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The Globalisation of Scientific Mobility, 1970-2014

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Abstract

This article provides an empirical assessment of global scientific mobility over the past four decades. Based on bibliometric data we find (i) an increasing diversity of origin and destination countries integrated in global scientific mobility, with (ii) the centre of gravity of scientific knowledge production and migration destinations moving continuously eastwards by about 1300 km per decade, (iii) an increase in average migration distances of scientists reflecting integration of global peripheries into the global science system, (iv) significantly lower mobility frictions for internationally mobile scientists compared to non-scientist migrants, (v) with visa restrictions establishing a statistically significant barrier affecting international mobility of scientists hampering the global diffusion of scientific knowledge.

Keywords: *Migration of Scientists, global migration patterns, migration barriers, visa restrictions*
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Introduction

International mobility is a key feature of careers in science and may contribute to the creation and international diffusion of scientific knowledge, which is hoped to benefit scientifically-advanced and catching-up societies alike. There is, however, a lack of sound empirical evidence to underpin such claims. From a theoretical point of view, it is far from certain that the international mobility of scientists leads to greater global scientific equality. While mobile researchers may gain individually by increasing their scientific productivity and expanding their professional networks – for instance through international conference attendance, visiting fellowships, undertaking PhDs and post-doctoral fellowship abroad, or even temporary or permanent migration for academic employment - it cannot be taken for granted that each national scientific system benefits equally from this scientific mobility. In fact, we can hypothesise that under certain circumstances an academic ‘brain drain’ will reinforce global scientific inequalities by draining developing countries of their scientific talent, thus undermining their future scientific capacity. Consequently, while globalisation may create new scientific opportunities and better access to scientific knowledge by making it easier for scholars to work anywhere, in many respects, mobility of scientists may also reinforce existing scientific inequalities and potentially erect new barriers to the diffusion of knowledge (Altbach 2004).

This raises fundamental questions about the extent to which scientific knowledge production and collaboration disseminate universally and lead to convergence between national science systems. This study enhances our understanding of the patterns and dynamics of academic mobility in global scientific knowledge production and dissemination processes over the last four decades.

The modern-day world of science is hierarchical and research universities in highly developed, mostly Western, countries are still at the top of the international knowledge system (Altbach 2004, Shils 1972, Czaika and Toma, 2017). It is often assumed that a globalisation of science facilitates increasing dissemination and improved access to scientific knowledge; however, the bulk of global scientific knowledge production – of about three million scientific publications per year – is still concentrated in a few hundred major universities and research institutions in these countries, which produce the lion's share of global scientific output (Royal Society 2011).

It is unclear how international scientific mobility has affected such inequalities over the past four decades. Some argue that the growing interconnectivity through developments in communication and transport technologies have made physical mobility less important and thus global access to scientific opportunities and knowledge more egalitarian, akin to more general arguments that globalisation processes have 'flattened' the world by making global opportunity structures more equal (Friedman 2005). Other scholars have argued that the globalisation of science is a highly asymmetrical process that furthers the concentration of scientific activity in particular countries and institutions (Horlings and Van Den Besselaar 2013). For instance, while international research collaborations appear to be highly concentrated within various global scientific hubs with vast disparities across wider and more peripheral world regions (Horlings and Van Den Besselaar 2013, Leydesdorff et al 2013), an increasing number of research institutions in some emerging Asian and Latin American economies are gradually expanding their scientific capacities to world class standards, which is often seen as evidence of a scientific catching up process (OECD 2008, Freeman 2006). However, these developments seem to shift global scientific imbalances only at the margin, and the question whether diffusion of scientific knowledge from global scientific hubs to peripheries is leading to a global scientific convergence remains open.

Overall, the links between increasing academic mobility, scientific collaboration and knowledge diffusion are theoretically and empirically under-explored. Academic mobility can be seen as an integral part of the global scientific system, in which the mobility of researchers is not only a driver of knowledge transfer, but also a consequence of inter-national and inter-institutional opportunity differentials for conducting high-level scientific research (Ackers 2005, King 2002, DTI 2002). The prestige and the scientific quality of an institution, or even a country, in a particular scientific discipline are seen as important pull factors, but social and professional networks have also been found to influence the mobility decisions of scientists (Williams et al 2004, Bauder 2015). Beyond professional motives, economic and non-economic factors, such as those related to individual life-cycles, seem to be influential in academics' mobility decisions (Stephan 2010, Oliver and Ackers 2005). The motivation to move, collaborate and exchange knowledge with other researchers is often linked to collegial affinity and intellectual complementarity to overcome cognitive, scientific and other resource limitations (Katz and Martin 1997). While the organisation of collaborative research seems to be largely driven by an autonomous process among individual researchers, the availability of information and communication technology (ICT) that facilitates long-distance collaboration does not seem to make 'physical mobility' superfluous in acting as a replacement, but instead makes such face-to-face contact even more important (Stichweh 1996). Despite increases in connectivity and bandwidth, physical co-location is still assumed to play a key role in the transfer and exchange of (tacit) knowledge through face-to-face interaction and informal communication (Stephan 2010, Katz and Martin 1997, Scellato et al 2015). Consequently, scientific mobility is both the result of international collaboration and a pre-condition for new collaborative ties, but to what extent and in which ways is rather unclear.

Drawing on bibliometric data from Elsevier's abstract and citation database of peer-reviewed literature, Scopus, we are able to construct scientific mobility data which covers research-active scientists globally since the 1970s. Every scientist is assigned a unique identifier, which can be combined with information on that scientist's affiliation to infer the international mobility of research-active scientists. An author who moves from an institution in one country to an institution in another country and keeps on publishing is hereby identified as a mobile scientist (Meho and Sugimoto 2009, Moed et al 2013, Moed and Halevi 2014). This method allows us to capture the intensity, direction, and diversification of global scientific movements. Finally, we provide some evidence on the role of mobility restrictions driving the pattern and dynamics of academic mobility. Migration policy variables have only recently been incorporated in quantitative tests on overall migration flows (Mayda 2010, Ortega and Peri 2013, Czaika and de Haas 2016), high-skilled migration (Czaika and Parsons 2017), international knowledge flows (Orazbayev 2017) and mobility of research scientists (Appelt et al 2015).

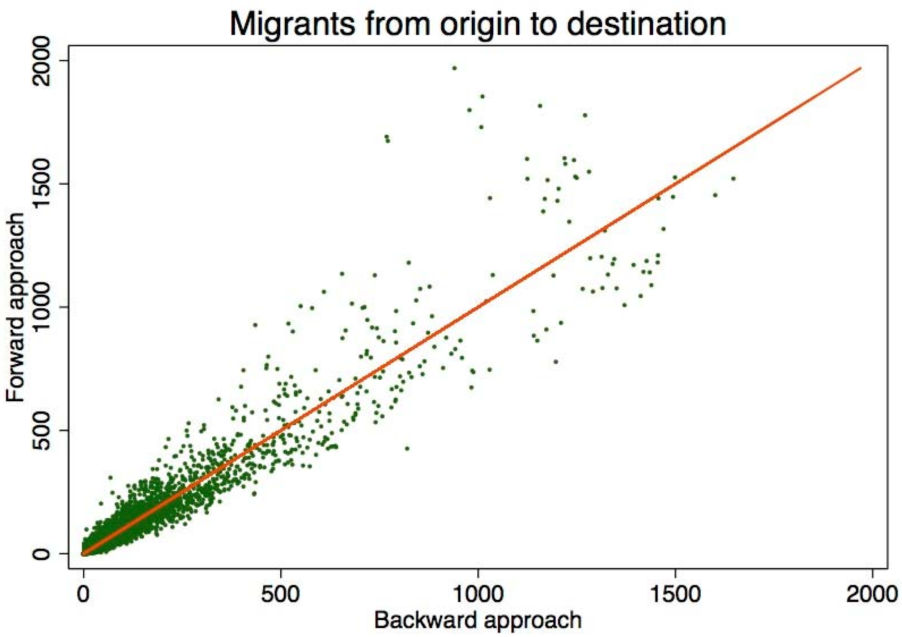
Data

The data on migration of scientists is constructed using the bibliometric information in Elsevier's Scopus database following a similar approach as Moed and Halevi (2014) and Appelt et al (2015). After extracting affiliation information of authors, based on the name disambiguation data provided by Scopus we can infer whether a person's country of affiliation has changed between different publications. There are several methodological considerations to be taken into account, and in constructing the migration data we follow, with some adjustments, the procedures outlined in Moed et al (2013) and Moed and Halevi (2014). Specifically, every author's country of affiliation in any given year is used to infer their place of residence in that year.[1]

Information on the author with single country affiliation in a given year was processed as follows: if information on the country of affiliation is missing for any given year, then this information is inferred based on past and future countries of affiliations using two approaches. The fill-forward approach assumes that the author did not change country of affiliation during the inactive years, i.e. during the years when there are no publications; the fill-backward approach assumes that the author changed the country of affiliation one year after the last known affiliation. Once the information on each author's country of affiliation in every year was obtained, the migration episodes were calculated whenever the author changed their country of affiliation. In contrast to Moed et al (2013), who use diachroneous and synchronous approaches to identify episodes of out- and in-migration, respectively, we count episodes of migration in a given year using information on all authors whose research activity includes this year, including the inferred location based on the fill-forward and fill-backward methods. Figure 1 indicates that both methods provide very similar and highly correlated estimates of scientific migrants.

[1] Note that this data might lag actual location due to the publishing lag.

Figure 1 *Comparison of migration flows calculated using forward and backward approaches*



Note that most of the authors have affiliations that allow unique identification of country of residence per year. However, a small share of the research-active authors report affiliations in multiple countries. The share of authors with affiliations in multiple countries varies over time, but is about 4% of the active authors in any given year. In such cases, migration events were calculated assuming that the multi-country authors move between the (multiple) countries of their affiliation. For example, if a researcher were affiliated with countries A and B in year 2000, but her publications in 2005 show affiliation with countries C and D, then there are four distinct migration events (A to C, A to D, B to C and B to D). The number of migration events calculated using this approach is highly correlated with the number of migrants that have single-country affiliation only. The Pearson correlation between the number of single-country migrants and the number of migrants that includes multi-country affiliations (i.e. authors with single- and multi-country affiliations are included) is 0.95, and the Spearman correlation is 0.79.

To examine the robustness of our measures we also count more restricted episodes of migration: migration episodes within the first two, three, and five years of the research careers are ignored, which is similar to the proxy for PhD students that is used by Moed et al (2013). The calculated aggregate measures are highly correlated, with pairwise Pearson correlation in the high .90s. As a further check, the aggregate flows were compared with the results from Appelt et al (2015), who use the same data, but calculate migration flows using information on the first and last publication for each author, hence ignoring intermediate migration events. Despite different approaches, our data is highly correlated with the results from Appelt et al (2015).

The number of documents in the Scopus database has increased rapidly since the 2000s, primarily driven by the increase in the number of research articles (see Figure 2), while the number of unique authors in the dataset has also increased significantly over time (see Figure 3).

Figure 2 *Growth in the number of documents in the Scopus database*

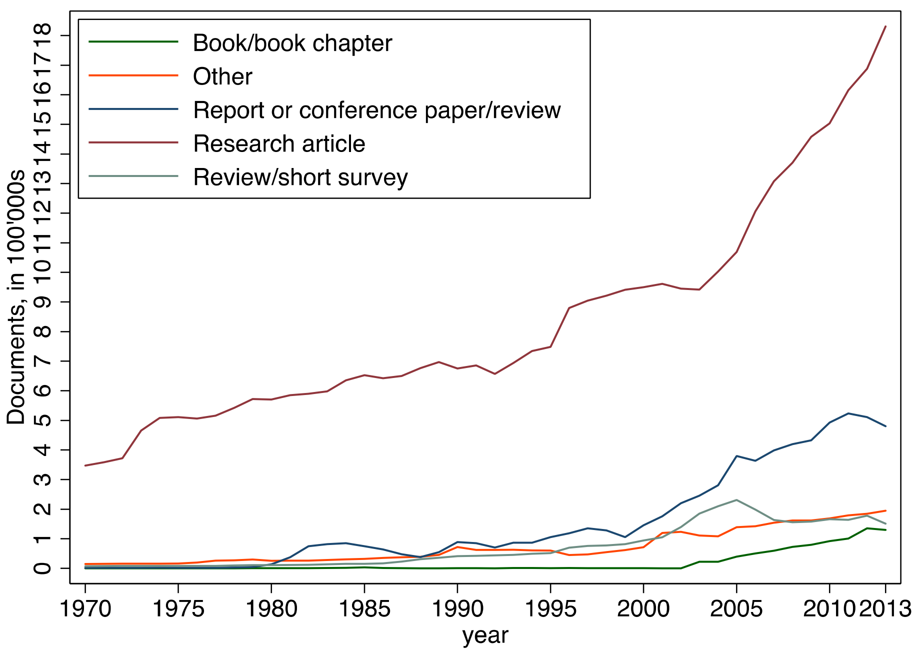
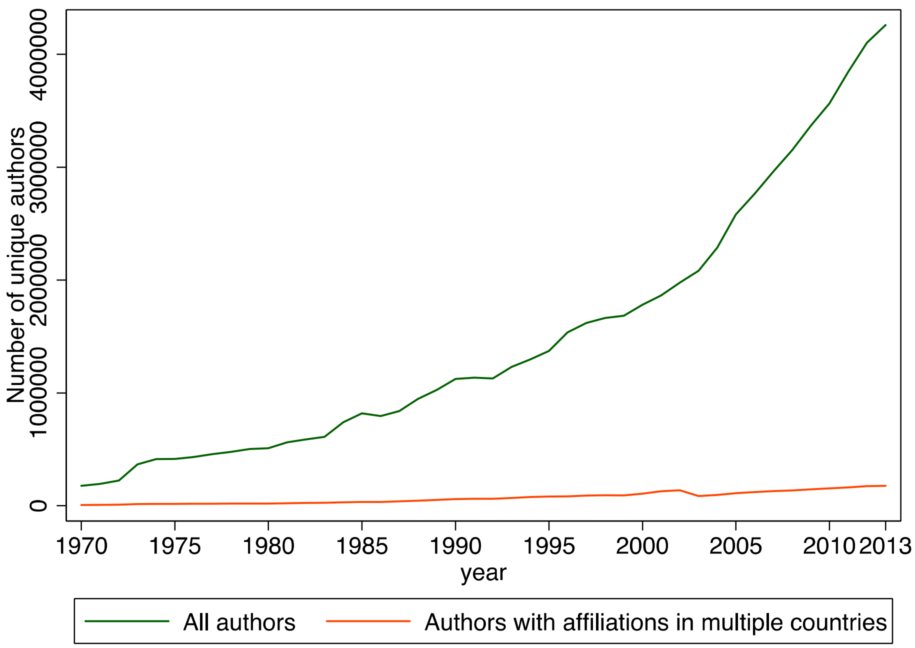


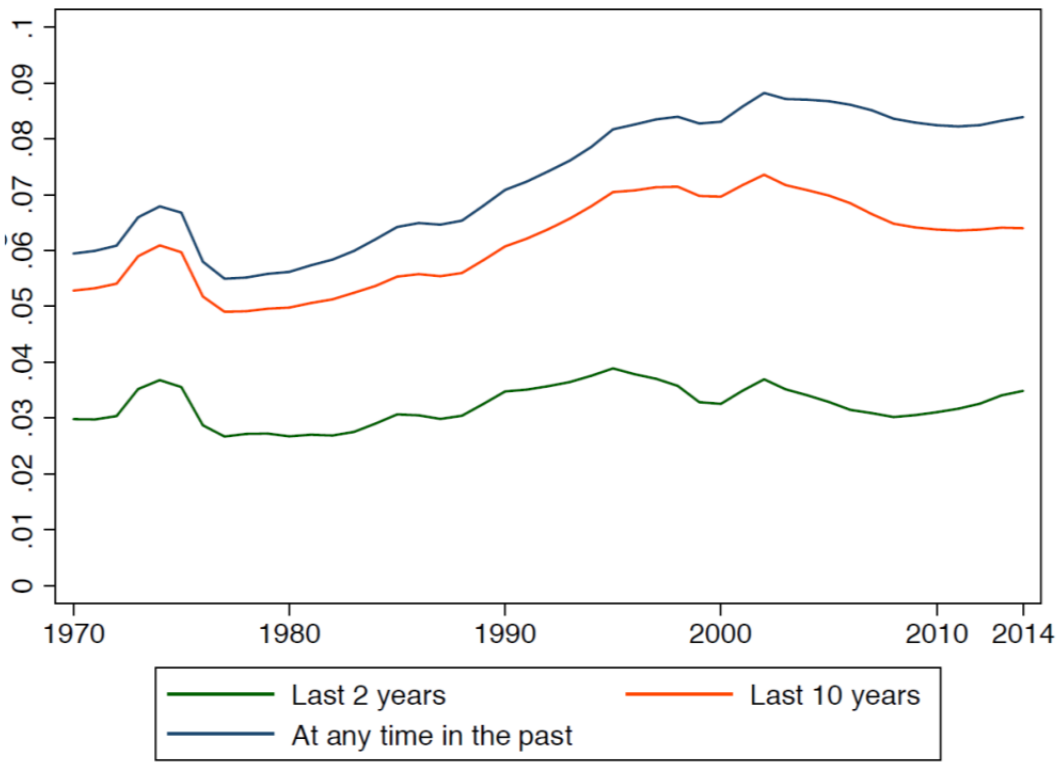
Figure 3 *Number of unique authors in the Scopus database*



Intensification of scientific mobility

Figure 4 reports the share of research-active scientists who have migrated internationally at (i) any time in the past or (ii) more recently within the last two or ten years. Despite some minor fluctuations over the last four decades, the share of those who migrated within the last two years has been remarkably stable, at around 3 per cent. Shares for those who migrated at any point or within the last decades have been increasing over the same time period and reached about 9 per cent in 2014. Consequently, at the global level, the migration share of scientists is about three times higher than that of non-scientist migrants, which has remained at roughly 3 per cent since the 1960s (Czaika and de Haas 2014).

Figure 4 *Share of scientists who changed country of affiliation within a given number of years.*



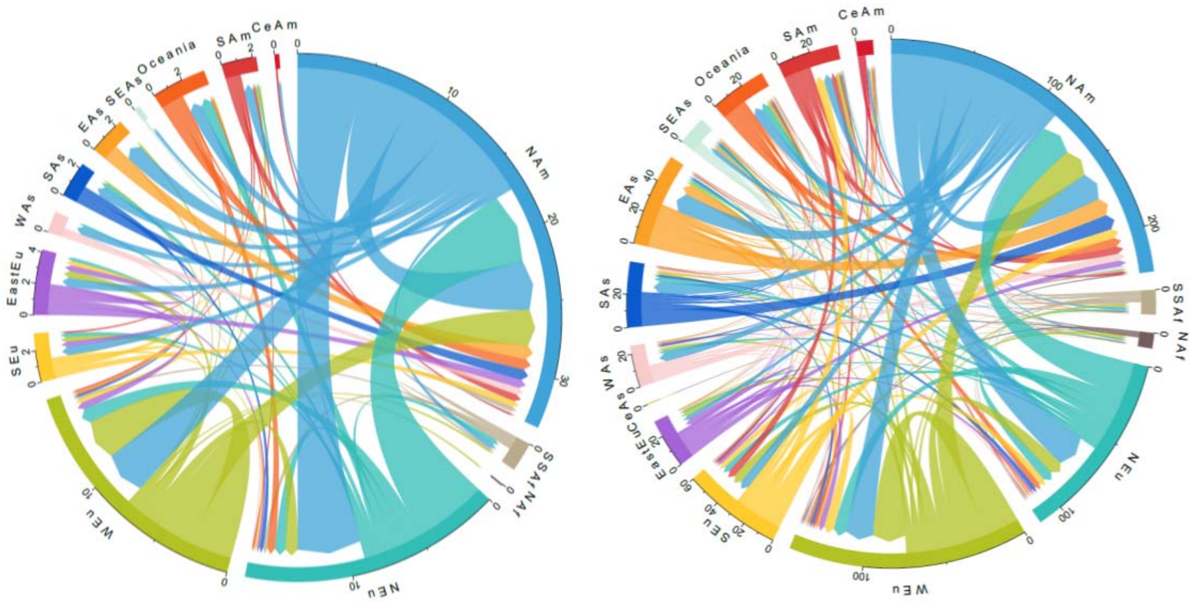
At the same time, while the share of research-active scientists that migrated has remained rather stable within a small range, the global annual number of internationally migrating scientists has increased by a factor of 22, from about 2,500 in 1970 to about 56,000 in 2014.[2]

Besides an overall increase in migration volume, major shifts in international flows of scientists over the last four decades have been directional. Figure 5 displays circle graphs of regional aggregates in inflows and outflows of research-active scientists during the 1970s and 2000s. In the 1970s, international flows of scientists were mostly directed towards North America (Nam), Northern Europe (NEu) and Western Europe (WEu). Those three regions hosted more than two-

[2] The 7.5-fold increase in the number of publications, from almost 400,000 in 1970 to nearly 3 million in 2014, can explain only part of the increase in the volume of migrant scientists.

thirds of all internationally mobile scientists (32,000 of the 44,000 scientists who migrated in the 1970s).

Figure 5 *Regional movements of scientists during 1970–1979 (left) and 2000–2014 (right)*



Note: *Figure shows regional inflows and outflows of mobile scientists in directions indicated by arrows; migration volumes are in units of 10,000 migrants over the ten-year period on the left diagram and 100,000 migrants over the fifteen-year period on the right diagram; Nam (North America), SSAf (Sub-Saharan Africa), NAf (North Africa), NEu (Northern Europe), WEu (Western Europe), SEu (Southern Europe), EastEu (Eastern Europe), WAs (Western Asia), SAs (South Asia), EAs (East Asia), SEAs (Southeast Asia), SAm (South America), CeAm (Central America). The diagrams were prepared based on Sander et al (2014).*

Interestingly, international flows within regional dyads and even within most country dyads are highly balanced so that these three world regions also established the major regions of origin. Analysis of major bilateral corridors in the 1970s shows that nine out of the top 10 corridors involved the United States (US) either as destination or origin country (see Table 1). This dominance of the US as a global academic powerhouse increased even further in the 2000s when all top ten bilateral flows either originated from (three) or were directed towards (seven) the US. However, the US has decreased its global share in inflows of research-active scientists over the last four decades, with about 23 per cent of all internationally mobile scientists directed towards the US in 2000s.

Table 1 *Top 10 bilateral migration corridors in 1970s (1971–1979) and 2000s (2000–2013)*

Origin	**Destination**	**1970s**	**2000s**	**Change in rank between 1970s and 2000s**
United Kingdom	United States	5277	39860	→
United States	United Kingdom	5051	37059	→
Canada	United States	2556	26441	↗
United States	Canada	3092	23382	↘
Germany	United States	1948	21064	↗
United States	Germany	2386	19294	↘
India	United States	882	16086	↗
China	United States	23	14910	↗
Japan	United States	1583	14379	↗
France	United States	964	13934	↗

The scientific world has certainly become more connected as formerly 'peripheral' countries and regions of the 'Global South' are now sending *and* receiving mobile scientists in significant numbers. This expansion of the global scientific playing field has been at the expense of the dominance of the three major regions, whose combined share of global inbound mobility numbers has decreased to just below 60 per cent in the 2000s (Figure 5, right). Regions such as Southern Europe and South America, formerly more peripheral, have gained in importance, but first and foremost East, Southeast and South Asia have multiplied their shares in global scientific mobility.

De-concentration of scientific mobility

Obviously, these global figures of internationally mobile scientists reflect broader trends and shifts in scientific activity and capacity of countries of origin *and* destination. In particular, this trend is not only driven by the two Asian economic powerhouses, China and India, but rather reflects a more general spatial expansion and diversification of the scientific landscape. Figure 3 displays measures of diversity of international scientific migration flows, and we find that from a global perspective, outbound and inbound flows of mobile scientists show decreasing levels of concentration.[3] The increasing spread of significant flows towards an increasing number of destination countries outside the 'traditional' global scientific core reflects growing professional *opportunities* for scientists in countries that are gradually catching up with scientific world leaders. At the same time, scientists from an increasing array of countries are becoming able to move internationally. Increasing transferability of credentials at post-graduate level, advancements in and growing standardisation of research training and skills, enables researchers from scientific peripheries to seek and occupy research and academic posts in an increasing number of destinations.

[3] Following Czaika and de Haas (2014), we differentiate between the spread of immigrant and emigrant populations at global and country levels. The global emigrant spread (e^{global}) measures the extent to which the total global population of mobile scientists is dispersed across destination countries, while the global immigrant spread (i^{global}) indicates the extent to which the global flow of mobile scientists comes from a diverse set of origin countries: $e_t^{global} = 1 - \sum_{o=1}^{O}(\frac{E_{ot}}{M_t})^2$ and $i_t^{global} = 1 - \sum_{d=1}^{D}(\frac{I_{dt}}{M_t})^2$. Respective measures weighted at country levels are calculated as follows: $e_t^{weighted} = \sum_{o=1}^{O}\left(1 - \sum_{d=1}^{D}\left(\frac{E_{odt}}{E_{ot}}\right)^2\right) * \frac{E_{ot}}{M_t}$ and $i_t^{weighted} = \sum_{d=1}^{D}\left(1 - \sum_{o=1}^{O}\left(\frac{I_{odt}}{I_{dt}}\right)^2\right) * \frac{I_{dt}}{M_t}$, with *E (I)* representing the number of emigrants (immigrants) from origin *o* to destination *d* at time *t*.

Figure 6 *Emigration and immigration spread at global and country level*

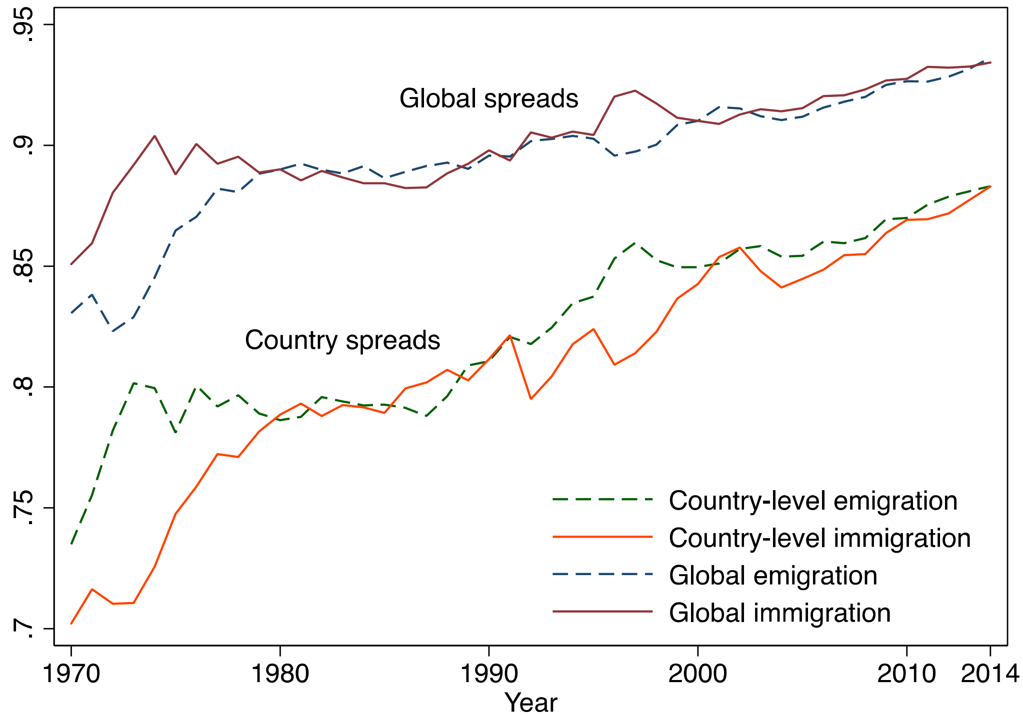
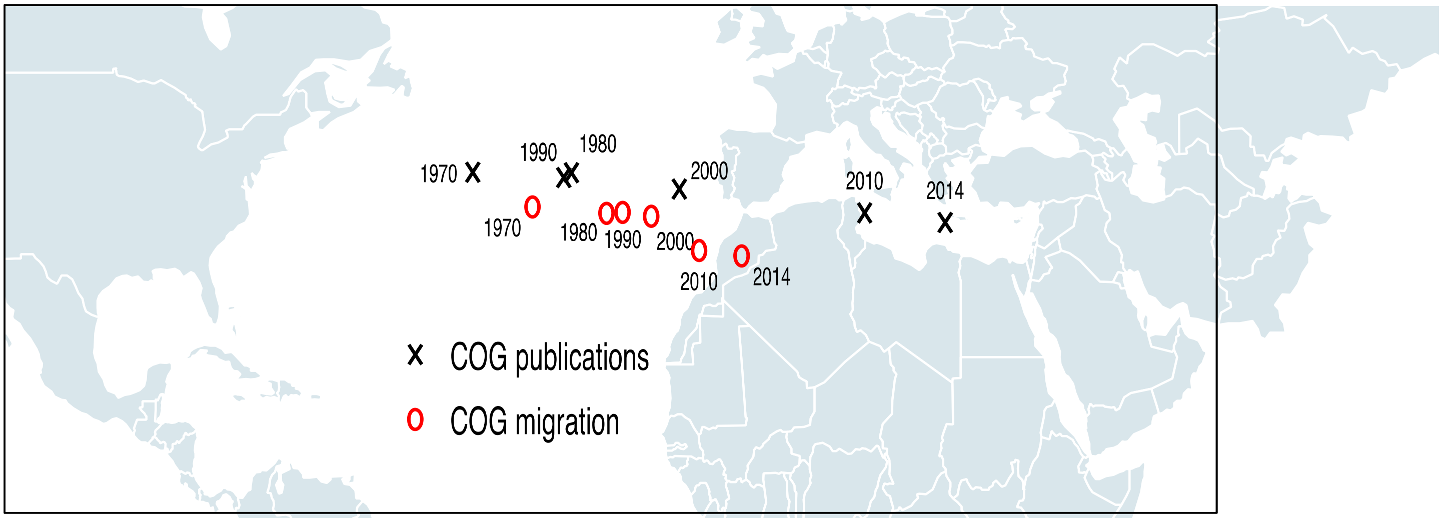


Figure 6 illustrates this trend of global scientific immigration and emigration flows in the steadily increasing level of diversification (spread) from around 0.85 in 1970 to about 0.93 in 2014 for both inflows and outflows. The same figure also shows that inbound and outbound flows, weighted at country level by the total country-specific number of research-active scientists, have become less concentrated. The lower, but equally increasing, diversification at country level suggests that country-specific inflows and outflows are on average less diversified than global flows. However, the degree of diversification of flows weighted at country level are converging towards the level of global diversification. This gradual diversification of origin and destination countries in the global scientific mobility system, both at country and global levels, corroborates the identified shifts in regional flows of mobile scientists over the past four decades

(Figure 5) with the emergence and establishment of numerous countries in the 'Global South' as new origins of and destinations for internationally mobile scientists.

Figure 7 *Global centres of gravity of scientific activity and migration destinations, 1970–2014*



Note: *COG = centre of gravity; calculation of the centre of gravity follows the procedure outlined in Quah (2011). Country-level publications and volume of in-migrants were used to measure the mass of each country (W). Please refer to the supplementary materials for the exact formulae used to calculate the centre of gravity.*

The increasing importance of countries in the southern hemisphere as emerging origins of and destinations for internationally mobile scientists has shifted the global gravity centre of scientific mobility.[4] Figure 7 traces the progression of the global gravity centre of inbound mobility of

[4] Calculation of world centre of gravity follows the methodology of Quah (2011). There are two modifications: we use country-level aggregates and we normalize the radius of Earth to 1. Each country was assigned a measure of 'mass' W, in a given year, equal to the number of publications by authors with affiliation in that country or to the number of incoming migrants (from all origins). Then, the latitude (a) and longitude (b) coordinates for each country were converted into Cartesian coordinates using:

$$x = cos(a)\, cos(b)$$
$$y = cos(a)\, sin(b)$$
$$z = sin(a)$$

Denoting the vector of coordinates as x_i, the centre of gravity $\vec{x}_{COG}$ is calculated by:

$$\vec{x}_{COG} = \sum_{i=1}^{N} W^i \vec{x_i} \Big/ \sum_{i=1}^{N} W^i$$

The centre of gravity's coordinates are projected on the cylindrical surface tangent to the Earth's equator using:

$$a = arcsin(x_{COG})$$

scientists, which has moved by about 2,800km: from the middle of the Atlantic in 1970, to eastern Morocco in 2014. This global shift in scientific mobility largely resembles the trajectory of the gravity centre for scientific publications. Between 1970 and 2014, the gravity centre of scientific output has moved by more than 5,800km to the west of Cyprus. This eastward progression of scientific activity and of migration destinations largely follows the trajectory identified by Quah (2011) with respect to economic power. Of interest, however, is the much more limited shift of the centre of gravity for scientific migration destinations compared to the more pronounced shift in scientific output towards the global East. This seems to reflect that both aspects of scientific globalisation are, at least partially, connected. While both centres of gravity were located very close together in the middle of the Atlantic in 1970, the dynamic of scientific output in terms of publications has moved more rapidly and to a larger extent than the dynamic of migration destinations. While both processes are certainly mutually interdependent, the observed pattern suggests that scientific capacity (measured by research output) is a necessary condition for international mobility of scientists, even though not sufficient.

Barriers to scientific mobility

Despite a growing 'global competition for talent' (OECD 2008), scientific mobility is certainly not barrier-free, as various economic, political and professional frictions continue to play a significant though declining role in shaping international flows of scientists. One way to quantify scientific mobility barriers is to look at the relationship between migration flows and geographical distance using a gravity framework.[5]

$$b = arctan(y_{COG}/z_{COG})$$

Information on distances and coordinates was taken from Mayer and Zignago (2011). Distances are hereby measured by distance between most populated cities (see http://www.cepii.fr/CEPII/).

[5] The literature on gravity in international trade has provided theoretical foundations for explaining patterns of trade that would be observed in the absence of barriers to trade (Anderson 2011). We use the data on all migrants to

Following Beine et al (2015), we consider an individual from origin *o* out of all origins *O*, who is deciding on migrating to destination d out of a set of destinations *D*. Let the individual's utility from this choice be given by:

$$U_{od} = w_{od} - c_{od} + \varepsilon_{od},$$

where w_{od} is the deterministic component of the utility, c_{od} is the cost associated with choosing destination d and ε_{od} is the individual-specific random component of the utility. Further assuming that ε_{od} is drawn from an extreme value type 1 distribution, then the probability of individual *o* migrating to destination *d* is given by:

$$p_{od} = Prob(o \to d) = \frac{\exp(w_{od} - c_{od})}{\sum_{l \in D} \exp(w_{ol} - c_{ol})} \ .$$

If there are P_o individuals at origin *o*, who make independent draws of the stochastic term, then the expected number migrants M_{od}^e that chose destination *d* will be given by:

$$M_{od}^e = p_{od} P_o = \frac{\exp(w_{od} - c_{od})}{\sum_{l \in D} \exp(w_{ol} - c_{ol})} P_o \ .$$

Let $\phi_{od} = \exp(-c_{od})$ and $\Omega_o = \sum_{l \in D} \exp(\ w_{ol} - c_{ol}\ )$, then

$$M_{od}^e = p_{od} P_o = \frac{\exp(w_{od})\, \phi_{od}}{\Omega_o} P_o \, .$$

We may consider the extreme case where all sources of friction to moving between origin *o* and destination *d*, i.e. set $c_{od} = 0 \ \forall o, d$, are removed. We may further assume that the deterministic component of utility of choice *d* is the same for all individuals across all countries of origin *o*,

construct the hypothetical counterfactual that would be observed in a frictionless world, in which the share of migrants leaving a particular origin towards a specific destination will be proportional to the share of migrants in the destination in the world migrant population. The procedure is identical to the one used by Head and Mayer (2013) except we use migration instead of trade flows.

$w_{od} = w_d \;\; \forall o, d$. In that case, the expected flow of individuals migrating from country o to destination *d* will be given by:

$$M_d^e = \sum_{i \in O} M_{id} = \sum_{i \in N_o} \frac{\exp(w_{id})}{\sum_{l \in D} \exp(w_{il})} P_i = \sum_{i \in N_o} \frac{\exp(w_d)}{\sum_{l \in D} \exp(w_l)} P_i$$

$$= \frac{\exp(w_d)}{\sum_{l \in D} \exp(w_l)} \sum_{i \in N_o} P_i = P_d \;\; .$$

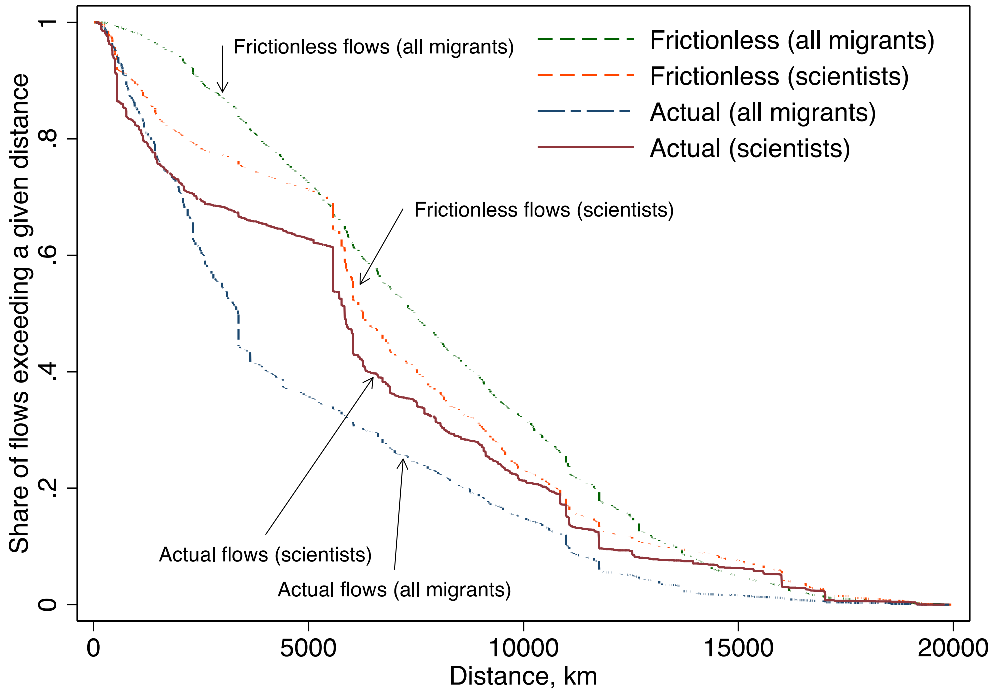
Given the size of the world population, $P^{ALL} = \sum_{i \in D} P_i$, we may then calculate the expected flow of migrants between origin *o* and destination *d* as $M_{od}^e = \frac{P_d P_o}{P^{ALL}}$, which is very similar to a standard gravity formulation. Using these frictionless ('cost-free') flows as a benchmark, we can estimate the influence of various frictions to mobility on international migration flows. An intuitive interpretation of the equation is that in the absence of any frictions between destinations, the proportion of migrants leaving origin *o* and moving to destination d, i.e. $\left({M_{od}}/{P_o} \right)$, would be equal to the share of population *j* in the world population $\left({P_d}/{P} \right)$.

Figure 8 plots friction curves for both mobile scientists as well as all international migrants which allows a comparison of the extent to which frictions affect the mobility of scientific knowledge workers against those of other, mostly less skilled, international migrants. The graphs report proportions of actual and 'frictionless' global migration flows taking place over distances greater than a particular value.[6] As a benchmark, a frictionless gravity model was used to predict the migration flows that would have taken place had there been no migration barriers *at all*.

[6] The data on bilateral mobility of migrants (not just researchers) comes from Abel and Sander (2014), which in turn estimates the global bilateral flows based on census data.

The frictionless distance-survival functions for scientist and all (non-scientist) migrants are quite similar, though in a frictionless world scientists would move shorter distances compared to other migrants. This can be explained by the rather unequal distribution of scientific activity across countries, for example the disproportionate number of scientific migrants within Europe compared to the number of non-scientific migrants. The functions for actual flows show that migration frictions are much smaller for scientists than for other migrants. The gap between actual and frictionless migration shares for scientists is very limited and almost non-existent over larger distances. Interestingly, the patterns of mobility for scientists and other migrants are very similar over shorter distances up to about 2,500 km, and very long distances of over 17,000 km. The difference shows up for medium and long distances: about 40 per cent of all internationally mobile scientists migrate less than 5,000 km, whereas this share is about 60 per cent for all international migrants. Actual flows decline much more strongly than if there were no barriers to mobility, and the impact of the barriers to mobility is stronger for non-scientific migrants, which is consistent with the migration literature finding generally lower barriers and higher migration propensity for better educated and more affluent people.

Figure 8 *Share of actual versus frictionless flows of scientist and other migrants by distance*



Note: *This diagram shows a distance-survival function, the proportion of flows that take place over distance greater than the value on the horizontal axis, using distance estimates from (39). For example, about 60 per cent of actual scientist migration flows take place over distances greater than 5,000 km. In the absence of barriers to mobility, we would expect to see the function given by the dashed line (for scientists).*

About 40 per cent of scientific flows are taking place over distances smaller than 5,000 km, compared to the 30 per cent that would be expected in a frictionless world. The distortion between actual and frictionless scientific flows has increased moderately over time for scientists, but declined for non-scientist migrants (see Figures 9 and 10). Figures 9 and 10 show that the impact of the barriers to mobility has increased for scientists (between 1970 and 2014), but decreased for all migrants (between 1990 and 2005).

Figure 9 *Barriers to mobility of scientists between 1970 and 2014*

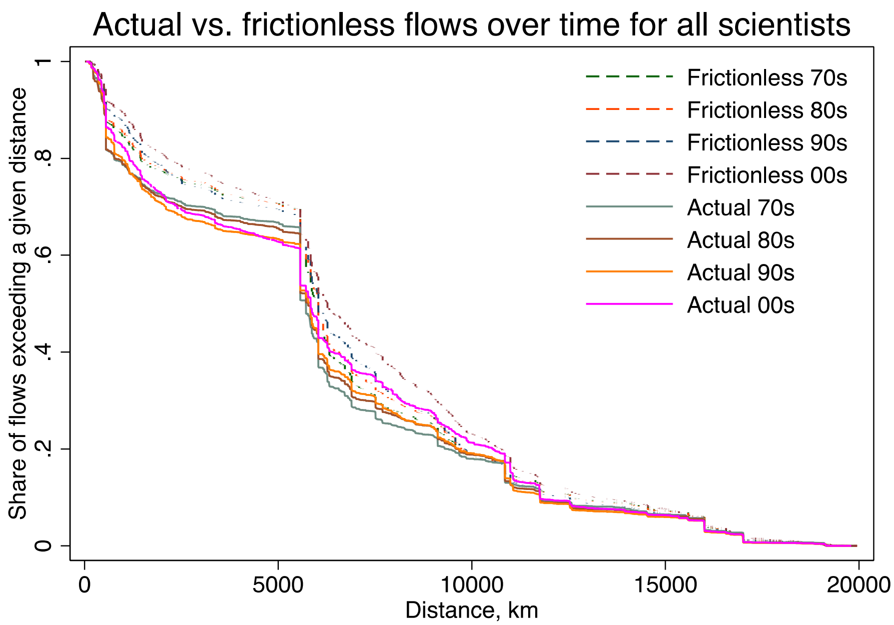
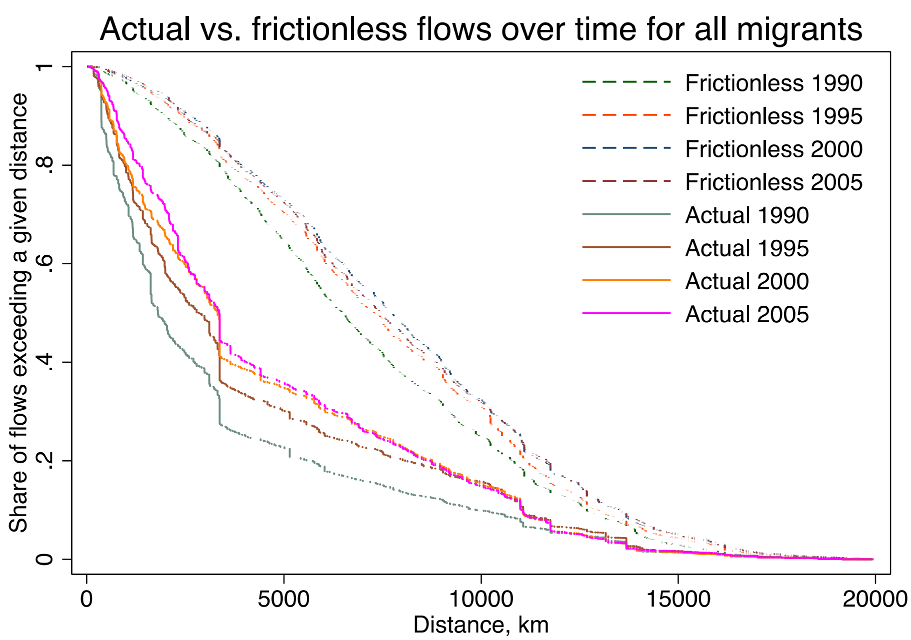


Figure 10 *Barriers to mobility of all migrants between 1970 and 2014*



Legal barriers to scientific mobility

Among other factors, legal barriers are seen as major frictions to human mobility, certainly for research-active scientists who would be unable to secure academic employment if residing in a country illegally. Visa restrictions in particular are considered important barriers to entry and have been recently empirically assessed as presenting considerable obstacles for international migration (Czaika and de Haas 2016), as well as for knowledge flows, tourism, trade, and foreign direct investment (FDI) (Czaika and Neumayer 2017, Orazbayev 2016). While Figure 8 suggests mobile scientists face fewer frictions than do other non-scientific migrants, we aim to quantify this finding more rigorously for one of the most important mobility barriers, namely visa restrictions. Recent advancement in compiling a unique global bilateral visa policy database covering up to 194 destination and 214 origin countries for the period 1973–2013 allows quantitative assessment of visa restrictions on bilateral flows of mobile scientists (Czaika et al 2017).

Identification of visa effects is achieved by employing the most stringent econometric specification that dyadic panel data allow, namely the inclusion of dyad fixed effects in combination with time fixed effects that vary for origin and destination country. Such a specification excludes the possibility that unobserved time-invariant heterogeneity across dyads as well as time-varying heterogeneity across countries bias the estimated visa effect (Anderson and Van Wincoop 2003, Baier and Bergstrand 2007). We estimate a gravity-type model without including any substantive control variables that vary at the level of countries. We estimate the following model:

$$(1) \quad \ln M_{odt} = \beta_1 + \beta_2 visa_{odt} + \eta_{od} + \gamma_{ot} + \theta_{dt} + \varepsilon_{odt}$$

where $\ln M_{odt}$ is the natural log of bilateral flows of research-active scientists from origin country o into destination country d in year t. The $visa_{odt}$ variable is our visa policy measure that is coded as one if destination country d imposes a visa restriction on mobile scientists from origin country o in year t.[7] η_{ij} are dyad fixed effects, γ_{ot} represents origin-specific year fixed effects (i.e. every origin country is allowed to have a separate intercept in every year), θ_{dt} represents the equivalent destination-specific year fixed effects, and ε_{odt} is an idiosyncratic error term.[8] The identification assumption is that $visa_{odt}$ is uncorrelated with the error term conditional on the dyad-specific, origin-specific year and destination-specific year fixed effects. Due to the three-dimensional panel data structure which provides the possibility of incorporating the largest possible number of fixed effects, we are able to minimise potential omitted variable bias as much as possible. The global coverage of our (unbalanced) dataset with 194 destinations and 214 origin countries also excludes any potential sample selection bias so that we have great confidence in the reliability and validity of the identified estimates. The only possible bias could come from variables that vary over time within dyads and are correlated with the visa policy variable. All other potential sources of bias have been eliminated by design.

[7] Our measure of international researcher flows could potentially be biased because it will include return of foreign nationals who studied abroad, since for them visa requirements (for their home country) will not apply. To reduce this bias, we have calculated a measure of migration flows that excludes migration events within the first two, three and five years. The calculated migration flows are highly correlated with the unadjusted flows (>0.9) and our estimation results do not change qualitatively.

[8] The dyad fixed effects account for the time-invariant multilateral resistance [4], whereas the source- and destination-specific year fixed effects account for time-varying multilateral resistance [6].

Table 2 *Visa restriction and scientific mobility (Panel FE regression), 1973–2013*

DV: Scientists flow (log)	(1)	(2)	(3)	(4)
Estimator	OLS	OLS	OLS	Pseudo-Poisson
Visa	-0.065*** (0.009)	-0.032*** (0.011)	-0.018*** (0.002)	-0.031*** (0.010)
R-squared (overall)	0.82	0.88	0.81	.
Observations	74,559	72,017	420,632	303,097
Dyad fixed effect	Yes	Yes	Yes	Yes
Time fixed effect	Yes	No	No	No
Origin-time fixed effect	No	Yes	Yes	Yes
Destination-time fixed effect	No	Yes	Yes	Yes

Note: Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. Models 1 and 2 report estimates of linear model with varying sets of fixed effects and exclusion of zero flows. Model 3 reports estimates of the same specification as Models 1 and 2 but including zero flows by adding +1 to the logged flows. Model 4 reports Poisson pseudo-maximum likelihood regression estimates of full dataset with dyad and origin-time/destination-time fixed effects, obtained using *(40)*.

Table 2 reports the estimated average effect of the visa restriction on international migration of research-active scientists is -0.03 in the most rigorous specifications (Models 2 and 4), which implies that bilateral mobility increases (decreases) on average by about three per cent as a consequence of a visa removal (introduction). This, although statistically significant, is practically a very small effect compared to the estimated visa effects on international travel or migration of non-scientists, for which respective effects are about 10 times larger (Czaika and Neumayer 2017, Czaika and de Haas 2016).

Conclusion

Based on a global analysis of internationally mobile scientists for the period 1970 to 2014, this study identifies an increasing diversification of countries of origin *and* destination attracting (back) increasing numbers of mobile scientists. Migration rates for scientists are more than three times larger than average rates for other international migrants and have slightly increased over the last four decades. However, major shifts in the globalisation of science are largely directional, with previously peripheral regions of the world increasingly integrating into the global scientific system of knowledge mobility. As a consequence, the global centre of gravity of scientific knowledge production and scientist-attracting places has been moving continuously eastwards by about 1,300 km per decade, with increasing average migration distances reflecting a continued integration of former scientific peripheries into the global science system. We have also identified significantly lower but non-negligible mobility frictions for internationally mobile scientists compared to other international migrants, with visa restrictions establishing a measurable barrier to the international mobility of scientists and the global diffusion of scientific knowledge.

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