ij} \ , \tag{6}$$

Define w_j as the wage in equilibrium for all inventors in country j and θ_{ij} as the moderator effect as defined before. Therefore, w_{ij}, including w_{jj}, may be defined as $w_j\theta_{ij}$. Note that for national inventors, $\theta_{ij} = 1$ and therefore $w_{jj} = w_j$. Hence, it is also worth noting that

$$w_i = \frac{w_{ij}}{\theta_{ij}} = \alpha_j \frac{Y_j}{L_j^I}. \tag{7}$$

Foreign labor supply

As it is customary in the migration literature, an individual utility maximization framework is used to identify individuals' decision to migrate or to stay in their origin countries. Let us assume that the utility given by individual k in country i is a positive function of personal income

$$u_i^k = g(w_i) + \varepsilon_i^k \tag{8}$$

where ε_i^k is an idiosyncratic individual-specific assessment – basically, anything that leads individual k to place a different value to u_i^k than the rest of the population. Let us further assume that the utility of migrating to another country j is a function of the expected personal income minus the cost of moving.

$$u_{ij}^k = g(w_{ij}) - C_{ij}^k + \varepsilon_{ij}^k \tag{9}$$

Define M_i as the size of the country's i born population/inventors; M_{ij} as the nationals from country i living in country j; and M_{ii} as the population/inventors residing in i. Following McFadden's (1974, 1981) results on the random utility approach to discrete choice problems, the probability of migrating can be written as

$$\Pr\left(u_{ij} = \max_k u_{ik}\right) = \frac{M_{ij}}{M_i} = \frac{\exp\left[g(w_j) - C_{ij}\right]}{\sum_k \exp\left[g(w_k) - C_{ik}\right]} \tag{10}$$

Furthermore it is possible to write the odds of migrating to destination country j versus staying in country i as

$$\frac{M_{ij}}{M_{ii}} = \frac{\exp[(g(w_{ij}) - C_{ij})]}{\exp[(g(w_{ii}))]} \tag{11}$$

For the sake of simplicity, we assume individuals' utility to be logarithmic in personal income. Thus, taking logs to the former expression yields the following equation

$$\ln\left[\frac{M_{ij}}{M_{ii}}\right] = \ln(w_{ij}) - \ln(w_{ii}) - \ln C_{ij} \tag{12}$$

We expect $\ln(w_{ij})$ to positively affect inflows of individuals to country j and $\ln(w_{ii})$ to be negatively related to outflows of workers, for any type of labor.

We also expect $\frac{\partial M_{ij}^{s}}{\partial w_{ij} \partial s} < 0$ - where s denotes the level of skills. That is to say, the expected personal income at destination positively affects the selection of highly-skilled migrants over the general migrants' population (see, among others, Beine et al., 2011).

Migration costs, C_{ij}, are the costs incurred by an individual k migrating from i to j, including information costs – generally proxied by physical distance, social and cultural differences, and the like. Migration costs are also affected by legal barriers, visa costs and, in general, receiving countries' restrictive immigration policy. We expect migration costs to negatively affect bilateral flows, so $C_{ij}^{s} > 0$, for any level of skills. However, again, $\frac{\partial C_{ij}^{s}}{\partial s} > 0$, which captures the fact that highly-skilled migrants face lower migration costs – they are better informed about job opportunities, they have better adaptive skills, they are able to better handle legal migration barriers, and the like.

Common language, common physical border, and common past colonial ties are expected to lower migration costs and therefore positively affect bilateral flows of individuals. Again, however, we expect them to have sizeable effects for the case of the general population, and more nuanced effects for the case of inventors, which would give us further evidence on the negative effects of migration costs on skills' selection.

Note that migration costs also include immigration policy variables at destination. We expect the immigration policy in destination countries to be positively selective in terms of skills: inventors are more eligible to be selected for high-skilled immigration programs than the general population.

Next, substituting (7) into (12) and assuming that Y_j / L_j^I can be fairly approximated by GDP per capita, y_j, yields the following expression[7]

$$\ln M_{ijt} = \ln(\alpha_{jt} y_{jt} \theta_{ijt}) - \ln(\alpha_{it} y_{it}) - \ln C_{ijt} + \tau_i + \tau_j + \delta_t + \varepsilon_{ijt} \tag{13}$$

where τ_i, τ_j, and δ_t account for origin-country, destination-country and time fixed effects to capture any country and time specific variable that might affect bilateral inventors' migration flows. As shown by Anderson and van Wincoop (2003), the inclusion of origin and destination fixed-effects in gravity models is in line with theoretical concerns regarding the correct specification of these models, which translates into more consistent estimations of the foci variables. $ln(M_{iit})$, $ln(\alpha_{it})$ and $ln(\alpha_{jt})$ enter the constant term, β_0, and thus the final estimable specification is as follows:

$$\ln M_{ijt} = \beta_0 + \ln(y_{jt}) - \ln(y_{it}) + \ln(\theta_{ijt}) - \ln(C_{ijt}) + \tau_i + \tau_j + \delta_t + \eta_{ij} \tag{14}$$

θ_{ij} is an additive function of bilateral variables likely to affect inventors' productivity, x_{ijt}^m, as mentioned before:

$$\theta_{ijt} = \gamma_\theta \cdot f(x_{ijt}^m) \; , \tag{15}$$

and C_{ij} another additive function of variables likely to affect migration costs, x_{ijt}^m, as

[7] The subscript *t* is now added to reflect the longitudinal dimension of our analysis.

$$C_{ijt} = \gamma_C \cdot g\left(x_{ijt}^m\right) \; . \tag{16}$$

All in all, the following estimable model is specified:

$$\ln M_{ijt} = \beta_0 + \ln y_{jt} + \ln y_{it} + \gamma_\theta \sum_m \beta_m x_{ijt}^m - \gamma_C \sum_m \rho_m x_{ijt}^m + \tau_i + \tau_j + \delta_t + \varepsilon_{ijt} \, , \tag{17}$$

Note that both θ_{ij} and C_{ij} include the same variables, and therefore, in principle, we will not be able to differentiate their separate effects on pair-wise migration flows of individuals. In consequence, rearranging (21), our baseline estimable specification is:

$$\ln M_{ijt} = \beta_0 + \ln y_{jt} - \ln y_{it} + \left(\gamma_\theta \beta_m + \gamma_C \rho_m\right) x_{ijt}^m + \tau_i + \tau_j + \delta_t + \varepsilon_{ijt} \, , \tag{18}$$

4.2. Empirical approach

Econometric estimation

As benchmark estimation, we run our models by OLS with robust standard errors. In order to deal with the large number of zeros of the dependent variable, we add 1 before the logarithmic transformation. However, we also deliver Poisson pseudo-maximum likelihood estimates (PPML) estimations. Santos Silva and Tenreyro (2006) show that the log-transformation of equation (22) may induce a form of heteroskedasticity of the error term because of such transformation of the data, yielding OLS to deliver inconsistent estimates of the elasticities of interest. Instead, the authors suggest estimating the multiplicative form of the model by PPML, which at the same time provides a natural way to deal with zero values of the dependent variable (see Burger et al., 2009).

Income per capita at destination and skill-selective immigration policies are likely to be simultaneously determined with migration flows. The agglomeration of skilled workers is typically associated with larger productivity levels and output (Ciccone and Hall, 1996). Similarly, ethnic diversity of skilled persons boosts economic outcomes, including per capita GDP and general economic development (Alesina et al., 2013). Likewise, policymakers are likelier to modify immigration policies in response to voters' perception towards the existing (skilled and unskilled) migration flows (Benhabib, 1996; Facchini et al., 2011; Facchini and Mayda, 2012). In this paper we follow the simpler route of providing single-equation estimates with no adjustment for possible endogeneity. However, we lag one period all time-variant explanatory variables in order to lessen potential biases caused by system feedbacks. In addition to this, we have been very careful in the selection of our control variables and inclusion of fixed effects so as to ensure that our foci variables do not pick up any confounding effect that might bias their point estimates.

Variables

Exploiting the residence and nationality information described above, we build a number of asymmetrical *S*x*R* matrices – being *S* the number of sending and *R* the number of receiving countries of our sample. That is, for each cell, we compute the stock of inventors (by patent) living in country j and original from country i, for annually repeated 5-year time windows. In particular, in the present paper we run our regressions for a number of 20 receiving and 147 sending countries – although robustness analyses include variations of these numbers – from 1990 to 2010 – explanatory variables are therefore computed from 1989 to 2005.

Note that our econometric analysis also uses general migration flows from the Ortega-Peri dataset (Ortega and Peri, forthcoming), who basically retrieved migration inflows to 15 OECD destination countries for a large number of years (1980-2005), from various sources.

GDP per capita data come from the Penn World Tables (version 7.0), expressed in US $ 2000 at PPP, also gathered from the Ortega-Peri dataset.

Physical distance, contiguity, colonial ties and same language constitute the dyadic migration costs and productivity moderator variables. These variables come from the CEPII distance database (Mayer and Zignago, 2011).

Suitable variables to proxy different aspects of immigration policy are unfortunately not readily available for a relatively large sample of receiving countries. Some studies exploit dichotomous variables signaling whether a given country j requires visa to non-migrant travelers from country i or country's i citizens benefit from visa waivers (Grogger and Hanson, 2011; Bertoli and Fernandez-Huertas, 2011). Others build ad-hoc indexes reflecting the yearly tightness or relaxation of entry laws (Mayda, 2005; Ortega and Peri, forthcoming). In this paper, we follow the route of using the share of visas a given country reserves for asylum seekers as a proxy for the skill bias of country specific immigration policies (as in Beine et al., 2011, among many others). The data come from the UN Population Division dataset. Since these data is provided every 5 years, we linearly interpolate the missing values. In order to supplement this analysis, we also use a dummy variable stating whether a given pair of sending-receiving countries belongs to the Schengen agreement or not, over time. We expect inventors from the Schengen agreement countries to face lower legal barriers to move between these countries. As in Ortega and Peri (forthcoming), we also include a dummy variable stating whether the destination country belongs to the Schengen agreement. The Schengen agreement implied the elimination of borders between the member states, but also the implementation of a common, more restrictive immigration policy with the rest of the world. A negative coefficient would indicate the existence of a common, European restrictive immigration policy.

5. Results

This section presents the regression results and the following sub-section will introduce some important robustness checks. First, we estimate inventors' migration from 147 sending to 20 receiving countries. Columns (1) and (2) present our baseline estimations, which include origin and destination per capita GDP, the typical variables accounting for migration costs (distance in logs, contiguity, common language, and colonial links), and origin, destination and time fixed effects. Columns (3) through (6) include different immigration policy variables, one at a time. Column (1) in table 1 presents the OLS estimations. As can be seen, destination GDP positively and significantly affects inventors' inflows, confirming our first hypothesis. Origin per capita GDP is also positive in column (1) and all through the remaining models, contrary to what we expected. A plausible explanation of this finding might well be that origin country GDP takes on board, not only pure pecuniary incentives to emigrate, but also the strength of the National System of Innovation in sending countries. In practice this translates into the fact that the countries most affected by the outflows of inventors are those at an intermediate stage of technological development: sufficiently economically developed to have a critical mass of highly-skilled workers but not enough to attract and retain them in the global war for talent. Equally, the sign and significance of the four variables proxing migration costs accord with the theory.

Columns (2) through (6) run Poisson pseudo-maximum likelihood (PPML) estimates instead which, it has been shown, are more apposite in gravity frameworks like the present one (Santos-Silva and Tenreyro, 2006, 2010). Comparing columns (1) and (2), the general conclusions with respect to the OLS estimations hold, although the coefficient estimates differ substantially. Thus, OLS seems to underestimate the effect of distance, common language and per capita GDP, whilst over-estimate the role of contiguity and colonial links, which are not significant anymore. Based on the arguments posit by Santos-Silva and Tenreyro (op. cit.), PPML estimates are preferred and presented in all the following tables.

[Table 1 about here]

Column (3) introduces the bilateral Schengen variable. The positive and significant coefficient shows that in and out-flows of inventors are boosted if both sending and receiving countries belongs to the Schengen agreement. Column (4) reports the results when the variable 'Schengen at destination' is included (the origin countries belonging to the Schengen agreement are removed). This resulting coefficient (negative and significant) seems to indicate that the European common immigration policy implied by the mentioned agreement harms the inflows of inventors from the rest of the world to the Schengen area. Column (5) includes the share of asylum seekers. Contrary to what we expected, the coefficient is positive, but not significant (slightly significant in column (6)). Therefore, it seems to be a slight positive association of the share of asylum seekers with highly skilled migration. Below, by comparing with the general population results, we will be able to say something about the skills' selection of immigration policy.

Table 2 introduces further controls to avoid our focal variables to pick up confounding factors that may bias their point estimates. In particular, the number of PCT patents at origin and destination are included, in order to control for the spatial distribution of patent documents, from where we retrieve inventors' information (WIPO IPSTATS). Failing to account for that may induce biased estimates. From a bilateral viewpoint, we also take into account the strength of economic linkages between country pairs by including the share of bilateral trade between a given pair over their total trade (COMTRADE data). Finally, two additional dummy variables are included: first, a dummy valued 1 if the sending country is a PCT member state at time t and the receiving country is not, and valued 0 otherwise. Second, a dummy variable valued 1 if the sending country is not a PCT member state at time t and the receiving country is a member state, and valued 0 otherwise. These variables are intended to control for an important issue already mentioned in the data section: patents can be applied through the PCT system if and only if the applicants are either residents or nationals of a member state. This rule is likely to affect the observed flows of inventors, especially when one of the two countries of a given pair does not belong to the PCT treaty.[8]

In general, most of the results encountered so far hold. It is worth reporting the change in sign of the asylum seekers variable, which is now negative (column (4)), as we would expect (although still non-significant) and the per capita GDP at origin coefficient, which turns out to be also negative (although non-significant) in these estimations. This result confirms our suspicions that the least developed countries are not necessarily the most affected by the brain drain of inventors, but those at an intermediate stage of technological development.

[Table 2 about here]

Table 3 reports the same estimated equation as before, but separately for general migrant population (odd columns) and for the case of inventors (even columns). Note that the number of observations is notably lower than from the previous tables. This is because general migration data contains numerous missing values and only migration to 15 receiving countries (instead of 20), and therefore an unbalanced panel is estimated using, for comparability reasons, the same observations in both population and inventors equations.

The results regarding general migration accord with previous findings and therefore we do not largely comment on them, but only compare them with inventors' migration coefficients. First, all the migration costs variables included in equations (1) and (2) seem to affect less inventors' mobility than general population mobility. Thus, it seems that larger migration costs positively select highly-skilled immigrants, as compared to the general population – highly-skilled migrants are better informed about job opportunities, they have better adaptive skills, they are able to better handle legal migration barriers, and the like. The exception of that is the 'common language' variable, which is significantly higher for the case of inventors. A plausible explanation is that language similarity might be relatively more important for the

[8] See the updated list of PCT members in: http://www.wipo.int/pct/guide/en/gdvol1/annexes/annexa/ax_a.pdf.

more-educated workers, since communication is more likely to be a prominent factor of highly-skilled occupations (Grogger and Hanson, 2011). The influence of both sending and receiving countries per capita GDP accords with the theory in both cases. However, contrary to what we expected, income at destination does not positively affect selection of highly-skilled immigrants – systematically larger coefficients for the case of general population than for the subgroup of inventors. In principle, this is somewhat contra-intuitive. A conceivable explanation for this is that, possibly, per capita GDP does not reflect the expected income this subclass of skilled people may realize.

[Table 3 about here]

Columns (3) through (10) introduce policy variables, as before, one at a time. Columns (3) and (4) illustrate the importance of the Schengen agreement for the case of inventors, but not for the remaining population – which is in line with the results in Grogger and Hanson (2011). Columns (5)-(6) evaluate the European common immigration policy with the rest of the world. The negative coefficient in both regressions accords with intuition – restrictive common immigration policy hampers migrants' inflows from the rest of the world. However, the large difference in coefficients seems to indicate a lack of skill-selective immigration policy towards the most skilled workers – inventors. The share of asylum seekers is introduced in columns (7) through (10). The coefficient is positive in both cases, though between 3 and 4 times larger for the case of general population – and barely significant for the case of inventors – which supports the idea of positive skill-selection towards inventors. This result accords with intuition, contrary to the former findings on the role of the European common immigration policy. In light of this mixed results, we acknowledge that efforts towards building immigration policy variables able to capture the skills' preferences of current immigration policies are required.

Robustness checks

Table 4 and Table 5 mimics Table 2, with few modifications. Table 4 exploits the information regarding all 147 countries by building squared inventors' mobility matrixes for each year, of 147 sending vs. 147 receiving countries. Broadly speaking, the results of this table compared to Table 2 remain virtually unchanged.

[Table 4 about here]

Table 5 focuses on South-North[9] mobility of inventors by removing the 20 receiving countries among the 147 group of sending countries. Although the main conclusions of this table, as compared to Table 2, remain unchanged, remarkable differences in coefficient estimates are worth noting. Thus, for instance, most of the coefficients accompanying typical migration costs variables are now larger than before, and colonial links turn out to be significantly important to boost South-North flows of inventors. On its side, per capita GDP at destination is now significantly larger. These results put together reinforce the idea that inventors from developed countries are relatively insensitive to GDP per capita differential in their migration decisions (as compared to the general population), but other factors are at work. Conversely, developing countries' inventors do pose relatively more importance to cross-country differences in personal income. Meanwhile, the share of asylum seekers variable is now negative (although still insignificant) which might be considered as further evidence of skills' selection in immigration policy.

[Table 5 about here]

Tables 6 and 7 mimics tables 2 and 3 but including origin-country fixed effects interacted with time fixed effects. Most of the results and conclusions hold. Note, importantly, that destination GDP is only significant in some of the estimations, and the majority of coefficients diminish considerably their point estimates. Arguably, the inclusion of year times origin-country fixed-effects remove a significant portion of country-pair variation, making more difficult to find significant correlations between variables. Further, in unreported results, we have repeated all our estimations including pair-wise fixed effects. In general, most of the results are comparable, with few exceptions: the Schengen bilateral variable turns out to be negative (with pair-wise fixed effects), which may be attributable to its low variability over time. Meanwhile, the share of asylum seekers variable seems to be negative (and sometimes significant) in a larger number of estimations.

[9] Note that the resulting 127 sending * 20 receiving countries matrix does not totally reflect the South-North mobility of inventors, since several developed countries (e.g., Luxembourg) are not in the 20-country sample. As a robustness check, we re-run these models removing other high-income countries (World Bank Classification) from the sending sample, and the results hold – countries removed from the sending sample in the unreported

6. Concluding remarks

The aim of this paper was twofold: first, we compile, use and evaluate a new database on international mobility of inventors, spanning a considerable range of years and for a large number of sending and receiving countries. Aside from the methodological improvement of collecting migration information for a larger number of countries and in a longitudinal framework, the focus on a specific class of super-skilled individuals is also worthwhile. As it has been argued, the tertiary educated labor force is generally highly heterogeneous, its movements implying deeply heterogeneous outcomes as well. Second, we test the influence of restrictive immigration policies on the inflows of inventors to a given receiving country. By comparison with the whole migrant population, new evidence on the skill-selection of immigration policies is provided. Results have also been supplied on the importance of typical migration costs and economic incentives variables to explain the migratory patterns of inventors. Again, by comparing the effect of these variables with the general migrant population, we also provide evidence on the skill-selection effect of such features.

As a general first conclusion we can convincingly assure that aggregated inventors' migration data retrieved from patent documents can be fairly used to study the migration patterns of this highly-skilled class of persons. In general, most of the results encountered accord with the theory and with what we expected, with few exceptions. Results also evidenced the importance of economic incentives for attracting and retaining talent, but also the strength of the knowledge base of countries in explaining in- and out-flows of inventors. It does also appear that typical migration costs tend to positive select immigrants in terms of skills, with the notable exception of language barriers. Finally, it is also worth mentioning that, given the existing proxies at hand, there seems to be some evidence of skill-selection in immigration policies towards favoring inflows of inventors above general population, with mixed results. In any case, these findings are relatively inconclusive due to the quality and the capacity to capture skills' selection of the immigration policy variables at hand. Further research definitely needs to address this issue.

In sum, there is still so much to learn about the determinants of immigration and emigration of this highly-skilled class of workers. Exploiting the information presented here could yield

robustness check include: the Czech Republic, Estonia, Greece, Hungary, Iceland, the Republic of Korea, Liechtenstein, Luxembourg, Poland, Portugal, Slovenia and Slovakia.

interesting results to understand not only what drives the international mobility of inventors and the global competition for talent, but also the relationship of this phenomenon with receiving countries innovation, sending countries development, and the international diffusion of ideas.

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Appendix 1.

List of receiving countries

Austria, Australia, Belgium, Canada, Switzerland, Germany, Denmark, Spain, Finland, France, United Kingdom, Ireland, Italy, Japan, Netherlands, Norway, New Zealand, Russian Fed., Sweden, and United States of America.

List of sending countries

United Arab Emirates, Albania, Armenia, Angola, Argentina, Austria, Australia, Azerbaijan, Bangladesh, Belgium, Burkina Faso, Bulgaria, Bahrain, Burundi, Benin, Brunei Darussalam, Bolivia, Brazil, Bhutan, Botswana, Belarus, Belize, Canada, Central African Republic, Congo, Switzerland, Côte d'Ivoire, Chile, Cameroon, China, Colombia, Costa Rica, Cape Verde, Cyprus, Czech Republic, Germany, Djibouti, Denmark, Dominica, Dominican Republic, Algeria, Ecuador, Egypt, Eritrea, Spain, Ethiopia, Finland, France, Gabon, United Kingdom, Georgia, Ghana, Gambia, Guinea, Equatorial Guinea, Greece, Guatemala, Guinea-Bissau, Hong Kong (SAR), China, Honduras, Croatia, Haiti, Hungary, Indonesia, Ireland, Israel, India, Islamic Republic of Iran, Italy, Jamaica, Jordan, Japan, Kenya, Cambodia, Republic of Korea, Kuwait, Kazakhstan, Lao People's Democratic Republic, Lebanon, Sri Lanka, Liberia, Lesotho, Lithuania, Luxembourg, Latvia, Libya, Morocco, Moldova, Madagascar, T F Y R of Macedonia, Mali, Mauritania, Malta, Malawi, Mexico, Malaysia, Mozambique, Namibia, Niger, Nigeria, Nicaragua, Netherlands, Norway, Nepal, New Zealand, Oman, Panama, Peru, Philippines, Pakistan, Poland, Portugal, Paraguay, Qatar, Russian Fed., Rwanda, Saudi Arabia, Sudan, Sweden, Singapore, Slovenia, Sierra Leone, Senegal, Suriname, El Salvador, Syria, Swaziland, Chad, Togo, Thailand, Tajikistan, Tunisia, Tonga, Turkey, Trinidad and Tobago, United States of America, United Republic of Tanzania, Ukraine, Uganda, Uruguay, Uzbekistan, Venezuela, Viet Nam, Yemen, South Africa, Zambia, and Zimbabwe.

Figure 1.a. Share of immigrant inventors, 1985-2010, by selected countries

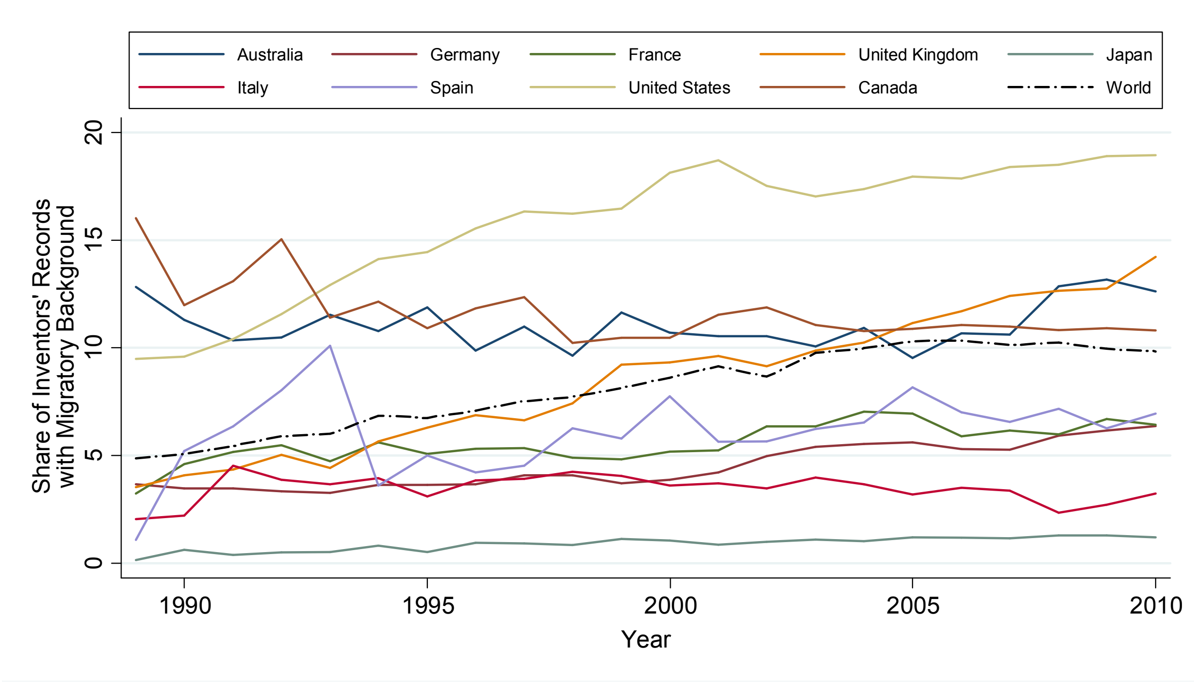

Figure 1.b. Share of immigrant inventors, 1989-2010 (immigrants from OECD countries excluded), by selected countries

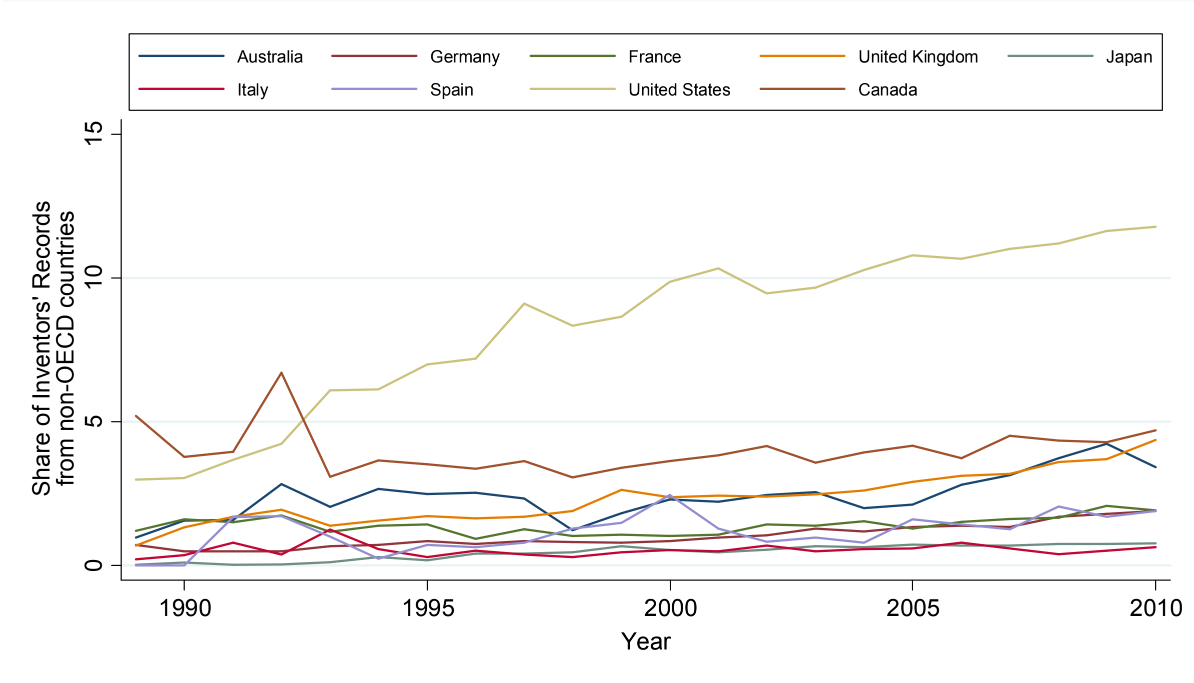

Figure 2. Emigration rates, 1995-2010, by continent

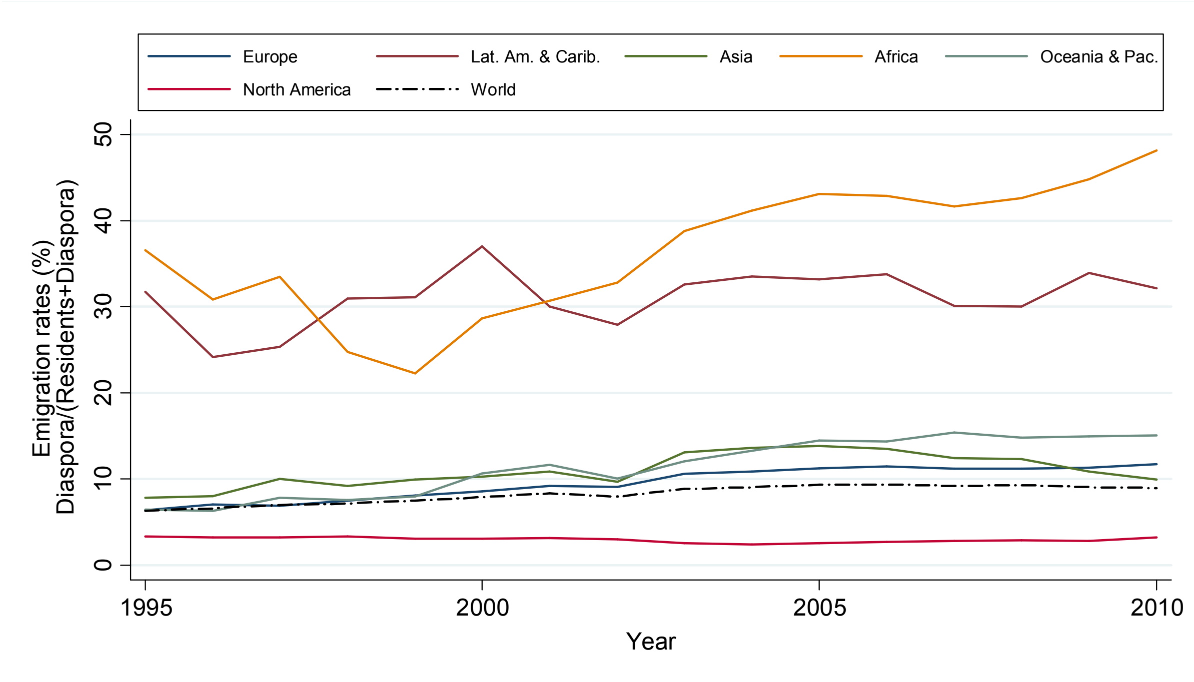

Table 1. Inventors' mobility, OLS and PPML estimations, 147*20 sending and receiving countries. Origin, destination and time FE.

	(1) OLS	(2) PPML	(3) PPML	(4) PPML	(5) PPML	(6) PPML
ln(Distance)	-0.350***	-0.621***	-0.608***	-0.690***	-0.621***	-0.608***
	(0.0108)	(0.0216)	(0.0212)	(0.0275)	(0.0217)	(0.0212)
Contiguity	0.587***	0.0254	-0.0273	-0.200**	0.0253	-0.0298
	(0.0445)	(0.0472)	(0.0475)	(0.0804)	(0.0473)	(0.0476)
Common language	0.268***	1.028***	1.013***	0.745***	1.028***	1.013***
	(0.0156)	(0.0486)	(0.0487)	(0.0625)	(0.0485)	(0.0486)
Colonial links	0.423***	-0.0365	-0.0405	0.152**	-0.0365	-0.0406
	(0.0260)	(0.0483)	(0.0492)	(0.0711)	(0.0483)	(0.0494)
ln(GDPp.c.) orig.	0.0723***	0.178*	0.206**	0.123	0.179*	0.209**
	(0.0153)	(0.0916)	(0.0911)	(0.0776)	(0.0916)	(0.0911)
ln(GDPp.c.) dest.	0.0701**	0.457***	0.517***	0.671***	0.429***	0.468***
	(0.0352)	(0.157)	(0.157)	(0.176)	(0.164)	(0.163)
Schengen			0.274***			0.285***
			(0.0511)			(0.0514)
Schengen dest.				-0.383***		
				(0.0585)		
Share asylum					0.00863	0.0163*
					(0.00962)	(0.00968)
Constant	0.931***	2.261	1.314	1.322	2.539	1.795
	(0.300)	(1.739)	(1.753)	(1.926)	(1.788)	(1.793)
Observations	46,460	44,880	44,880	42,591	44,880	44,880
Pseudo R2	0.735	0.940	0.941	0.954	0.940	0.941
Origin FE	Yes	Yes	Yes	Yes	Yes	Yes
Destination FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Log Lik.	-54698.73	-266724.91	-264939.77	-209989.93	-266679.85	-264784.62

Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. Per capita GDP at origin presents several missing observations: for 1990, missing data correspond to Azerbaijan, Eritrea, Cambodia and Latvia; for 1991, to Eritrea; and for 2005, to Cyprus, Gabon, Lesotho, Oman, Rwanda, Thailand, Uzbekistan and Zimbabwe. The different number of final observations between columns (1) and (2) is due to the inclusion of fixed effects in pseudo-maximum likelihood estimations: the PPML method automatically drops the country-specific fixed-effects (and their corresponding observations) for which the country has zero recorded inventors' flows to every other country in the sample in order to achieve convergence. Results are comparable to other count data methods without removing these observations (see Santos Silva and Tenreyro, 2010, for further details).

Table 2. Inventors' mobility, PPML, 147*20 sending and receiving countries. Origin, destination and time FE. Includes additional controls

	(1) PPML	(2) PPML	(3) PPML	(4) PPML	(5) PPML
ln(Distance)	-0.450***	-0.438***	-0.551***	-0.450***	-0.438***
	(0.0251)	(0.0244)	(0.0284)	(0.0251)	(0.0244)
Contiguity	0.00812	-0.0484	-0.204***	0.00817	-0.0497
	(0.0420)	(0.0424)	(0.0750)	(0.0419)	(0.0423)
Common language	0.941***	0.925***	0.696***	0.941***	0.924***
	(0.0439)	(0.0443)	(0.0566)	(0.0439)	(0.0442)
Colonial links	-0.0608	-0.0620	0.121*	-0.0608	-0.0621
	(0.0451)	(0.0465)	(0.0643)	(0.0451)	(0.0466)
ln(GDP p.c.) orig.	-0.113	-0.0874	-0.0754	-0.113	-0.0845
	(0.0705)	(0.0703)	(0.0671)	(0.0707)	(0.0705)
ln(GDP p.c.) dest.	0.449***	0.522***	0.732***	0.454***	0.498***
	(0.141)	(0.141)	(0.163)	(0.147)	(0.145)
ln(# patents) orig.	0.223***	0.228***	0.213***	0.223***	0.227***
	(0.0372)	(0.0366)	(0.0346)	(0.0370)	(0.0365)
ln(# patents) dest.	0.636***	0.650***	0.771***	0.638***	0.644***
	(0.0840)	(0.0852)	(0.0980)	(0.0866)	(0.0884)
ln(EXP+IMP)	0.211***	0.209***	0.147***	0.210***	0.209***
	(0.0211)	(0.0203)	(0.0148)	(0.0211)	(0.0203)
Orig.PCT/ Dest.nonPCT	1.156***	1.175***	1.240***	1.158***	1.169***
	(0.274)	(0.281)	(0.353)	(0.275)	(0.280)
Orig.nonPCT/ Dest.PCT	-0.0264	-0.0359	-0.0368	-0.0262	-0.0371
	(0.0981)	(0.0972)	(0.0930)	(0.0980)	(0.0972)
Schengen		0.305***			0.310***
		(0.0468)			(0.0473)
Schengen dest.			-0.368***		
			(0.0539)		
Share asylum				-0.00158	0.00749
				(0.00908)	(0.00913)
Constant	-5.473***	-6.750***	-9.586***	-5.546**	-6.439***
	(2.097)	(2.105)	(2.319)	(2.216)	(2.214)
Observations	44,880	44,880	42,591	44,880	44,880
Pseudo R2	0.961	0.962	0.970	0.960	0.962
Origin FE	Yes	Yes	Yes	Yes	Yes
Destination FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
Log Lik	-246238.65	-244004.73	-196197.95	-246237.20	-243973.35

Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. Per capita GDP at origin presents several missing observations: for 1990, missing data correspond to Azerbaijan, Eritrea, Cambodia and Latvia; for 1991, to Eritrea; and for 2005, to Cyprus, Gabon, Lesotho, Oman, Rwanda, Thailand, Uzbekistan and Zimbabwe.

Table 3. Inventors' mobility versus general population migration flows, PPML, 147*20 sending and receiving countries. Origin, destination and time FE. Includes additional controls.

	(1) PPML	(2) PPML	(3) PPML	(4) PPML	(5) PPML	(6) PPML	(7) PPML	(8) PPML	(9) PPML	(10) PPML
	Pop.	Inventors	Pop.	Inventors	Pop.	Inventors	Pop.	Inventors	Pop.	Inventors
ln(Distance)	-0.869***	-0.439***	-0.870***	-0.420***	-0.887***	-0.487***	-0.865***	-0.439***	-0.863***	-0.419***
	(0.0391)	(0.0296)	(0.0396)	(0.0288)	(0.0421)	(0.0386)	(0.0386)	(0.0296)	(0.0391)	(0.0288)
Contiguity	0.210**	0.0234	0.212**	-0.0186	0.276**	-0.0639	0.207**	0.0234	0.204**	-0.0203
	(0.0981)	(0.0530)	(0.0986)	(0.0539)	(0.114)	(0.101)	(0.0989)	(0.0530)	(0.0996)	(0.0538)
Common language	0.774***	0.917***	0.775***	0.896***	0.704***	0.672***	0.775***	0.917***	0.774***	0.895***
	(0.0594)	(0.0488)	(0.0595)	(0.0495)	(0.0650)	(0.0647)	(0.0592)	(0.0488)	(0.0593)	(0.0494)
Colonial links	1.055***	-0.175***	1.054***	-0.183***	1.164***	-0.109	1.052***	-0.175***	1.054***	-0.183***
	(0.0686)	(0.0511)	(0.0685)	(0.0529)	(0.0776)	(0.0828)	(0.0690)	(0.0511)	(0.0689)	(0.0531)
ln(GDPpc)ori.	-0.314***	-0.111	-0.316***	-0.0900	-0.319***	-0.0778	-0.268***	-0.111	-0.266***	-0.0856
	(0.0893)	(0.0699)	(0.0898)	(0.0697)	(0.0914)	(0.0665)	(0.0909)	(0.0702)	(0.0915)	(0.0701)
ln(GDPpc)des.	1.129***	0.480***	1.124***	0.556***	1.046***	0.838***	0.235	0.479***	0.238	0.514***
	(0.207)	(0.163)	(0.208)	(0.164)	(0.231)	(0.201)	(0.233)	(0.173)	(0.234)	(0.171)
ln(# pat.)orig.	0.0749*	0.218***	0.0749*	0.223***	0.0725*	0.208***	0.0746*	0.218***	0.0746*	0.222***
	(0.0412)	(0.0369)	(0.0412)	(0.0364)	(0.0407)	(0.0338)	(0.0403)	(0.0368)	(0.0403)	(0.0362)
ln(# pat.)dest.	0.752***	0.739***	0.753***	0.738***	0.817***	0.916***	0.701***	0.739***	0.699***	0.732***
	(0.0904)	(0.0958)	(0.0909)	(0.0972)	(0.102)	(0.114)	(0.0943)	(0.0978)	(0.0949)	(0.100)
ln(EXP+IMP)	0.0281**	0.190***	0.0279**	0.191***	0.0209	0.135***	0.0306**	0.190***	0.0308**	0.191***
	(0.0141)	(0.0210)	(0.0141)	(0.0205)	(0.0135)	(0.0148)	(0.0136)	(0.0211)	(0.0136)	(0.0205)
Orig.PCT/ Dest.nonPCT	1.362***	0.628***	1.360***	0.634***	1.316***	0.578***	1.313***	0.628***	1.314***	0.632***
	(0.177)	(0.186)	(0.177)	(0.185)	(0.181)	(0.198)	(0.177)	(0.186)	(0.178)	(0.185)
Orig.nonPCT/Dest.PCT	-0.0928	-0.0279	-0.0909	-0.0349	-0.0739	-0.0352	-0.0767	-0.0279	-0.0789	-0.0366
	(0.0919)	(0.0999)	(0.0925)	(0.0990)	(0.0940)	(0.0936)	(0.0916)	(0.0998)	(0.0923)	(0.0991)
Schengen			-0.0286	0.318***					0.0358	0.326***
			(0.0714)	(0.0526)					(0.0715)	(0.0534)
Schengen dest.					-0.195**	-0.377***				
					(0.0823)	(0.0614)				
Share asylum							0.120***	0.000217	0.120***	0.0101
							(0.0146)	(0.00957)	(0.0147)	(0.00963)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	PPML	PPML	PPML	PPML	PPML	PPML	PPML	PPML	PPML	PPML
	Pop.	Inventors	Pop.	Inventors	Pop.	Inventors	Pop.	Inventors	Pop.	Inventors
Constant	-5.290*	-7.315***	-5.224*	-8.439***	-4.971*	-13.23***	4.560	-7.304***	4.519	-7.945***
	(2.767)	(2.368)	(2.778)	(2.373)	(2.957)	(2.700)	(2.993)	(2.524)	(2.995)	(2.518)
Observations	30,057	29,067	30,057	29,067	28,366	27,376	30,057	29,067	30,057	29,067
Pseudo R2	0.643	0.967	0.643	0.967	0.653	0.976	0.642	0.967	0.641	0.968
Origin FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Destination FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Log Lik.	-19698414	-205837	-19698026	-203807	-18171703	-162506	-19437523	-205837	-19436923	-203753

Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Table 4. Inventors' mobility, PPML, 147*147 sending and receiving countries. Origin, destination and time FE. Includes additional controls

	(1) PPML	(2) PPML	(3) PPML	(4) PPML	(5) PPML
ln(Distance)	-0.378***	-0.369***	-0.458***	-0.378***	-0.368***
	(0.0246)	(0.0239)	(0.0280)	(0.0246)	(0.0239)
Contiguity	0.0330	-0.0261	-0.188**	0.0330	-0.0269
	(0.0426)	(0.0429)	(0.0744)	(0.0426)	(0.0428)
Common language	0.923***	0.904***	0.709***	0.923***	0.903***
	(0.0433)	(0.0435)	(0.0546)	(0.0433)	(0.0434)
Colonial links	-0.125***	-0.125***	-0.0137	-0.125***	-0.124***
	(0.0450)	(0.0466)	(0.0659)	(0.0450)	(0.0466)
ln(GDP p.c.) orig.	-0.111	-0.0836	-0.0636	-0.111	-0.0825
	(0.0741)	(0.0738)	(0.0707)	(0.0742)	(0.0739)
ln(GDP p.c.) dest.	0.473***	0.538***	0.736***	0.474***	0.533***
	(0.125)	(0.124)	(0.140)	(0.125)	(0.124)
ln(# patents) orig.	0.213***	0.219***	0.205***	0.214***	0.218***
	(0.0386)	(0.0380)	(0.0358)	(0.0386)	(0.0379)
ln(# patents) dest.	0.360***	0.369***	0.378***	0.360***	0.373***
	(0.0478)	(0.0476)	(0.0531)	(0.0470)	(0.0467)
ln(EXP+IMP)	0.244***	0.240***	0.186***	0.244***	0.241***
	(0.0232)	(0.0223)	(0.0183)	(0.0232)	(0.0223)
Orig.PCT/ Dest.nonPCT	1.029***	1.014***	1.047***	1.030***	1.011***
	(0.167)	(0.166)	(0.181)	(0.168)	(0.167)
Orig.nonPCT/ Dest.PCT	-0.0390	-0.0492	-0.0503	-0.0389	-0.0498
	(0.0991)	(0.0980)	(0.0932)	(0.0990)	(0.0980)
Schengen		0.333***			0.337***
		(0.0464)			(0.0465)
Schengen dest.			-0.364***		
			(0.0518)		
Share asylum				-0.00103	0.00554
				(0.00636)	(0.00621)
Constant	-5.774***	-6.578***	-7.455***	-5.776***	-6.579***
	(1.112)	(1.122)	(1.197)	(1.112)	(1.121)
Observations	272,450	272,450	245,399	272,450	272,450
Pseudo R2	0.951	0.953	0.963	0.951	0.953
Origin FE	Yes	Yes	Yes	Yes	Yes
Destination FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
Log Lik	-331941.62	-329199.36	-269881.58	-331940.64	-329171.14

Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table 5. Inventors' mobility, PPML, South-North mobility, 127*20 sending and receiving countries. Origin, destination and time FE. Includes additional controls

	(1) PPML	(2) PPML	(3) PPML	(4) PPML	(5) PPML
ln(Distance)	-1.106***	-1.074***	-1.025***	-1.106***	-1.074***
	(0.0405)	(0.0394)	(0.0385)	(0.0404)	(0.0391)
Contiguity	-0.925***	-0.936***	-0.871***	-0.925***	-0.937***
	(0.110)	(0.114)	(0.122)	(0.110)	(0.115)
Common language	1.349***	1.326***	1.301***	1.349***	1.326***
	(0.0576)	(0.0573)	(0.0568)	(0.0578)	(0.0574)
Colonial links	0.412***	0.434***	0.516***	0.412***	0.434***
	(0.0927)	(0.0943)	(0.0923)	(0.0926)	(0.0946)
ln(GDP p.c.) orig.	-0.112*	-0.114*	-0.102*	-0.112*	-0.112*
	(0.0590)	(0.0580)	(0.0571)	(0.0588)	(0.0578)
ln(GDP p.c.) dest.	0.872***	0.918***	0.794***	0.873***	0.905***
	(0.172)	(0.169)	(0.176)	(0.175)	(0.171)
ln(# patents) orig.	0.136***	0.145***	0.124***	0.137***	0.144***
	(0.0206)	(0.0200)	(0.0191)	(0.0204)	(0.0198)
ln(# patents) dest.	1.100***	1.109***	1.076***	1.100***	1.107***
	(0.142)	(0.142)	(0.143)	(0.144)	(0.145)
ln(EXP+IMP)	0.0663***	0.0635***	0.0637***	0.0663***	0.0636***
	(0.00831)	(0.00807)	(0.00828)	(0.00833)	(0.00808)
Orig.PCT/ Dest.nonPCT	-0.818***	-0.820***	-0.824***	-0.818***	-0.822***
	(0.148)	(0.148)	(0.148)	(0.148)	(0.148)
Orig.nonPCT/ Dest.PCT	-0.0301	-0.0290	-0.0280	-0.0301	-0.0292
	(0.0503)	(0.0502)	(0.0489)	(0.0504)	(0.0503)
Schengen		0.682***			0.684***
		(0.100)			(0.102)
Schengen dest.			-0.329***		
			(0.0603)		
Share asylum				-0.000141	0.00469
				(0.0159)	(0.0157)
Constant	-10.53***	-11.45***	-10.11***	-10.53***	-11.29***
	(2.656)	(2.616)	(2.723)	(2.820)	(2.774)
Observations	38,800	38,800	38,240	38,800	38,800
Pseudo R2	0.995	0.995	0.995	0.995	0.995
Origin FE	Yes	Yes	Yes	Yes	Yes
Destination FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
Log Lik	-102929.55	-102073.90	-97047.58	-102929.55	-102070.98

Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. Per capita GDP at origin presents several missing observations: for 1990, missing data correspond to Azerbaijan, Eritrea, Cambodia and Latvia; for 1991, to Eritrea; and for 2005, to Cyprus, Gabon, Lesotho, Oman, Rwanda, Thailand, Uzbekistan and Zimbabwe.

Table 6. Inventors' mobility, PPML, 147*20 sending and receiving countries. Origin, destination, and time FE, and origin FE*time FE

	(1) PPML	(2) PPML	(3) PPML	(4) PPML	(5) PPML
ln(Distance)	-0.179***	-0.172***	-0.242***	-0.179***	-0.171***
	(0.0286)	(0.0277)	(0.0374)	(0.0286)	(0.0277)
Contiguity	-0.0315	-0.0827**	-0.272***	-0.0314	-0.0843**
	(0.0381)	(0.0381)	(0.0687)	(0.0380)	(0.0381)
Common language	0.817***	0.803***	0.603***	0.817***	0.802***
	(0.0398)	(0.0404)	(0.0529)	(0.0399)	(0.0405)
Colonial links	-0.122***	-0.118***	-0.0113	-0.122***	-0.118***
	(0.0429)	(0.0440)	(0.0668)	(0.0429)	(0.0441)
ln(GDP p.c.) dest.	0.189	0.257**	0.557***	0.192	0.226*
	(0.125)	(0.125)	(0.153)	(0.132)	(0.130)
ln(# patents) dest.	0.593***	0.604***	0.705***	0.594***	0.596***
	(0.0761)	(0.0770)	(0.0907)	(0.0790)	(0.0806)
ln(EXP+IMP)	0.550***	0.543***	0.488***	0.550***	0.543***
	(0.0280)	(0.0272)	(0.0299)	(0.0280)	(0.0272)
Orig.PCT/ Dest.nonPCT	1.531***	1.570***	1.815***	1.534***	1.550***
	(0.197)	(0.204)	(0.238)	(0.203)	(0.210)
Orig.nonPCT/ Dest.PCT	-0.893***	-0.926***	-1.232***	-0.895***	-0.906***
	(0.252)	(0.255)	(0.287)	(0.256)	(0.260)
Schengen		0.300***			0.307***
		(0.0417)			(0.0433)
Schengen dest.			-0.305***		
			(0.0469)		
Share asylum				-0.000976	0.00861
				(0.00772)	(0.00790)
Constant	-3.632**	-4.594**	-8.469***	-3.685*	-4.161**
	(1.844)	(1.834)	(2.162)	(1.997)	(1.973)
Observations	41,000	41,000	38,711	41,000	41,000
Pseudo R2	0.969	0.970	0.977	0.969	0.970
Origin FE	Yes	Yes	Yes	Yes	Yes
Destination FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
Origin FE* Year FE	Yes	Yes	Yes	Yes	Yes
Log Lik	-215525.24	-213535.92	-176099.33	-215524.71	-213495.87

Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. Per capita GDP at origin presents several missing observations: for 1990, missing data correspond to Azerbaijan, Eritrea, Cambodia and Latvia; for 1991, to Eritrea; and for 2005, to Cyprus, Gabon, Lesotho, Oman, Rwanda, Thailand, Uzbekistan and Zimbabwe.

Table 7. Inventors' mobility versus general population migration flows, OLS, 147*20 sending and receiving countries. Origin, destination, and time FE, and origin FE*time FE

	(1) PPML	(2) PPML	(3) PPML	(4) PPML	(5) PPML	(6) PPML	(7) PPML	(8) PPML	(9) PPML	(10) PPML
	Pop.	Inventors	Pop.	Inventors	Pop.	Inventors	Pop.	Inventors	Pop.	Inventors
ln(Distance)	-0.426***	-0.103***	-0.411***	-0.0765**	-0.451***	-0.0451	-0.836***	-0.102***	-0.393***	-0.0725**
	(0.0414)	(0.0330)	(0.0417)	(0.0310)	(0.0453)	(0.0485)	(0.0365)	(0.0330)	(0.0411)	(0.0309)
Contiguity	0.106	-0.0337	0.0789	-0.0915*	0.197**	-0.179**	0.248**	-0.0343	0.0783	-0.0958*
	(0.0746)	(0.0510)	(0.0754)	(0.0500)	(0.0902)	(0.0909)	(0.0986)	(0.0510)	(0.0741)	(0.0496)
Common language	0.592***	0.702***	0.576***	0.662***	0.542***	0.580***	0.657***	0.701***	0.569***	0.659***
	(0.0528)	(0.0468)	(0.0531)	(0.0460)	(0.0584)	(0.0627)	(0.0594)	(0.0466)	(0.0521)	(0.0455)
Colonial links	0.889***	-0.201***	0.916***	-0.192***	0.958***	-0.284***	1.080***	-0.202***	0.917***	-0.193***
	(0.0644)	(0.0506)	(0.0651)	(0.0523)	(0.0722)	(0.0824)	(0.0663)	(0.0507)	(0.0652)	(0.0526)
ln(GDPpc)des	1.191***	0.233	1.220***	0.343**	1.300***	0.536***	0.677***	0.145	0.442**	0.178
	(0.194)	(0.150)	(0.195)	(0.148)	(0.210)	(0.196)	(0.228)	(0.166)	(0.220)	(0.160)
ln(# patents) dest.	0.607***	0.724***	0.586***	0.694***	0.659***	0.855***	0.725***	0.737***	0.580***	0.723***
	(0.0780)	(0.0929)	(0.0783)	(0.0944)	(0.0854)	(0.111)	(0.0939)	(0.0933)	(0.0816)	(0.0965)
ln(EXP+IMP)	0.411***	0.581***	0.411***	0.580***	0.378***	0.570***	0.0257**	0.583***	0.424***	0.583***
	(0.0259)	(0.0294)	(0.0259)	(0.0275)	(0.0268)	(0.0343)	(0.0131)	(0.0295)	(0.0254)	(0.0274)
Orig.PCT/ Dest.nonPCT	1.844***	0.682	2.073***	0.705	0.551	0.644	1.531***	0.671	2.759***	0.684
	(0.349)	(0.519)	(0.491)	(0.515)	(0.821)	(0.545)	(0.161)	(0.517)	(0.463)	(0.511)
Orig.nonPCT/ Dest.PCT	-0.392	0.164	-0.614	0.165	0.907	0.186	-0.0998	0.164	-1.350***	0.165
	(0.314)	(0.488)	(0.466)	(0.483)	(0.808)	(0.510)	(0.0769)	(0.486)	(0.437)	(0.479)
Schengen			0.465***	0.468***					0.548***	0.492***
			(0.0720)	(0.0455)					(0.0698)	(0.0471)
Schengen dest.					-0.0493	-0.411***				
					(0.0757)	(0.0582)				
Share asylum							0.0913***	0.0166	0.111***	0.0323***
							(0.0144)	(0.0105)	(0.0134)	(0.0107)
Constant	-11.27***	-6.273***	-7.866***	-7.262***	-7.749***	-11.70***	-1.986	-5.537**	0.0888	-5.952***
	(2.494)	(2.175)	(2.347)	(2.141)	(2.902)	(2.588)	(2.535)	(2.334)	(2.634)	(2.286)
Observations	23,155	20,365	23,155	20,365	21,693	18,903	23,155	20,365	23,155	20,365

	(1) PPML	(2) PPML	(3) PPML	(4) PPML	(5) PPML	(6) PPML	(7) PPML	(8) PPML	(9) PPML	(10) PPML
	Pop.	Inventors	Pop.	Inventors	Pop.	Inventors	Pop.	Inventors	Pop.	Inventors
Adjusted R2	0.754	0.980	0.752	0.981	0.757	0.987	0.655	0.980	0.762	0.982
Origin FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Destination FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Origin FE* Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Log Lik	-13225976	-148118	-13172972	-144575	-12393885	-118161	-16260891	-148017	-12986772	-144208

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