CENTRO STUDI LUCA D'AGLIANO

WWW.DAGLIANO.UNIMI.IT

CENTRO STUDI LUCA D'AGLIANO
DEVELOPMENT STUDIES WORKING PAPERS

N. 410

December 2016

International knowledge flows and the administrative barriers to mobility

*Sultan Orazbayev**

* University College London

ISSN 2282-5452

International knowledge flows and the administrative barriers to mobility*

Sultan Orazbayev†

November 9, 2016

Abstract

The literature on diffusion of knowledge has shown positive influence of physical and cultural proximity, common language and contiguity on the speed and magnitude of international knowledge flows. Knowledge diffusion is also facilitated by co-location, even temporary one, which helps researchers form personal ties and exchange tacit information through face-to-face contact. However, the ability of researchers to disseminate the results of their work, especially recent or on-going research, through temporary co-location (including international conferences, workshops and seminars) will be affected by the administrative barriers to mobility ('paper walls'), for example travel visas. This paper uses a gravity-style empirical model to examine the link between the administrative barriers to mobility of the skilled workers (and students) and the magnitude/direction of international knowledge flows between 45 countries from 1990 to 2014. Additional calculations use information on travel visa requirements between 134 countries in year 2004. The results suggest that higher administrative barriers to mobility between countries are associated with reduced bilateral knowledge flows, especially of recent knowledge, and this negative effect can persist for about 9 years. The persistent effect of 'paper walls' is asymmetric and a country's ability to import knowledge is affected more by the administrative barriers of the knowledge-exporting country, suggesting that co-location plays an important role for successful transfer of knowledge.

Keywords: visa; diffusion of knowledge; academic mobility; skilled workers; immigration policy.

JEL codes: F10, F29, O33, R10.

*I would like to thank Miriam Manchin for guidance, Elodie Douarin and Francesco Fasani for comments and feedback on an earlier version, as well as (in reverse alphabetical order) Camilo Umana Dajud, Eugene Nivorozhkin, Svetlana Makarova, Karuna Krishnaswamy, Matte Hartog, Andres Gomez, Raphael Espinoza, seminar participants at UCL (SSEES), London Institute for Mathematical Sciences, Harvard (CID), Oxford (IMI), Data Natives (2016) and UCL Conference on micro-macro determinants of growth in emerging economies for helpful feedback. I would also like to thank Anna Sansome for support with data acquisition.

†University College London: s.orazbayev@ucl.ac.uk.

1 Introduction

Many empirical studies have shown that diffusion of knowledge can be described by a gravity-based framework which includes factors that have been shown to affect the flows of goods and services, FDI and people (e.g. MacGarvie 2005; Drivas and Economidou 2015; Peri 2005). A common finding is that physical proximity, common language and border are associated with better diffusion of knowledge, as proxied by patent citations. The relative importance of these factors is smaller for knowledge flows than for trade, FDI or migration due to the 'weightless' and tariff-free nature of knowledge, which reduces the transaction costs and allows knowledge to reach farther than trade or migration (Peri 2005).[1]

At the same time, there is a large literature showing the importance of colocation and localised knowledge spillovers (e.g. Jaffe et al. 1993; Head et al. 2015). One of the benefits of colocation is that it allows authors to develop personal ties, which facilitate transfer of knowledge through the social research network (Jöns 2009; Jonkers and Cruz-Castro 2013; Head et al. 2015). The importance of social networks has been also shown to facilitate trade (e.g. Rauch 2001) and FDI (e.g. De Simone and Manchin 2012). However, development of such research networks and personal ties requires some face-to-face contact. The effect of colocation on collaboration and knowledge transfer has been shown both through field and natural experiments, see Boudreau et al. (2012) and Catalini (2015), respectively. The ability of researchers from different countries to colocate temporarily will depend on the factors that affect the mobility of researchers.

The analysis of the barriers to diffusion of knowledge usually includes geographic, cultural and socio-economic barriers to diffusion. Recent work on the importance of administrative barriers to mobility shows that travel visa restrictions matter for trade, FDI (Neumayer 2011; Dajud 2014), migration and academic mobility (Czaika and Haas 2016; Appelt et al. 2015). If administrative barriers to mobility affect the mobility of scientists and development of bilateral research networks, will they also play a role in determining the direction and magnitude of knowledge flows?

Knowledge does not require a travel visa and can flow across borders without restrictions.[2] The 'paper trail' left by knowledge flows will reflect the flow of knowledge deemed relevant by researchers (Jaffe et al. 1993). Knowledge, especially recent research, can be disseminated internationally via pre-prints or working paper series, but transfer of tacit knowledge and on-going research may require

[1] For example, Head et al. (2015) show that the role of distance is decreased after correcting for personal ties between authors.

[2] There can be restrictions on weapons- or military-related research, but these domains are highly regulated and diffusion of knowledge in these domains is likely to be governed by a very different process.

face-to-face contact between the researchers, which in turn depends on their mobility. The 'paper walls', created by the administrative barriers to mobility, can have an impact on the diffusion of knowledge by raising the cost of researcher mobility, limiting opportunities for face-to-face contact and development of cross-border research networks. For example, travel visa requirements are likely to reduce opportunities for development of personal ties and increase the cost of temporary colocation, such as attending foreign conferences or presenting work at research seminars abroad.[3] Such informal, face-to-face communication channels can be important for the diffusion of knowledge, especially cutting-edge research or work-in-progress which are not yet widely disseminated (Boudreau et al. 2012; Trippl 2013; Wang 2015; Catalini 2015; Iaria and Waldinger 2015).

Stricter migration policy can also reduce the number of incoming migrant scientists or increase outflow of scientists from the country. For example, Appelt et al. (2015) report negative effects of visa restrictions on mobility of scientists. Another example comes from numerous accounts of the difficulties encountered by academics, especially from outside European Economic Area, in migrating permanently or temporarily to UK (e.g. Mavroudi and Warren 2013; Times Higher Education 2014; Kõu and Bailey 2014).

Identifying the effect of administrative barriers could be complicated by correlation between the strictness of a policy and physical or cultural distance between countries. The determination of migration policy is driven by macro-level considerations, often of a political or security-oriented nature (Luedtke et al. 2010; Neumayer 2010; Lawson and Lemke 2011; Czaika and Haas 2016), and hence the immigration policy toward skilled workers can be seen as an exogenous source of variation from the perspective of knowledge flows. For example, if country A imposes a visa restriction on country B based on security considerations, then this will increase the cost of face-to-face contact between researchers from A and B, but it does not make the knowledge generated in countries A and B less relevant. If the 'paper walls' do not represent a barrier for knowledge flows, then we will observe no changes in the 'paper trails' (i.e. citations) between these countries. Adding controls for various country, country-time and country-pair specific factors, the exogeneity of immigration policy helps to identify the effect of administrative restrictions to mobility of skilled workers and students on the direction and magnitude of knowledge flows.

This paper explores the impact of administrative barriers to mobility of skilled workers and students on the direction and magnitude of knowledge flows. Specifically, how does immigration policy of the country in which the knowledge flow

[3]Ng and Whalley (2008) give examples of visa or work permit application costs, including processing time, for several countries, and estimate the global cost of the visa system to be about 0.3% of world GDP. The cost of a passport also varies across countries and can be substantial, see McKenzie (2005).

originates ('knowledge-exporting' country) affect its knowledge flows? By controlling for knowledge diffusion costs (through standard controls used in the literature - physical distance, common language/border and fixed effects to capture other sources of heterogeneity) and exploiting the variation in administrative barriers to mobility, it's possible to establish a link between the immigration policy/travel visa restrictions and the bilateral knowledge flows.

The knowledge flows are tracked via their 'paper trail' in the form of publication-level citations among economists.[4] The information on citations is taken from Thomson Reuters' Web of Science database for over 430 thousand publications in Economics and almost 6 million cited-citing publication pairs. The dataset includes information on the country of affiliation of all cited and citing authors, but unfortunately, publications prior to 2008 do not explicitly match each author to their respective affiliation. By aggregating the citations to the country-level it is possible to track the 'paper trails' of the aggregate international knowledge flows without identifying individual author affiliations.

The information on administrative barriers comes from a recently-released dataset, DEMIG POLICY, which contains information on more than 6'500 policy changes in 45 countries over 1721-2014 period (sample coverage prior to 1990 varies by country), see DEMIG (2015). This dataset contains policy-level information about its target group (low-skilled, high-skilled, students, irregular migrants, etc.), how large the change is (e.g. fine-tuning vs. major policy change) and several other policy properties. This dataset is used to construct country-specific indexes that measure whether a country becomes more or less open to skilled migrants and students. These indexes are then used to examine whether changes in the immigration policies towards skilled workers and students affect the magnitude and direction of knowledge flows between country pairs. The results suggest that by increasing the barriers to immigration of skilled workers and students a country *reduces* its knowledge 'exports' to other countries, with a slightly smaller, but still negative effect of the increase in immigration barriers of the 'knowledge-importing' country.

Another question explored in this paper is to what extent travel visa requirements (as another measure of the administrative barriers to mobility) affect the magnitude of bilateral knowledge flows. The data on travel visa requirements comes from Neumayer (2011), who collected it from IATA's Travel Information Manual for year 2004. This is a different dataset on administrative measures and it is used to check whether visa requirements (as an example of administrative barriers to mobility) also affect the magnitude of bilateral knowledge flows.[5] The

[4]The author is working on creating the dataset that will include other disciplines.

[5]This data, unfortunately, is coded as country-pair specific information without preserving the direction of visa restrictions. For example, a variable for unilateral visa restriction will equal

results support findings based on immigration policy estimates and show that visa requirements are associated with reduced bilateral knowledge flows.

The main contribution of the paper is in showing that administrative barriers to mobility of the highly-skilled can distort the knowledge flows by affecting their magnitude in both directions. By raising the immigration barriers towards skilled workers and students a country reduces opportunities for face-to-face contact and development of personal ties between researchers from both countries, which in turn reduces both how much of this country's knowledge flows to other countries and how much the country receives in knowledge flows from other countries. The results also show that stricter immigration policy of the country which receives the knowledge flow (citing or 'knowledge-importing' country) can also reduce the bilateral knowledge flows. The similarity in the role of administrative barriers in both the knowledge-'importing' and 'exporting' countries suggests that knowledge flows from a country are affected by both the incoming and outgoing researchers. This provides an indirect support of the 'brain circulation' hypothesis, rather than 'brain drain' or 'brain gain' (Saxenian 2005).

Supporting calculations show that the role of administrative barriers can be reduced, but not eliminated, by the presence of bilateral research networks, proxied by the bilateral stock of skilled migrants. The results show that the effect of administrative barriers to mobility is more important for flows of recent knowledge, as proxied by citations to papers published at most 1 year ago (with gradual decrease of the coefficients as the citation lag increases to 10 years and more). Finally, the effect of immigration policy towards skilled workers and students is persistent, having a significant impact for about 9 years.

To check the consistency of these results, additional estimations are performed using cross-sectional data on travel visa restrictions in year 2004. Previous research shows that visa restrictions affect negatively volumes of trade, FDI, migration and academic mobility. The findings in this paper show that travel visa restrictions also matter for international knowledge flows.

The main research results are supported by two independent sources of data on the administrative barriers to mobility and a range of robustness checks. Thus, this paper shows that by following the 'paper trails' it is possible to see the distorting influence of the 'paper walls' on knowledge flows. This finding can be useful for policy-makers, especially when formulating immigration policy for skilled workers and students, because it shows that greater administrative barriers to mobility can have unintended effects on knowledge flows. While outside the scope of this paper, it is likely that the reduced knowledge flows will be associated with weaker long-term development.

---

to 1 if either country A imposes a visa on country B or vice versa. This does not allow examining the direction of knowledge flows, but the magnitude of knowledge flows can still be examined.

The remainder of the paper is organised as follows. The next section provides a summary of related literature and how the current paper contributes to the literature. Section 3 describes the data used in the paper and how the immigration policy index was constructed. The framework used for estimating the effects of administrative barriers is explained in Section 4, while the main results and robustness checks are presented in Section 5. The final section concludes with a discussion of the findings. Supporting tables and figures are collected in the Appendix A.

2 Related literature

The research in this paper relates to several strands of the literature on the diffusion of knowledge and academic mobility. The first strand is on the impact of various geographic, cultural, informational and economic barriers on the diffusion of knowledge. Another strand is the importance of administrative restrictions to mobility for various economic outcomes, such as trade, FDI, migration and academic mobility. These two strands are linked by a third strand that examines the impact of academic mobility on the flow of knowledge.

The diffusion of knowledge has been tracked in the literature by patent citations and scientific article citations. One of the big research questions has been on the role of distance in the diffusion of knowledge, with a general conclusion that distance has a negative effect on the diffusion of knowledge (Drivas and Economidou 2015). A recent paper by Head et al. (2015) shows that the role of distance declines after personal ties between authors are taken into account. However, distance still matters to the extent it affects the accessible social network. While improvements in telecommunications lower the communication costs for distant collaboration, face-to-face interaction has been shown to be a complement, rather than a substitute for electronic communication, Agrawal and Goldfarb (2008). Another example on the role of distance can be seen in Agrawal, Galasso, et al. (2014) who examine the connection between road infrastructure and innovation. Agrawal, Galasso, et al. (2014) find that better transportation infrastructure allows innovators to access more distant knowledge inputs and increase their innovative activity: a 10% increase in the stock of highways causes almost 2% increase in regional patenting over a five-year period.

Other factors that are often used in the literature are common language and common border. MacGarvie (2005) examines how patent citations[6] are affected by the stocks of patent counts, physical distance, common language, FDI, telephone communications, and finds that common language and FDI enhance diffusion of

[6]The patent citations are aggregated to a cited-citing country pair with the years of the citing and the cited patents. This allows additional controls for 'vintage' of the cited patents.

knowledge (for FDI the effect is significant only between technologically-similar countries). The effect of distance is negative, but its importance declines over time. This finding is robust to including control for a possible decrease of knowledge localisation over time.

The role of administrative barriers on mobility was examined empirically only very recently and mainly focused on visa requirements (Neumayer 2006). Multiple studies have shown the negative effect of visa requirements on trade, FDI, migration and academic mobility.

Czaika and Haas (2016) use information on visa restrictions in 38 countries over 1973-2012 period to examine the effect of visas on international migration. They find that visa restrictions significantly decrease the circulation of residents of different countries, encouraging long-term settlement in the destination country. This finding is particularly interesting in the context of network formation, because it suggests that visa restrictions might have a positive effect on the size of diasporas.[7] Czaika and Haas (2016) also report the asymmetric responses to visa introduction/removal: introduction of visas affects the bilateral flows with a significant lag (20% after 10 years), while removal of a visa requirement leads to a much quicker increase in the bilateral flows (30% increase after 3 years).

A recent study by Appelt et al. (2015) finds that administrative barriers in the form of visa requirements reduce both the academic mobility (as reflected in the number of migrant scientists) and the number of cross-border scientific collaborations. The effect of mutual visa restrictions on international scientific collaborations is more than double the effect of only one country imposing the restrictions. A possible interpretation of this is that unilateral visa still permits migration of scientists towards the country that does not impose the restriction, hence international research networks can still form. Once the second visa restriction is implemented, such one-directional flows cease, which limits the development of bilateral research network and leads to reduced number of scientific collaborations.

Mavroudi and Warren (2013) conducted interviews with non-European Economic Area postgraduate students and staff at UK universities and report the constraining effect of immigration policy on the mobility of highly-skilled workers and students. Reduced academic mobility is likely to have a negative impact on development of personal ties and informal collaborations. A more extreme example from UK is the case of Dr. Miwa Hirono, a Japanese citizen who worked at the University of Nottingham for nearly seven years before she was denied a permission to remain the UK (Times Higher Education 2015; Garrett 2015). The reason behind this decision was that Dr. Hirono's visits abroad exceeded the government-stipulated limit of 180 days per year. This was particularly troubling, since the time spent abroad was to attend meetings and conduct fieldwork for a

[7] Also see Ackers (2005) for an interesting discussion on 'scientific' diasporas.

government-funded project, as well as to present the findings at seminars and conferences (Times Higher Education 2015). This may seem like an extreme example, yet anecdotal evidence suggests that this is not an isolated incident (Garrett 2015).

An important historical anecdote is related to the Rosalind Franklin's, a scientist who provided important contribution to the model of DNA structure (among her many other contributions), journey to the United States. Maddox (2003) writes that Franklin was denied US visa due to the consul's concern that she would be "gainfully employed in competition with American labor". Only with significant support from US-based researchers, Franklin managed to get permission to travel to the United States, where she gave a series of lectures and met many scientists working on related research topics. During this visit, Franklin was able to get important "virus samples, promises of collaboration from leading scientists around the States...", she also made "...contacts with American virus laboratories that would form the basis of the greater part of her work for the next three years" (Maddox 2003, page 247). Curiously, in a letter home Rosalind Franklin noted the following about American scientists working in the area of fundamental biology: "In spite of the vast distances, they all know each other rather well, and constantly exchange visits" (Maddox 2003, page 242). Another historical case is Tjalling Koopmans' visit to USSR after which Koopmans shared his observations (and knowledge) with US-based colleagues (Düppe 2016). One specific example mentioned by Düppe (2016) is Soviet research on 'evolutionary game theory' by Israel Gelfand and Michael Tsetlin, however despite Koopmans' efforts to disseminate this research he found that "the more the individual in question is actively doing mathematical research in game theory, the less he is inclined to stop and contemplate quite different formalizations of games". These historical examples show the importance of mobility and face-to-face contact, though naturally this is not the only determinant of successful knowledge transfer.

The studies of academic mobility emphasise its role in development of research networks, which in turn have been shown to facilitate the diffusion of knowledge. Mobile academics help to develop research networks both at the destination and at the origin.

An interesting case study looked at US Fulbright Fellowship recipients (Kahn and MacGarvie 2014), who are required to return to their home country after completion of studies. By comparing the returnees' performance to that of similar scientists that remain in the US, Kahn and MacGarvie (2014) show that returnees are more frequently cited at home (than similar foreign-born scientists in the US) and direct their own citations towards home-country articles. At the same time, returnees continue citing US-based authors, at least in the short/medium term after they return. Finally, foreign-born scientists in the US were found the attract a higher proportion of potential citations from their home countries than from

third countries. This is also indicative of the positive role of research networks in the diffusion of knowledge. Other empirical studies support this finding for research networks at the destination (e.g. Franzoni et al. 2012) and at the origin (e.g. Wang 2015).

Using survey data on almost 2000 international academic visitors to Germany, Jöns (2009) argues that visits from international researchers to post-World War II Germany helped to reintegrate Germany into the global scientific community. In addition to collaborations, the international visitors provided personal ties/contacts which helped to increase academic mobility and further collaborations by German scientists. A similar observation was reported by Guth and Gill (2008), who interviewed PhD students and researchers from Poland and Bulgaria. The role personal ties shows up in their study, many PhD students that studied abroad reported that their supervisor provided information on opportunities abroad. The power of networks in determining which scientist migrates is also discussed in Ackers (2005).

Borjas and Doran (2012) examine a natural experiment related to the collapse of the USSR. The influx of Soviet mathematicians into the United States resulted in a crowding out of US-based mathematicians whose research overlapped with that of the Soviet researchers. Another study that examined this historical episode from the perspective of knowledge flows is by Abramitzky and Sin (2014). Abramitzky and Sin (2014) use information on book translations, highlighting their purpose of transmitting knowledge between languages, over the period from 1980 to 2000 as a proxy for diffusion of broad knowledge, and find increased flows of 'Western' knowledge into the former Satellite countries following the decline of communism.

Academic mobility is also important for temporary visits, allowing distant collaborators to work face-to-face. The importance of this personal contact has been shown in the experimental setting by Boudreau et al. (2012). After exposing a random subset of test subjects to colocation and face-to-face interactions, the probability of the test subjects' collaboration increased by 70%. This suggests that barriers to academic mobility may significantly decrease collaborations and the diffusion of knowledge. A similar effect of colocation on collaborations has been shown for an interesting natural experiment, temporary relocation of scientific workers due to asbestos removal in Paris, which lead to greater collaboration for the (temporarily) collocated research labs (Catalini 2015). The international flows of knowledge can also be disrupted by events that prevent communication between researchers from different countries, Iaria and Waldinger (2015) show that World War I had a large impact on the flows of knowledge between the countries from the opposing camps. Longer research visits or permanent academic migration also stimulate the diffusion of knowledge, for example Azoulay et al. (2012) find that relocation of scientists increases academic citations to their prior work from

the new location.

The present paper contributes to the literature by examining empirically the importance of immigration policy in the knowledge-'exporting' and 'importing' countries in affecting the magnitude and direction of international knowledge flows. The knowledge flows are proxied by citations among economists. A citation is interpreted as an 'import' of knowledge from the country in which the cited paper's author resided when it was published. The results shows that greater administrative barriers to mobility of skilled workers and students are associated with lower knowledge flows between a pair of countries. To the best of the author's knowledge this is the first empirical study that examines the negative effect of administrative barriers on the diffusion of knowledge using a global dataset on citation flows.[8]

Calculations show that a country's openness towards skilled workers and students not only increases the 'imports' of knowledge, but also helps to raise the 'exports' of a country's knowledge. This 'circulation' effect has been advanced in the literature (Saxenian 2005), but there were no empirical studies showing this effect for knowledge flows.[9]

The robustness of results is checked using additional specifications. The robustness checks are also used to argue for the direction of causality, linking the administrative barriers to their effect on the knowledge flows. The paper also expands the literature that has already shown the effects of administrative barriers to mobility for trade, FDI, migration, academic collaborations and mobility (as cited above).

3 Data and descriptive statistics

The dependent variable of interest, bilateral knowledge flow, is proxied by aggregate citation count per year between pairs of countries. This data is obtained from Thomson Reuters' Web of Science (WOS), by examining the country of affiliation of all authors of the citing and cited publications in Economics.

The data from WOS is based on approximately 430 thousand articles published in Economics journals indexed by Web of Science with information on 5.6 million citations (not limited to Economics journals). To construct the gross citation counts at country-pair level the following procedure was used. For every publication, the affiliations of authors were processed to identify the countries of affiliation. For the cases of multiple affiliations per author the following proce-

[8] Appelt et al. (2015) examine the effect of visas for international collaborations, which can also be seen as a proxy for diffusion of knowledge, however their focus in on the academic mobility.

[9] The closest result is again by Appelt et al. (2015) who show that academic mobility is better described as 'brain circulation' with scientists showing relatively greater mobility towards countries that are catching up.

dures were used. For Web of Science each distinct country of affiliation was used as a separate entry. For example, if an author reported two affiliations, one in the United States and another one in Kazakhstan, then their paper would be associated with both countries. After this procedure, each publication is associated with a set of unique countries representing countries of affiliations of the authors. Combining this data with the information on citations, the aggregate citation count was calculated from 1980 to 2015 for all country pairs in the sample. The bilateral aggregate citation matrix is sparse, with a lot of zero observations, see Table 1. Any analysis that would focus just on the observed (positive) knowledge flows is likely to be subject to the selection effect, because the estimation will be based on a sample that is not randomly selected. To address the selection effect the estimations are done using Poisson regressions, see Section 4 for further details.

Table 1: Number of country-pairs by the presence of knowledge flows.

	Number of country pairs	Share of total
No observed knowledge flows	30416	0.73
Knowledge flows in one direction only	4378	0.10
Knowledge flows in both directions	7026	0.17

Source: own calculations based on Web of Science data. Notes: knowledge flows are calculated as the sum of all citations between the cited and citing country over 1990-2015; this means that within a single year the number of countries with zero knowledge flows is likely to be larger.

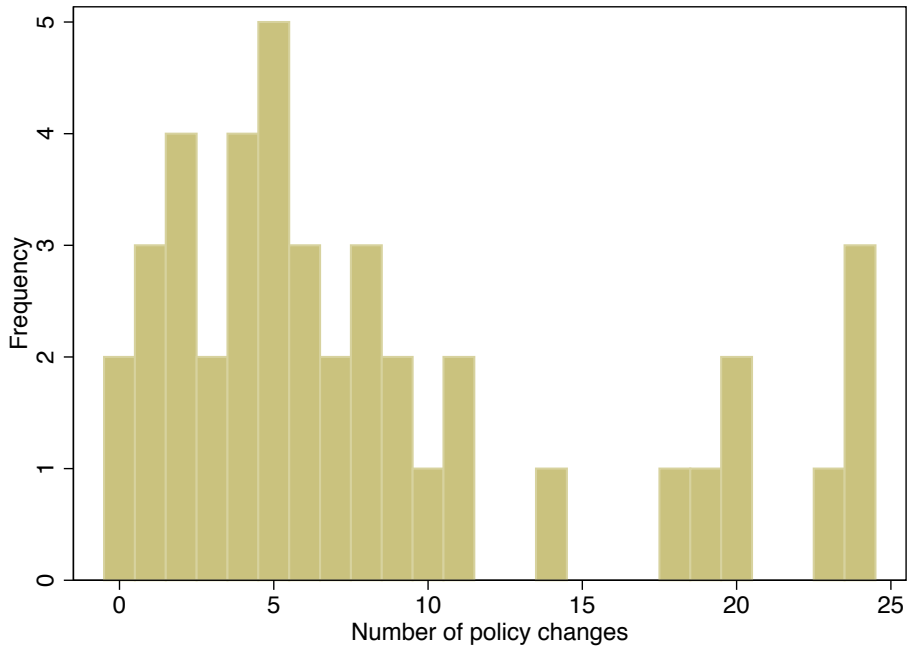
The data on administrative barriers to mobility comes from two independent sources — International Immigration Institute's DEMIG POLICY dataset and International Civil Aviation Association's November 2004 Travel Information Manual. DEMIG POLICY is a recently-released dataset which contains detailed information on approximately 6500 migration policies in 45 countries from 1721 to 2014 (DEMIG 2015). The sample coverage prior to 1990 varies by country, and bulk of the observations are in 1945-2013 period. Each country's policy measure is categorised depending on the target group (all migrants, high-skilled, low-skilled, students, irregular migrants and other categories), the importance of the policy (low, medium, high), its impact on restrictiveness (neutral, more/less restrictive) and several other important characteristics. This dataset is used to construct a country-specific index of administrative barriers to the mobility of high-skilled workers and students.[10] The index for high-skilled migrants is constructed as follows: for every country the index is initialised at zero and after that the index is increased (decreased) by 0.5 if a more (less) restrictive policy of medium importance was implemented or by 1 if a more (less) restrictive policy of high importance

[10] A similar index is calculated for low-skilled workers to be used as a robustness check.

was implemented.[11]

Many countries have implemented only a few changes in policy towards skilled workers over this period of time, but as Figure 1 shows there are only 2 countries that experienced no change at all. The variation of the index of administrative barriers is very large for the countries that implemented many changes. Figure 2 shows the time variation for five countries with the largest number of changes.

Figure 1: Number of changes in the policy towards skilled workers and students over 1990–2014.

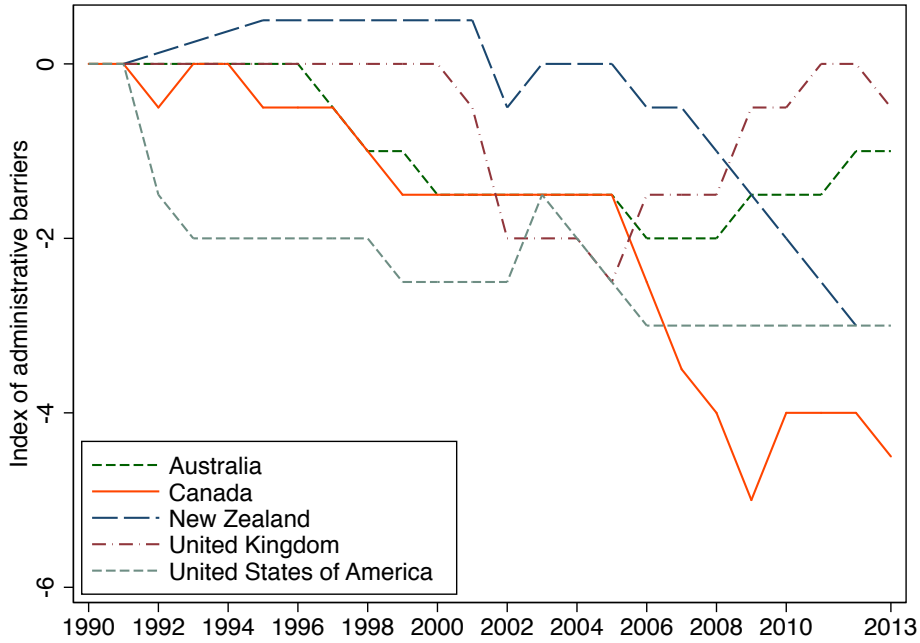


Source: own calculations based on DEMIG POLICY data. Note: the vertical axis shows the number of countries that have experienced the number of policy changes given on the horizontal axis.

Figure 3 shows that many countries have reduced administrative barriers towards high-skilled workers and students over 1990–2014 period. On average, countries that have made their policy towards highly-skilled workers more strict or did not change it between 1990–2014 have lower growth rate in their knowledge 'exports', proxied by the number of times the papers published by authors residing in the country are cited by authors from other countries. This simple correlation suggests that there may be a link between diffusion of knowledge and the migration policy towards high-skilled workers and students.

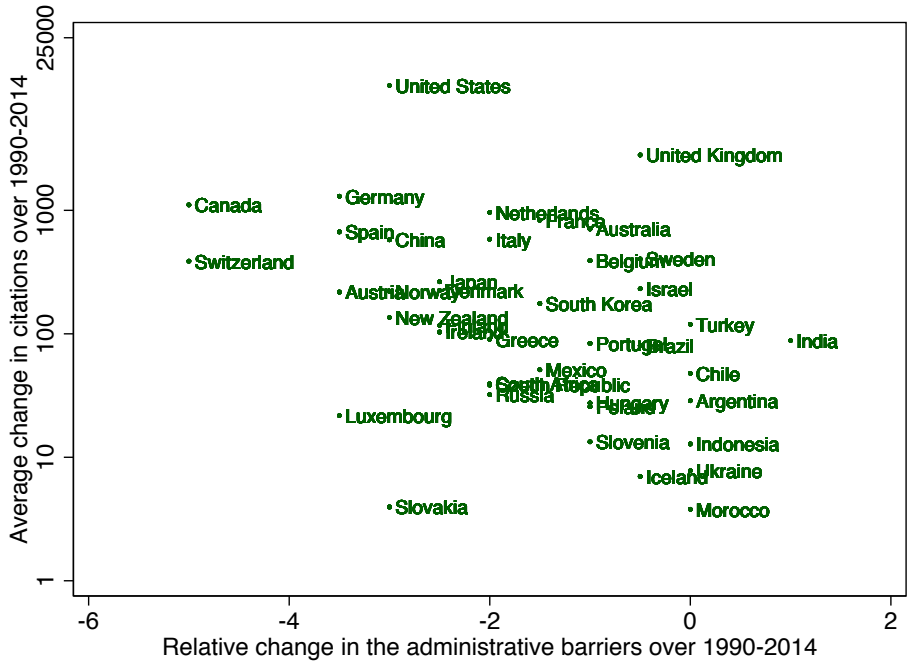
[11]The index is constructed using information on policies that regulated legal entry and stay, integration, or border and land control.

Figure 2: Indexes of administrative barriers towards skilled workers and students over 1990–2014 for the countries with the greatest number of policy changes.



Source: own calculations based on DEMIG POLICY data. Note: the vertical axis shows the index of administrative barriers towards skilled workers and students, a higher number indicates greater barriers.

Figure 3: Relative change in knowledge exports and administrative barriers for the highly-skilled workers and students over 1990–2014.



Source: own calculations based on Web of Science and DEMIG POLICY data. Note: the vertical axis shows the average change in the number of times a country has been cited (i.e. a paper with at least one author claiming affiliation inside the country has been cited by authors from another country); the horizontal axis shows the difference between the value of an index of administrative barriers for the skilled workers and students in 2014 and 1990.

The second source of information on administrative barriers to mobility comes from Neumayer (2011), who extracted information on visa requirements from a November 2004 edition of the manual widely used in the aviation industry, IATA's Travel Information Manual. This information is available only for year 2004 and only at a dyad-level, i.e. without information on the direction of visa restrictions. For example, in the dataset a unilateral visa dummy is equal to 1 if either country A imposes visa restriction against country B or vice versa, but not both.

Table 2 shows the average bilateral citation count for 2005-2008 period by visa restrictions of the country pair. The largest volume of knowledge flows, proxied by bilateral citation counts, occurs between countries that have no visa restrictions against each other. On average, countries with visa restrictions cite each other fewer times. This can be misleading because whether countries have visa restrictions or not will be correlated with a range of other variables that affect diffusion of knowledge - for example, geographical proximity, common language and borders, historical links between countries.[12] Most of the country pairs in the sample do not cite each other (median bilateral citation count is zero for any category of restrictions). Another observation is that the second visa requirement is not associated with a large change the magnitude of knowledge flows.[13]

Table 2: Average bilateral knowledge flows by visa restrictions.

	Average bilateral citation count				
	Mean	Standard deviation	Share of zero flows	Max	N
No visa restrictions	19.96	216.44	63.9	8685.75	6300
Unilateral visa restriction	1.28	21.29	82.5	1179.00	12846
Bilateral visa restrictions	0.88	29.81	89.5	2668.25	17526
After removing the United States from the sample					
No visa restrictions	8.25	50.54	64.5	1091.50	6232
Unilateral visa restriction	0.45	2.82	83.6	125.38	12636
Bilateral visa restrictions	0.49	7.63	89.9	501.62	17422

Source: own calculations based on Web of Science data. Notes: visa information is based on year 2004 data, the average bilateral citations are calculated over 2005-2008 period; unilateral visa restriction means that only one of the two countries in a country pair imposed a visa restriction, while bilateral visa restriction means that both countries in a country pair imposed visa restrictions on each other.

Appelt et al. (2015) report that the effect of having bilateral visa restrictions on academic migration is more than double the effect of only one country imposing

[12]The data on dyad-specific variables is taken from Neumayer (2011), who in turn used data from Mayer and Zignago (2011).

[13]There could be a meaningful difference in the *direction* of flows, but the travel visa information from Neumayer (2011) is coded at dyad-level and is symmetric by design which does not allow distinguishing the direction of flows.

visa restrictions, while Neumayer (2011) shows that the effect of bilateral visa restrictions on trade and FDI is larger than for unilateral visa restrictions, but only marginally so for FDI. The explanation offered in Neumayer (2011) is that the stocks of FDI are often asymmetric, with one country responsible for most of the FDI, which would render the impact of the second visa requirement negligible. This might also be an appropriate description of the asymmetry of knowledge flows, especially between a technologically-advanced country and a catching up country.

The descriptive statistics show a correlation between administrative barriers to mobility and knowledge flows, so the rest of the paper will explore whether this link remains after controlling for confounding factors, such as physical proximity, common language and border or other country-pair specific factors.

4 Empirical framework

This section describes the empirical framework used to determine the specifications which will be used to estimate the role of administrative barriers to mobility on knowledge flows. The framework is similar to Appelt et al. (2015) and Head et al. (2015).

The stock of knowledge in each country accumulates over time, providing intellectual capital for researchers at home and abroad. Countries with a larger stock of knowledge have greater capacity to 'export' knowledge abroad. However, the volume of knowledge flows will also depend on the absorptive capacity of the 'knowledge'-importing country, reflecting how active a country is in growing its own stock of knowledge. At the same, time there will be other factors that affect the volume of knowledge flows, reflecting communication and collaboration costs over greater distances, localised knowledge spillovers and other factors affecting diffusion of knowledge.

These negative factors can be mitigated by academic mobility, giving researchers opportunities to develop research networks, to participate in international collaborations, to develop personal ties through face-to-face contacts. The mobility of academics in turn will be affected by immigration policies, especially towards skilled workers (and to some extent students[14]). For example, if two countries are relatively restrictive in their immigration policy, then the researchers from these countries will face it costly to develop personal ties and collaborate across borders, both of which are important for transfer of tacit knowledge and also of recent knowledge. This means that a country's strict immigration policy will make its knowledge more difficult/costlier to access and at the same time will make it

[14]During the study period, students will often acquire knowledge developed at their destination country, and will be referring to this knowledge upon return.

costly to access knowledge in other countries (by restricting or increasing the cost of foreign researchers visiting the country).

To model the above framework empirically, consider the flow of citations from country i (citing country) to country j (cited country) in year t, $F_{ij,t}$, which indicate that knowledge is flowing from the cited to the citing country in year t. The flow of citations will depend on the stock of knowledge available in the cited country, $K_{j,t}$, and the absorptive capacity of the citing country i, $A_{i,t}$. This flow will be affected by the costs of knowledge transfer, $C_{ij,t}$, which will include time-invariant country-pair specific factors, e.g. distance, common language, variables capturing country- and time-specific heterogeneity, and also the administrative barriers to mobility of the high-skilled which can vary over time and can reduce opportunities for collaboration, face-to-face contact, presentation at conferences/seminars and such.

$$F_{ij,t} = A_{i,t}^{\alpha} K_{j,t}^{\kappa} C_{ij,t}^{-1} \tag{1}$$

The flow of knowledge will be modelled via information on citations in academic publications among economists, representing transfer of knowledge from the cited country j to citing country i in year t.[15]

The absorptive capacity of country i, $A_{i,t}$ will be proxied by the amount of new papers published by country i in year t.[16] The stock of knowledge in the cited country, $K_{j,t}$ will be proxied by the stock of publications in country j at time t. This choice of proxies is primarily motivated by the source of the data (citations on academic papers), however other valid proxies can be considered, for example the absorptive capacity could be approximated with the number of researchers in a given country, while the stock of knowledge could be proxied by the number of existing patents. Finally, the influence of administrative barriers and other factors that can affect diffusion of knowledge will be collected in cost factor, $C_{ij,t}$, including factors such geographical distance, common language, past colonial ties, and the migration policies of the citing and cited countries.

The multiplicative formulation suggests that bilateral knowledge flows will be zero if the stock of knowledge in the 'exporter' is zero and/or the absorptive capacity of the 'importer' is zero. Cost factor is assumed to be strictly positive and non-decreasing in its arguments. The arguments of the cost function will include physical distance between the citing and the cited countries, dummies capturing dyad-specific information (colonial history, common language and border) and

[15] As a further distinction it is possible to track the year of the paper to which the citations are made. Such distinction would allow controlling for 'vintage' effects, see MacGarvie (2005). The time gap between the cited and citing papers can convey important information about the speed of knowledge diffusion, this distinction is explored in Table 5.

[16] The stock of existing papers and the number of new papers published are highly correlated, so including stocks of publications in the cited and citing countries does not change the results.

administrative barriers to mobility. Assuming that the cost factor can be modelled as an exponential function of its arguments (this is similar to (Head et al. 2015)) we can rewrite the equation in one of the two ways (the log-transformations assume positive value of the argument):

$$F_{ij,t} = exp(\alpha \log A_{i,t} + \kappa \log K_{j,t} - \mathrm{C}_{ij,t}), \tag{2}$$

$$\log F_{ij,t} = \alpha \log A_{i,t} + \kappa \log K_{j,t} - \mathrm{C}_{ij,t}. \tag{3}$$

These equations can be estimated using either Poisson (Equation 2) or OLS (Equation 3) with error terms clustered at the country-pair level. The main tables present the results for Poisson, while OLS results are provided in the appendix.

4.1 Identification strategy

Estimation of equations 2 and 3 does not necessarily indicate a causal relationship, moreover the estimated coefficients could, in general, be biased. The strategy for identifying the causal impact of higher costs of face-to-face collaboration will rely on a source of exogenous variation in the cost of collaboration by residents of a particular country — travel visa requirements and immigration policy towards skilled workers and students (including origin and destination policies). These measures of administrative barriers to mobility are exogenous from the perspective of scientific collaborations, because imposition (or removal) of such 'paper walls' is guided by political, macroeconomic and security-based considerations (e.g. Luedtke et al. 2010; Neumayer 2006). The rationale behind the processes underlying imposition and removal of 'paper walls' also addresses the reverse causality concern, suggesting that the reverse causal effect of knowledge flows on migration policy is likely to be small, if any.

Another concern could be the bias in estimation due to omission of variables that affect both the dependent variable (bilateral knowledge flows) and the variable of interest (administrative barriers). One candidate, based on the large literature on localised knowledge spillovers, is physical proximity. Countries that are located close to each other are likely to have larger bilateral knowledge flows and also are likely to have more favourable migration policy towards each other. To ensure that the potential omitted variable bias is minimised the variables that are typically used in the empirical gravity literature are included in the estimations, these variables include colonial link in the past, common language, common border, physical distance (log) (e.g. Neumayer 2011; Appelt et al. 2015). In addition to that, the following strategies are used: for specifications that contain policy information at country-year (based on DEMIG POLICY data), fixed effects are introduced at country, year and country-pair levels; for specifications that contain country-pair

information on bilateral administrative barriers (based on country-pair visa information) country fixed effects are included to capture potential effects that will affect bilateral knowledge flows and are unrelated to administrative barriers.

Finally, the sample selection bias could result because the estimation is based on a sample that is not randomly selected. This is of a particular concern since the median bilateral knowledge flow is 0, suggesting that positive knowledge flows are observed for a non-random sample of countries. To address this concern the equations are estimated using Poisson models on the full, rectangularised dataset with zero values of bilateral knowledge flows.[17]

There are two independent sources of data on administrative barriers to mobility, one is a panel and the other one is at cross-sectional level, which will lead to two versions of the estimated equations.

4.2 Immigration policy of countries over time – DEMIG POLICY data

The first specification will use country-year information on migration policy towards high-skilled workers and students from DEMIG POLICY dataset. The country-year nature of the data allows including dyad-specific fixed effects as a general control for country-pair specific factors. This means that cost variable, $C_{ij,t}$, will include the administrative barriers as follows: $C_{ij,t} = P_{i,t} + P_{j,t} + X_{ij} + Y_i + Y_j + Z_t$, where $P_{i,t}$ and $P_{j,t}$ are country-specific indexes of immigration policy towards skilled workers and students, while X_{ij},Y_i, Y_j and Z_t are country-pair, country i, country j and time fixed effects, respectively. The equation estimated with this data is:

$$F_{ij,t} = exp(\alpha \log A_{i,t} + \kappa \log K_{j,t} + \beta_1 P_{i,t} + \beta_2 P_{j,t} + X_{ij} + Y_i + Y_j + Z_t + \epsilon_{ij,t}),$$

where the negative signs on the cost arguments have been absorbed into the coefficients for convenience.

4.3 Cross-sectional data on bilateral visa requirements

The second specification will use information on visa requirements by country-pairs from IATA's Travel Information Manual for year 2004 (see Neumayer 2011). This

[17] Another possible approach is to use a Heckman selection model. There is no clear theoretical motivation for the Heckman exclusion restriction, i.e. a variable that would strongly affect selection into a positive bilateral knowledge flows and at the same time have no effect on the flows themselves. One solution is to model the selection equation in the same way as the level equation, hence the identification is relying on the non-linearity of the inverse Mills' ratio (see Neumayer 2011). The results based on this approach qualitatively are the same, because there is no clear motivation for the selection equation these results are not included in the tables.

approach is similar to other research on the effects of visas on trade/FDI (Neumayer 2011), academic mobility (Appelt et al. 2015) and diffusion of knowledge (MacGarvie 2005). The advantage of this approach is that it examines the effects of administrative barriers at the country-pair level, while the previous estimation relies on the policy measures at a country-level. The data on travel visa requirements is available only as a cross-section, so the knowledge flows information is collapsed to the country-pair level using information on years 2005–2008 (same time period as in Neumayer 2011) and time subscripts will be dropped.

This dataset allows modelling the cost function as follows: $C_{ij} = V_{ij}^{one} + V_{ij}^{both} + X_{ij} + Y_i + Yj$, where V_{ij}^{one} is a dummy equal to one if one country in a pair imposes a visa restriction (but not both), while V_{ij}^{both} is a dummy equal to one if both countries impose a visa restriction against each other. Variables X_{ij}, Y_i, Y_j capture country- and country-pair specific heterogeneity, and the cross-sectional data source implies that we cannot include Z_t in the estimation. The estimated equation will be:

$$F_{ij} = exp(\beta_1 V_{ij}^{one} + \beta_2 V_{ij}^{both} + \beta_3 X_{ij} + Y_i + Y_j + \epsilon_{ij}), \tag{4}$$

where X_{ij} incorporates the dyad-specific variables such as physical distance, common language, etc. Note that visa information is coded at dyad-level and is symmetric (the dummy on single visa is equal to 1 if country A imposes a visa restriction against country B or if country B imposes a restriction against country A), which does not allow examining the effects of visas on the direction of knowledge flows, but can be used to examine the effect on average bilateral knowledge flows, so F_{ij} represents the average bilateral knowledge flows over 2005–2008. There are no controls for A_i and K_j since in the cross-sectional framework these are captured by the country fixed effects.

The main hypothesis in this paper is that the administrative barriers to mobility will have a negative impact on bilateral knowledge flows. Hence, we would expect positive coefficients for favourable migration policy and negative coefficient on the barriers to mobility (such as visas).

In line with the literature on diffusion of knowledge, it is expected that the physical distance will affect negatively the bilateral knowledge flows, while factors such as common language or border will have a positive effect. The coefficients on administrative barriers to mobility should be negative, indicating their role in increasing the cost of international collaboration and decreasing opportunities for face-to-face contact and development of personal ties.

5 Main results

5.1 Immigration policy towards skilled workers and students (DEMIG POLICY data)

The results support the negative role of administrative barriers to mobility in affecting the magnitude and direction of the knowledge flows. Table 3 shows that greater administrative barriers towards high-skilled workers and students in a knowledge-'exporting' country reduce the volume of knowledge flows from that country, while stricter immigration policy in a knowledge-'importing' country also leads to a reduction in the volume of knowledge flows. Together these results imply that greater barriers towards mobility of high-skilled workers and students decrease a country's knowledge flow in both directions – the country 'exports' less of its own knowledge and 'imports' less of other countries' knowledge.

Table 3: The effect of immigration policy on knowledge flows.

	Aggregate citations per year		
Stock of papers in the cited country	81.371	57.843	59.857
	(7.884)***	(3.254)***	(3.181)***
New papers in the citing country	95.102	64.435	65.485
	(8.898)***	(3.983)***	(3.447)***
Openness for high-skilled and students, cited country	2.926	2.100	
	(1.016)***	(0.809)***	
Openness for high-skilled and students, citing country	2.064	1.369	
	(0.596)***	(0.461)***	
Colonial link in the past		-14.544	-14.167
		(8.350)*	(8.334)*
Common language		5.038	5.212
		(2.424)**	(2.418)**
Common border		1.583	1.665
		(1.699)	(1.690)
Physical distance, log		-11.005	-10.919
		(1.034)***	(1.027)***
Pseudo R2	0.99	0.99	0.99
N	34,742	33,825	33,825
Cited country dummies	Yes	Yes	Yes
Citing country dummies	Yes	Yes	Yes
Citing-cited country-pair dummies	Yes	No	No
Year dummies	Yes	Yes	Yes

* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$

Source: own calculations based on Web of Science data. Note: this table shows the marginal effects, Table A.1 shows the Poisson coefficients; the dependent variable is the aggregate count of citations per year from the citing to the cited country; estimation procedure is Poisson with standard errors clustered by country-pair; the results are qualitatively similar if the United States is dropped from the sample.

The constructed index of barriers for skilled-workers and students makes it somewhat harder to interpret the coefficients in Table 3, but to give some context to

a change in administrative barriers consider the following examples. The index of administrative barriers for skilled workers and students was decreased by 0.5 for the following examples of policy changes (country and year of policy implementation are given in brackets): fee on recruitment of skilled workers from abroad (Indonesia, 2003), quota on foreign workers (India, 2009), high-skilled immigration programme terminated (Czech Republic, 2010), introduction of minimum salary for foreign workers (India, 2010), quota for skilled workers (UK, 2011), entry visas for highly-skilled abolished (Norway, 2013) and other similar changes.

The marginal effects in Table 3 suggest that the effect of such policy changes for the 'average' country is a reduction in the average bilateral knowledge 'export' of about 2 citations per year. This is about 3% decrease using the average value of bilateral flows among all countries. However, the relative importance of an increase in administrative barriers is much larger for countries that already have significant barriers, e.g. in the form of travel visas. For such countries the relative effect can be nearly 50% drop in the knowledge flows (cf. Table 2). At the same time, such restrictive policy would decrease the volume of knowledge 'imports' by about 1 citation per year, which again can be very high if there are already significant barriers between the countries.

Of course, a more open immigration policy towards high-skilled workers would suggest similarly high increases in bilateral knowledge flows. Some of the examples of less restrictive policies, which reduce the index by 0.5, are: fast-track work permits for high-skilled (United Kingdom, 2000), program to attract high-skilled workers (China, 2008), EU Blue Card implementation (Spain, 2009), high-skilled are exempt from quota (Russia, 2010), visitor visa for academics (New Zealand, 2011), quicker procedures for sponsors of high-skilled migrants (Netherlands, 2013), introduction of a 'talent visa' for skilled workers (China, 2013) and similar policies.

5.2 Visa requirements and average bilateral knowledge flows

Table 4 shows several specifications estimated on the bilateral visa data from Neumayer (2011). The results show that visa restrictions have a significant negative impact on average bilateral knowledge flows. This finding is robust to different estimation procedures (Poisson, OLS, Heckman selection model).[18] Also, in most specifications the effect of bilateral visa restriction (i.e. both countries imposing visa requirements on each other) is not statistically significantly different from unilateral visa restriction (i.e. only one country imposing a visa restriction). This

[18]The results based on Heckman selection are qualitatively similar to the results from Poisson and OLS estimations. However, there is no clear theoretical justification for an exclusion restriction that can be used to identify the selection, so these results are not included in the main table, but are available on request.

is similar to the Neumayer (2011)'s result for FDI, where the argument was that typically only one country in a given pair maintains large FDI stocks in another country, hence the impact of second visa requirement is negligible. The same argument could be applied for the knowledge flows, suggesting that a meaningful increase in bilateral knowledge flows requires elimination of any visa restrictions between the countries (at least for the skilled workers and students).

Table 4: The effect of visa requirements on average bilateral knowledge flows.

	Average bilateral citation flows		
	absolute value		logarithm
	Poisson		OLS
Colonial link in the past	-0.233	-0.259	-0.317
	(0.049)***	(0.061)***	(0.104)***
Common language	-0.009	0.027	-0.062
	(0.031)	(0.034)	(0.057)
Common border	-0.034	0.002	0.174
	(0.023)	(0.030)	(0.076)**
Physical distance, log	-0.084	-0.177	-0.258
	(0.023)***	(0.017)***	(0.026)***
Stock of FDI, log	0.039		
	(0.011)***		
Bilateral migrant stock, log	0.046		
	(0.011)***		
Volume of trade, log	0.052		
	(0.022)**		
Regional trade agreement	-0.019		
	(0.041)		
Bilateral visa restriction	-0.205	-0.291	-0.501
	(0.081)**	(0.098)***	(0.055)***
Unilateral visa restriction	-0.068	-0.189	-0.585
	(0.052)	(0.082)**	(0.042)***
Pseudo R2/Adj. R2	0.98	0.98	0.75
N	4777	32580	6168
Country FE	Yes	Yes	Yes
p-value for equality of visa coefficients	0.12	0.31	0.09

* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$

Source: own calculations based on Web of Science data. Note: the dependent variable is the absolute value or logarithm of the average bilateral citation count between a pair of countries over 2005-2008 time period; right-hand side variables are from year 2004 or the closest available year (data from (Neumayer 2011)); estimation procedure is Poisson/OLS with clustered standard errors (clustering at country-pair level); the results are qualitatively similar if the United States is dropped from the sample.

The diffusion of recent knowledge

If the administrative barriers to mobility prevent diffusion of knowledge via reducing personal, face-to-face contacts, then the effect of 'paper walls' should be strongest for diffusion of recent knowledge.

Using information on the year in which an article was published and the year of the citing article it is possible to construct aggregate citation count for articles that are at most N years old, checking to what extent the administrative barriers affect these more recent knowledge flows. Table 5 shows that the administrative barriers have a relatively stronger effect in the short and medium terms. The largest coefficient is observed for $N = 1$, which means that 'paper walls' have the largest effect on diffusion of recent knowledge. As N increases, the impact of immigration policy in the 'knowledge-exporting' country diminishes.

Such monotonic pattern is not observed for the immigration policy of the citing ('knowledge-importing') country, however it must be noted that the dependent variable represent bilateral knowledge flows, while immigration policy of the citing country can lead to important 'diversion' effects that increase knowledge flows between certain countries at the expense of flows from other countries.

Table 5: The diffusion of recent knowledge and the role of immigration policy (marginal effects).

	Count of citations from citing to cited within the first N years			
	All years	1	5	10
Openness for high-skilled and students, cited country	1.846	0.370	1.597	1.926
	(0.746)**	(0.048)***	(0.323)***	(0.600)***
Openness for high-skilled and students, citing country	1.286	0.092	0.694	1.106
	(0.455)***	(0.054)*	(0.259)***	(0.376)***
Mean of the dependent variable	72.96	5.79	34.23	57.44
Relative marginal effect (cited)	0.03	0.06	0.05	0.03
Relative marginal effect (citing)	0.02	0.02	0.02	0.02
Number of observations	32829	29508	32207	32725
Log pseudolikelihood	-70902	-31443	-58872	-67457
Cited-citing country-pair dummies	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes

* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$

Source: own calculations based on Web of Science data. Note: the dependent variable is the aggregate citation count per year (from the citing to the cited country), estimation procedure is Poisson pseudo-maximum likelihood with standard errors clustered by country-pair; the full table showing the marginal effects for citations to publications from 1 to 10 years can be found in the Appendix, see Table A.4.

5.3 Robustness

Even though the omitted variable bias and sample selection were addressed in the main results by the appropriate choice of covariates (including the fixed effects) and the estimation technique (Poisson with robust standard errors clustered at a country-pair level), it is possible that some variable contemporaneously affects the knowledge flows and migration policy. To address this concern, the equations were estimated using lagged values of the immigration policies in the cited and citing countries. The results presented in Table 6 show that the coefficients on lagged values of administrative barriers to mobility are still significant and the significance of cited country's immigration policy persists for about 9 years. There is also notable asymmetry in the persistence of past policy — policy of the knowledge-exporting country remains persistent, while that of the knowledge-importing country is rather short-lived. This indicates that the ability to visit researchers in the knowledge-exporting country is important for successful diffusion of knowledge (at least to the extent that this is reflected in citations data).

Table 6: The persistence of changes in the immigration policy.

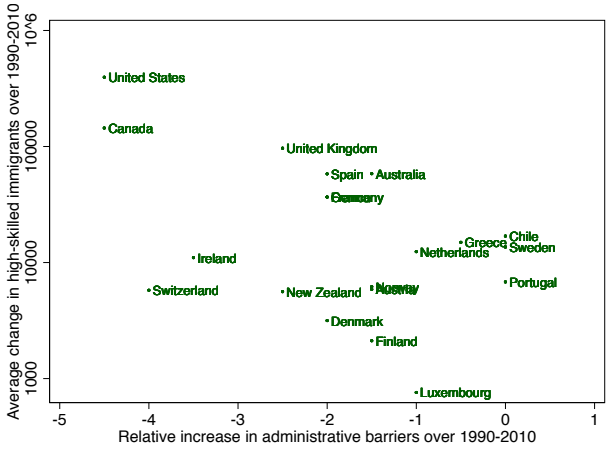
	Count of citations from citing to cited			
	Impact of policy implemented N years ago			
	1	5	9	10
Lagged openness for high-skilled and students, cited country	0.015	0.021	0.023	0.012
	(0.004)***	(0.009)**	(0.009)***	(0.009)
Lagged openness for high-skilled and students, citing country	0.009	-0.002	-0.005	-0.009
	(0.005)*	(0.009)	(0.009)	(0.010)
Number of observations	15144	15144	15144	15144
Log pseudolikelihood	-23288	-23288	-23288	-23288

Source: own calculations based on Web of Science data. Note: the dependent variable is the aggregate citation count per year (from the citing to the cited country), estimation procedure is Poisson pseudo-likelihood with clustered standard errors (at country-pair level); immigration policy of the cited country remains significant for 9 years, while policy of the citing country loses significance after 2 years; the full table listing lags from 1 to 10 years can be found in Table A.5 in the Appendix.

One specific variable that could influence the magnitude of knowledge flows is presence of skilled migrant networks. The literature cited in Section 2 shows that research networks play an important role in the diffusion of knowledge. If personal, face-to-face contact was not an important part of knowledge diffusion, then a larger research community abroad could mitigate the effects of a more strict immigration policy in the cited country. By combining information on the bilateral stocks of

high-skilled migrants from Brücker et al. (2013),[19] it's possible to examine any possible interactions between the size of the bilateral skilled migrant stock and immigration policy towards skilled workers and students. By design, less strict immigration policy towards high-skilled migrants should result in larger inflows of skilled migrants, which can also be seen in Figure 4.

Figure 4: Relative change in the stock of immigrants and administrative barriers for the highly-skilled workers over 1990–2010.



Source: own calculations based on data from Brücker et al. (2013) and DEMIG POLICY. Note: the vertical axis shows the average annual change in the number of high-skilled immigrants (from all destinations in the database); the horizontal axis shows the increase in the value of an index of administrative barriers for the skilled workers from 1990 to 2010.

Table 7 shows that including information on bilateral stocks of high-skilled migrants only marginally moderates the relative importance of administrative barriers in the cited country and slightly increases the coefficient on the barriers in the citing country. This result suggests that while bilateral skilled migrant networks aid in facilitating knowledge flows, immigration policy does play an important role for the direction and magnitude of knowledge flows, especially recent knowledge which may require personal, face-to-face contact.

Another way to test the relevance of immigration policy changes is to do a 'placebo test' by including future values of the policy in the estimated equation. Table 8 shows that future policy variables do not have an effect on the bilateral citations.

The evidence from the robustness checks is generally supportive of the impact of administrative barriers on the knowledge flows. The role of administrative barriers is shown to be larger for flows of more recent knowledge. Immigration

[19]The values of bilateral stocks in year 2005 are used in the regressions.

Table 7: The role of bilateral high-skilled migrant networks.

	Aggregate citations per year		
Stock of papers in the cited country	107.487 (5.789)***	106.118 (5.786)***	105.061 (5.237)***
New papers in the citing country	108.135 (5.914)***	107.446 (5.997)***	107.301 (5.635)***
Openness for high-skilled and students, cited country	2.423 (1.143)**	2.430 (1.174)**	2.370 (1.198)**
Openness for high-skilled and students, citing country	2.229 (0.874)**	2.307 (0.889)***	2.584 (0.830)***
Common language		11.425 (3.869)***	6.926 (3.533)**
Common border		7.271 (2.733)***	7.194 (2.159)***
Physical distance, log		-9.718 (3.140)***	-6.292 (2.452)**
Regional trade agreement		13.458 (4.922)***	15.594 (4.202)***
Bilateral stock of high-skilled migrants, log			7.392 (1.346)***
N	17,393	17,393	17,393
Cited country dummies	Yes	Yes	Yes
Citing country dummies	Yes	Yes	Yes
Citing-cited country-pair dummies	Yes	No	No
Year dummies	Yes	Yes	Yes
High-skilled openness x migrant stock interaction	No	No	Yes

* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$

Source: own calculations based on Web of Science data. Note: this table shows the marginal effects; the dependent variable is the aggregate citation count from the citing to the cited countries; estimation procedure is Poisson with standard errors clustered by country-pair.

Table 8: A placebo test using leading changes in the immigration policy.

	Count of citations from citing to cited Impact of policy N years in the future			
	1	2	3	5
Leading openness for high-skilled and students, cited country	0.013 (0.011)	0.014 (0.013)	0.014 (0.013)	0.007 (0.014)
Leading openness for high-skilled and students, citing country	0.006 (0.008)	0.010 (0.009)	0.010 (0.011)	0.009 (0.012)
Number of observations	31192	29435	27756	24165
Log pseudolikelihood	-64727	-58990	-53486	-43396

Source: own calculations based on Web of Science data. Note: the dependent variable is the aggregate citation count per year (from the citing to the cited country), estimation procedure is Poisson pseudo-likelihood with clustered standard errors (at country-pair level); the full table listing leading values from 1 to 10 years can be found in Table A.6 in Appendix A.

policy continues to matter if the bilateral stocks of high-skilled migrants on the migration flows are added as a control. A 'placebo test' using leading values of the policy suggests that future policy changes have no effect on current knowledge flows, which provides supportive evidence of the direction of causality from the administrative barriers to the knowledge flows.

6 Discussion and conclusion

The results obtained using three independent sources of data (Web of Science, IATA, DEMIG POLICY) suggest that administrative barriers to mobility have a negative effect on bilateral knowledge flows. Estimations using information on country-specific immigration policy show that the negative effect of stricter policy towards skilled workers and students can be persistent, affecting knowledge flows from a country with a maximum lag of about 9 years. Moreover, the policy has larger influence on flows of recent knowledge (citations to papers less than N years old, with $N = 1$ showing the strongest influence), supporting the hypothesis that administrative barriers to mobility may be limiting the international flow of recent knowledge via personal, face-to-face contacts. This is further supported by the asymmetry of the persistent effect — past administrative barriers in the knowledge-exporting country, rather than the knowledge-importing country, have a persistent influence on current knowledge flows.

The effects on knowledge flows might appear relatively innocuous in the short-term, yet they are likely to have an important long-term effect by changing the productivity and innovations in the industry.[20]

This leads to interesting policy implications for countries that are interested in catching up to the current technological frontier, which will require greater amount of knowledge 'imports' — by making their immigration policy towards the high-skilled and students less restrictive, such countries can increase bilateral knowledge 'imports' from other countries and at the same time increase 'exports' of their own knowledge to other countries. Greater academic mobility has a positive effect on the magnitude of both incoming and outgoing international knowledge flows. Hence, an increase in immigration openness of the technologically-advanced countries does not necessarily indicate a 'brain drain', but a 'brain circulation', at least in the medium-term perspective. Furthermore, the policy makers might want to consider the link between administrative barriers and knowledge flows

[20]This claim might be too strong given that knowledge flows in this paper were calculated for citations among economists. As long as the pattern of knowledge flows in Economics is representative of the flows in other areas of science, especially those more directly applicable to engineering and manufacturing, then we would expect spillovers from academic research into productivity (Jaffe 1989).

when formulating immigration and development policies.

The results are robust to different specifications, and confirmed by using different, independent measures of the administrative barriers to mobility. While causality is notoriously difficult to infer in non-experimental data, the placebo test based on the leading values of the immigration policy provides evidence supporting the causal effect of the administrative barriers on the magnitude of knowledge flows.

One limitation of this study is that by focusing on the aggregate flows, there is no distinction between quality of the cited and citing articles. It might be expected, for example, that publications of more importance will diffuse more rapidly and farther, despite any administrative barriers to the mobility of the authors. One possible way to examine the effect of visas and immigration policy is to look at the publication-level data to see how an individual paper is cited. This micro-level approach will allow introducing additional controls at the paper-level (e.g. Iaria and Waldinger 2015; Head et al. 2015).

Another limitation is that the information on the administrative barriers was either a single country-panel or a country-pair cross-section. Once the data on the administrative barriers at country-pair panel-level becomes available, it would be interesting to check how the international knowledge flows respond to shocks in 'paper walls'.

In conclusion, the main contribution of this paper is to show that the administrative barriers to mobility ('paper walls') can have a large and persistent effect on the direction and magnitude of the international knowledge flows. The evidence obtained from the paper trails left by knowledge flows suggests that, though weightless, knowledge flows can be deflected by the 'paper walls'. This has important policy implications, especially for countries that are catching up in terms of technological and scientific development. By having a more open immigration policy towards the skilled workers and students, a country is likely to experience not a 'brain gain', but 'brain circulation'. As the researcher mobility increases, the knowledge flows increase in both directions.

References

Abramitzky, Ran and Isabelle Sin (2014). "Book translation as idea flows: the effects of the collapse of communism on the diffusion of knowledge". In: *Journal of the European Economic Association* 12.6, pp. 1453–1520.

Ackers, Louise (2005). "Moving People and Knowledge: Scientific Mobility in the European Union". In: *International Migration* 43.5, pp. 99–131.

Agrawal, Ajay, Alberto Galasso, and Alexander Oettl (2014). "Roads and innovation". In: *Rotman School of Management Working Paper* 2478752.

Agrawal, Ajay and Avi Goldfarb (2008). "Restructuring Research: Communication Costs and the Democratization of University Innovation". In: *American Economic Review* 98.4, pp. 1578–90.

Appelt, Silvia, Brigitte van Beuzekom, Fernando Galindo-Rueda, and Roberto de Pinho (2015). "Which factors influence the international mobility of research scientists?" In: *Global Mobility of Research Scientists: The Economics of Who Goes Where and Why*, pp. 177–214.

Azoulay, Pierre, Joshua S. Graff Zivin, and Bhaven N. Sampat (2012). "The Rate and Direction of Inventive Activity Revisited". In: chap. The Diffusion of Scientific Knowledge across Time and Space, p. 107.

Borjas, George J and Kirk B Doran (2012). "The collapse of the Soviet Union and the productivity of American Mathematicians". In: *The Quarterly Journal of Economics* 1143, p. 1203.

Boudreau, Kevin, Ina Ganguli Prokopovych, Patrick Gaule, Eva Catharina Guinan, and Karim R Lakhani (2012). "Colocation and scientific collaboration: evidence from a field experiment". In:

Brücker, Herbert, Stella Capuano, and Abdeslam Marfouk (2013). "Education, gender and international migration: insights from a panel-dataset 1980-2010". mimeo.

Catalini, Christian (2015). "Microgeography and the direction of inventive activity". In: *Rotman School of Management Working Paper* 2126890.

Czaika, Mathias and Hein de Haas (2016). "The effect of visas on migration processes". In: *International Migration Review*.

Dajud, Camilo Umana (2014). "Do visas hinder international trade in goods?" mimeo.

De Simone, Gianfranco and Miriam Manchin (2012). "Outward Migration and Inward FDI: Factor Mobility between Eastern and Western Europe". In: *Review of International Economics* 20.3, pp. 600–615.

DEMIG (2015). "DEMIG POLICY, version 1.3, Online Edition". International Migration Institute, University of Oxford.

Drivas, Kyriakos and Claire Economidou (2015). "Is geographic nearness important for trading ideas? Evidence from the US". In: *The Journal of Technology Transfer* 40.4, pp. 629–662.

Düppe, Till (2016). "Koopmans in the Soviet Union: a travel report of the summer of 1965". In: *Journal of the History of Economic Thought* 38.1, pp. 81–104.

Franzoni, Chiara, Giuseppe Scellato, and Paula Stephan (2012). "Foreign-born scientists: mobility patterns for 16 countries". In: *Nature Biotechnology* 30.12, pp. 1250–1253.

Garrett, Bradley (2015). *Why I'm resisting the Conservative's war on foreign intellectuals in Britain*. The Conversation.

Guth, Jessica and Bryony Gill (2008). "Motivations in East–West doctoral mobility: Revisiting the question of brain drain". In: *Journal of Ethnic and Migration Studies* 34.5, pp. 825–841.

Head, Keith, Yao Amber Li, and Asier Minondo (2015). *Geography, Ties, and Knowledge Flows: Evidence from Citations in Mathematics*. Tech. rep. HKUST Institute for Emerging Market Studies.

Iaria, Alessandro and Fabian Waldinger (2015). "International Knowledge Flows: Evidence from the Collapse of International Science in the Wake of WWI". Mimeo.

Jaffe, Adam B (1989). "Real effects of academic research". In: *The American Economic Review*, pp. 957–970.

Jaffe, Adam B, Manuel Trajtenberg, and Rebecca Henderson (1993). "Geographic localization of knowledge spillovers as evidenced by patent citations." In: *Quarterly Journal of Economics* 108.3, p. 577.

Jonkers, Koen and Laura Cruz-Castro (2013). "Research upon return: The effect of international mobility on scientific ties, production and impact". In: *Research Policy* 42.8, pp. 1366–1377.

Jöns, Heike (2009). "'Brain circulation' and transnational knowledge networks: studying long-term effects of academic mobility to Germany, 1954–2000". In: *Global Networks* 9.3, pp. 315–338.

Kahn, Shulamit and Megan MacGarvie (2014). "Do Return Requirements Increase International Knowledge Diffusion? Evidence from the Fulbright Program". In:

Kõu, Anu and Ajay Bailey (2014). "'Movement is a constant feature in my life': Contextualising migration processes of highly skilled Indians". In: *Geoforum* 52, pp. 113–122.

Lawson, Robert A. and Jayme S. Lemke (2011). "Travel visas". In: *Public Choice* 153.1, pp. 17–36.

Luedtke, Adam, Douglas G. Byrd, and Kristian P. Alexander (2010). "The Politics of Visas". In: *The Whitehead Journal of Diplomacy and International Relations* 11, p. 147.

MacGarvie, Megan (2005). "The determinants of international knowledge diffusion as measured by patent citations". In: *Economics Letters* 87.1, pp. 121–126.

Maddox, Brenda (2003). *Rosalind Franklin: The dark lady of DNA*. New Ed edition. HarperCollins.

Mavroudi, Elizabeth and Adam Warren (2013). "Highly skilled migration and the negotiation of immigration policy: Non-EEA postgraduate students and aca-

demic staff at English universities". In: *Geoforum* 44. Global Production Networks, Labour and Development, pp. 261–270.

Mayer, Thierry and Soledad Zignago (2011). *Notes on CEPII's distances measures: The GeoDist database*. Tech. rep. Working paper 2011-25.

McKenzie, David J (2005). "Paper walls are easier to tear down: Passport costs and legal barriers to emigration". In: *World Bank Policy Research Working Paper* 3783.

Neumayer, Eric (2006). "Unequal Access to Foreign Spaces: How States Use Visa Restrictions to Regulate Mobility in a Globalized World". In: *Transactions of the Institute of British Geographers* 31.1, pp. 72–84.

Neumayer, Eric (2010). "Visa restrictions and bilateral travel". In: *The professional geographer* 62.2, pp. 171–181.

Neumayer, Eric (2011). "On the detrimental impact of visa restrictions on bilateral trade and foreign direct investment". In: *Applied geography* 31.3, pp. 901–907.

Ng, Eric C. Y. and John Whalley (2008). "Visas and work permits: Possible global negotiating initiatives". In: *The Review of International Organizations* 3.3, pp. 259–285.

Peri, Giovanni (2005). "Determinants of knowledge flows and their effect on innovation". In: *Review of Economics and Statistics* 87.2, pp. 308–322.

Rauch, James E (2001). "Business and social networks in international trade". In: *Journal of economic literature*, pp. 1177–1203.

Saxenian, AnnaLee (2005). "From brain drain to brain circulation: Transnational communities and regional upgrading in India and China". In: *Studies in comparative international development* 40.2, pp. 35–61.

Times Higher Education (2014). *Non-EU scholars struggling with the UK's visa policy.*

Times Higher Education (2015). *Miwa Hirono: my Home Office hell.*

Trippl, Michaela (2013). "Scientific mobility and knowledge transfer at the interregional and intraregional level". In: *Regional Studies* 47.10, pp. 1653–1667.

Wang, Dan (2015). "Activating Cross-border Brokerage: Interorganizational Knowledge Transfer through Skilled Return Migration." In: *Administrative Science Quarterly* 60.1, pp. 133–176.

A Appendix: Additional tables

Table A.1: The effect of immigration policy on knowledge flows.

	Bilateral citations from citing to cited		
Stock of papers in the cited country	0.803	0.817	0.845
	(0.034)***	(0.046)***	(0.045)***
New papers in the citing country	0.939	0.910	0.925
	(0.031)***	(0.056)***	(0.048)***
Openness for high-skilled and students, cited country	0.029	0.030	
	(0.010)***	(0.011)***	
Openness for high-skilled and students, citing country	0.020	0.019	
	(0.006)***	(0.006)***	
Colonial link in the past		-0.205	-0.200
		(0.117)*	(0.117)*
Common language		0.071	0.074
		(0.034)**	(0.034)**
Common border		0.022	0.024
		(0.024)	(0.024)
Physical distance, log		-0.155	-0.154
		(0.014)***	(0.014)***
N	34,742	33,825	33,825
Cited country dummies	Yes	Yes	Yes
Citing country dummies	Yes	Yes	Yes
Citing-cited country-pair dummies	Yes	No	No
Year dummies	Yes	Yes	Yes

* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$

Source: own calculations based on Web of Science data. Note: the dependent variable is the aggregate count of citations per year from the citing to the cited country; estimation procedure is Poisson with standard errors clustered by country-pair; the results are qualitatively similar if the United States is dropped from the sample.

Table A.2: The effect of migration openness on knowledge flows, including policy towards low-skilled workers.

	Aggregate citations per year		
Stock of papers in the cited country	0.828	0.843	0.840
	(0.034)***	(0.045)***	(0.041)***
New papers in the citing country	0.944	0.913	0.920
	(0.031)***	(0.053)***	(0.045)***
Openness for low-skilled, cited country	-0.073	-0.087	
	(0.018)***	(0.021)***	
Openness for low-skilled, citing country	-0.018	-0.025	
	(0.016)	(0.014)*	
Openness for high-skilled and students, cited country	0.039	0.042	
	(0.010)***	(0.012)***	
Openness for high-skilled and students, citing country	0.023	0.023	
	(0.006)***	(0.007)***	
Colonial link in the past		-0.232	-0.225
		(0.084)***	(0.086)***
Common language		0.052	0.054
		(0.029)*	(0.029)*
Common border		0.028	0.029
		(0.019)	(0.019)
Physical distance, log		-0.060	-0.060
		(0.023)***	(0.023)***
Bilateral migrant stock, log		0.052	0.052
		(0.010)***	(0.010)***
Regional trade agreement		0.152	0.149
		(0.043)***	(0.044)***
Pseudo R2	0.99	0.99	0.99
N	34,742	33,825	33,825
Cited country dummies	Yes	Yes	Yes
Citing country dummies	Yes	Yes	Yes
Citing-cited country-pair dummies	Yes	No	No
Year dummies	Yes	Yes	Yes

* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$

Source: own calculations based on Web of Science data. Note: the dependent variable is the bilateral citation count between countries, estimation procedure is Poisson with clustered standard errors (by country-pair).

Table A.3: The effect of immigration policy on (log) knowledge flows.

	Bilateral citations from citing to cited (log)		
Stock of papers in the cited country	0.389	0.367	0.391
	(0.035)***	(0.036)***	(0.037)***
New papers in the citing country	0.591	0.595	0.604
	(0.032)***	(0.034)***	(0.035)***
Openness for high-skilled and students, cited country	0.138	0.135	
	(0.012)***	(0.012)***	
Openness for high-skilled and students, citing country	0.086	0.071	
	(0.011)***	(0.011)***	
Colonial link in the past		-0.004	0.004
		(0.108)	(0.103)
Common language		0.188	0.183
		(0.049)***	(0.048)***
Common border		0.147	0.141
		(0.047)***	(0.047)***
Physical distance, log		-0.211	-0.213
		(0.021)***	(0.021)***
Adj. R2	0.92	0.90	0.90
N	20,715	19,911	19,911
Cited country dummies	Yes	Yes	Yes
Citing country dummies	Yes	Yes	Yes
Citing-cited country-pair dummies	Yes	No	No
Year dummies	Yes	Yes	Yes

* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$

Source: own calculations based on Web of Science data. Note: the dependent variable is the logarithm of aggregate count of citations per year from the citing to the cited country; estimation procedure is OLS with standard errors clustered by country-pair; the results are qualitatively similar if the United States is dropped from the sample.

Table A.4: The diffusion of recent knowledge and the role of immigration policy.

	Count of citations from citing to cited within the first N years										
	All years	1	2	3	4	5	6	7	8	9	10
Openness for high-skilled and students, cited country	1.846	0.370	0.723	1.022	1.292	1.597	1.802	1.926	1.980	1.980	1.926
	(0.746)**	(0.048)***	(0.099)***	(0.164)***	(0.245)***	(0.323)***	(0.396)***	(0.472)***	(0.527)***	(0.571)***	(0.600)***
Openness for high-skilled and students, citing country	1.286	0.092	0.222	0.336	0.523	0.694	0.843	0.927	1.025	1.072	1.106
	(0.455)***	(0.054)*	(0.089)**	(0.158)**	(0.211)**	(0.259)***	(0.288)***	(0.313)***	(0.339)***	(0.357)***	(0.376)***
Mean of the dependent variable	72.96	5.79	12.29	19.82	27.36	34.23	40.22	45.64	50.27	54.15	57.44
Relative marginal effect (cited)	0.03	0.06	0.06	0.05	0.05	0.05	0.04	0.04	0.04	0.04	0.03
Relative marginal effect (citing)	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Number of observations	32829	29508	31092	31670	31944	32207	32495	32558	32622	32704	32725
Log pseudolikelihood	-70902	-31443	-41999	-49666	-54962	-58872	-61741	-63786	-65465	-66572	-67457
Cited-citing country-pair dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$

Source: own calculations based on Web of Science data. Note: the dependent variable is the aggregate citation count per year (from the citing to the cited country), estimation procedure is Poisson pseudo-maximum likelihood with standard errors clustered by country-pair.

Table A.5: The persistence of changes in the immigration policy.

	Count of citations from citing to cited Impact of policy implemented N years ago										
	0	1	2	3	4	5	6	7	8	9	10
Stock of papers in the cited country	0.821	0.821	0.822	0.823	0.824	0.825	0.827	0.830	0.832	0.830	0.831
	(0.040)***	(0.040)***	(0.040)***	(0.040)***	(0.040)***	(0.040)***	(0.041)***	(0.042)***	(0.042)***	(0.043)***	(0.044)***
New papers in the citing country	0.909	0.909	0.909	0.910	0.909	0.907	0.909	0.908	0.906	0.901	0.899
	(0.049)***	(0.049)***	(0.049)***	(0.048)***	(0.047)***	(0.047)***	(0.046)***	(0.046)***	(0.047)***	(0.047)***	(0.047)***
Openness for high-skilled and students, cited country	0.025	0.013	0.016	0.017	0.019	0.023	0.026	0.030	0.031	0.030	0.027
	(0.010)**	(0.011)	(0.011)	(0.011)	(0.010)*	(0.010)**	(0.010)***	(0.010)***	(0.010)***	(0.010)***	(0.010)***
Openness for high-skilled and students, citing country	0.018	0.010	0.017	0.016	0.017	0.018	0.018	0.018	0.018	0.017	0.016
	(0.006)***	(0.007)	(0.006)***	(0.006)***	(0.006)***	(0.006)***	(0.006)***	(0.007)***	(0.007)***	(0.007)**	(0.006)**
Lagged openness for high-skilled and students, cited country		0.015	0.014	0.015	0.020	0.021	0.028	0.034	0.032	0.023	0.012
		(0.004)***	(0.005)***	(0.006)**	(0.007)***	(0.009)**	(0.009)***	(0.010)***	(0.009)***	(0.009)***	(0.009)
Lagged openness for high-skilled and students, citing country		0.009	0.001	0.002	0.001	-0.002	0.004	0.004	0.004	-0.005	-0.009
		(0.005)*	(0.007)	(0.009)	(0.009)	(0.009)	(0.009)	(0.009)	(0.008)	(0.009)	(0.010)
Number of observations	32829	15144	15144	15144	15144	15144	15144	15144	15144	15144	15144
Log pseudolikelihood	-70902	-23288	-23288	-23288	-23288	-23288	-23288	-23288	-23288	-23288	-23288

* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$

Source: own calculations based on Web of Science data. Note: the dependent variable is the aggregate citation count per year (from the citing to the cited country), estimation procedure is Poisson pseudo-likelihood with clustered standard errors (at country-pair level).

Table A.6: A placebo test using leading changes in the immigration policy.

	Count of citations from citing to cited Impact of policy implemented in N years in the future										
	0	1	2	3	4	5	6	7	8	9	10
Stock of papers in the cited country	0.821	0.808	0.795	0.791	0.788	0.801	0.829	0.871	0.862	0.879	0.909
	(0.040)***	(0.041)***	(0.041)***	(0.041)***	(0.043)***	(0.043)***	(0.047)***	(0.048)***	(0.051)***	(0.057)***	(0.063)***
New papers in the citing country	0.909	0.894	0.875	0.872	0.864	0.861	0.882	0.909	0.912	0.934	0.942
	(0.049)***	(0.050)***	(0.049)***	(0.051)***	(0.054)***	(0.054)***	(0.054)***	(0.050)***	(0.048)***	(0.051)***	(0.055)***
Openness for high-skilled and students, cited country	0.025	0.010	0.007	0.009	0.013	0.013	0.022	0.036	0.046	0.039	0.038
	(0.010)**	(0.005)*	(0.006)	(0.006)	(0.008)	(0.011)	(0.014)	(0.016)**	(0.014)***	(0.014)***	(0.012)***
Openness for high-skilled and students, citing country	0.018	0.011	0.008	0.006	0.008	0.009	0.014	0.031	0.038	0.038	0.038
	(0.006)***	(0.005)**	(0.007)	(0.008)	(0.006)	(0.007)	(0.008)*	(0.013)**	(0.015)***	(0.016)**	(0.016)**
Leading openness for high-skilled and students, cited country		0.013	0.014	0.014	0.009	0.007	0.004	0.004	0.008	0.005	0.009
		(0.011)	(0.013)	(0.013)	(0.013)	(0.014)	(0.015)	(0.015)	(0.015)	(0.019)	(0.022)
Leading openness for high-skilled and students, citing country		0.006	0.010	0.010	0.010	0.009	0.000	0.004	0.002	0.003	-0.001
		(0.008)	(0.009)	(0.011)	(0.012)	(0.012)	(0.013)	(0.012)	(0.014)	(0.011)	(0.010)
Number of observations	32829	31192	29435	27756	25977	24165	22435	20572	18788	16922	15144
Log pseudolikelihood	-70902	-64727	-58990	-53486	-48285	-43396	-38733	-34309	-30307	-26715	-23288

* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$

Source: own calculations based on Web of Science data. Note: the dependent variable is the aggregate citation count per year (from the citing to the cited country), estimation procedure is Poisson pseudo-likelihood with clustered standard errors (at country-pair level).