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WHICH FACTORS INFLUENCE THE INTERNATIONAL MOBILITY OF RESEARCH SCIENTISTS?

Silvia Appelt[a], Brigitte van Beuzekom[a], Fernando Galindo-Rueda[acd] and Roberto de Pinho[b]

Abstract

This paper investigates the factors that influence the international mobility of research scientists using a new measure of mobility derived from changes in affiliations reported by publishing scientists in a major global index of scholarly publications over the period 1996-2011. Using a gravity-based empirical framework, our research shows that measures of geographic and socioeconomic and scientific distance correlate negatively with scientist mobility between two countries. Scientific collaboration appears to be a major factor associated with the mobility of scientists. The analysis shows that the mobility of scientists particularly relies on flows of tertiary-level students in the opposite direction, from destination to origin country. This provides strong evidence that brain circulation is a complex and multi-directional phenomenon. For a majority of country pairs (dyads) in our sample, the mobility of scientists is generally better described by commensurate knowledge flows in both directions, rather than one dominating the other. The analysis also shows that mobility can be positively influenced by convergence in economic conditions and resources dedicated to R&D, as well as reduced visa-related restrictions.

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1. Introduction

It is widely held that mobile talent contributes to the creation and diffusion of knowledge, particularly tacit knowledge as it is often shared through direct personal interactions (OECD, 2001, 2008 and 2010). The international mobility of skilled human resources can play an important role in driving scientific progress, not only at the level of a given country, but also on a global basis. Highly skilled individuals exhibit particular mobility patterns whose implications have warranted attention by researchers and policy makers alike. It is for example known that the share of foreign-born among doctorate holders is higher than for other tertiary level graduates (Carrington and Detragiache, 1998; Docquier and Marfouk, 2006; OECD, 2008). Figures from the OECD/UNESCO/Eurostat study on the careers of doctorate holders[1] reveal that in 2009, an average of 14% of national citizens with a doctorate degree had been internationally mobile in the previous 10 years (Auriol et al. 2013), confirming earlier findings reported in Auriol (2010).

Factors such as relative wage premia, career advancement and research opportunities, research facilities, the opportunity to work with significant peers and in prestigious institutions, increased autonomy and freedom to debate and carry out research are considered to be strong drivers of mobility among the highly skilled.[2] These factors come into play alongside migration policy settings as well as family and personal factors (OECD, 2010). The globalisation of the education and research systems associated with policies aimed at attracting talent appears to have contributed to the international mobility of the very highly skilled. Global competition for talent operates at the level of institutions and firms, and governments also play an active role through a number of policies.

From the perspective of organisations investing in knowledge embedded in people, a potential downside of mobility is the risk that the period over which benefits can be accrued may be too short to make the investment worthwhile. As a result, the discussion on international mobility of skilled labour has often been framed as a competitive process in which individual countries or organisations strive to attract or retain talent. However, while highly relevant, this perspective underplays the broader significance of knowledge flows in a global science and innovation system, ignoring in large part the role of offsetting flows and the scope for specialisation and mutual gains arising from mobility. For example, returning professionals can make the knowledge they have acquired available to their home country and can also maintain networks abroad which facilitate continuing knowledge exchange and collaboration.

Most countries have in place a range of policies to encourage the mobility of scientists or highly-skilled individuals more generally, with policies that range from economic incentives to encourage inflows, immigration-oriented assistance, procedures for recognising foreign qualifications and support for research abroad (OECD, 2008 and 2014b). There is generally more support for inflows of researchers and other highly-skilled than for outflows, perhaps because countries judge outward mobility to be already adequate or because they are reluctant to encourage it in light of the aforementioned arguments (OECD, 2014a). The OECD Innovation Strategy of 2010 stated that policies on mobility should aim to support knowledge flows and the creation of enduring linkages and networks across countries, enabling movement on a short-term or circular basis (OECD, 2010). Several national agencies and even non-profit organisations provide support for academic sabbaticals abroad and to host visiting researchers from overseas.[3]

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1. For further information on indicators on the careers of doctorate holders, see www.oecd.org/sti/cdh.
2. The study on the Careers of Doctorate Holders indicate that academic motivations are the main self-reported drivers of past and planned international mobility decisions. Subject to constraints, researchers appear to use international mobility as a mechanism to gain personal access to leading researchers, centres of expertise and networks that enable them to progress in their research careers.
3. The so-called “Sandwich” PhD grants programs available from Brazil’s main funding agencies could be seen as a concrete example of such policies. The PhD candidate begins and finishes her PhD studies at a

This paper investigates the potential drivers of the mobility of a population of particularly high relevance to policy makers using a new measure of international scientist mobility. An indicator developed for the OECD Science, Technology and Industry Scoreboard 2013 tracks changes in the affiliation of scientific authors publishing in scholarly journals over the period 1996-2011 (OECD, 2013a). Changes in authors' institutional affiliations, as reported on publications, are not always related to actual changes in scientists' location but can serve as a reasonably good proxy measure of mobility. A significant advantage is that the use of publication records provides a more comprehensive coverage across all countries in a way that is not subject to the gaps in survey coverage that can be found in related international analyses of scientist mobility.

The paper seeks to explore which economic, cultural and scientific factors and linkages between origin and destination countries help explain the observed, aggregate international scientist mobility patterns over the 1996-2011 period. Using bibliometric data to capture scientist mobility independent of patenting activity, it sets out to provide further evidence on a number of topical questions:

- Which model best describes the international scientist mobility network – a net flow, brain-drain picture, or a more complex brain circulation pattern?
- How does scientist mobility behave relative to scientific collaboration?
- Which aspects of absorptive capacity matter (e.g. R&D intensity of host and sending country) as a factor for driving scientist flows? Is mobility sensitive to variables under policy control?

The remainder of this report is structured as follows: Section 2 reviews the literature on the mobility of scientists as a specific group among the population of highly skilled individuals. Section 3 sets out the analytical framework, describing the empirical approach and research questions addressed by the empirical study. Highlighting the observed patterns of scientist mobility, Section 4 describes the construction of the analytical database and provides a definition of the variables employed in the regression analysis. Section 5 presents the econometric results. Section 6 concludes with some suggestions for further research.

2. Review of the literature

The body of empirical work on the incidence, causes and impacts of mobility among the highly skilled, and among scientists in particular, has drawn on various types of data sources. These include targeted surveys (Auriol, 2010; Auriol et al., 2013; Scellato et al., 2012; Franzoni et al., 2012; Gibson and McKenzie, 2013; Trippl 2013), general surveys and censuses as typically used for migration (Docquier and Rapoport, 2009 and 2012), repositories of curricula vitae (Dietz et al., 2000; Bozeman and Corley, 2004; Jonkers and Tijssen, 2008; Cañibano et al., 2011), or a combination thereof (Hunter et al., 2009). In addition to these sources, published documents subject to some form of expert validation, as it the case of scientific publications subject to peer review and patent applications subject to examination (Trajtenberg, 2005 and other references cited below), can also provide a basis for tracking the mobility of disambiguated authors and inventors, respectively.

Scientific publication records not only help measure international scientific collaboration through co-authorship patterns (Narin et al. 1991; Luukkonen et al. 1993; Yoshikane and Kagura, 2004; Wagner and Leydesdorff, 2005; Wagner 2005; Abramo et al., 2012; Science Europe and Elsevier, 2013), but can also inform the analysis of scientist mobility (Pierson and Cotegrave, 2000; Laudel, 2003; Elsevier, 2011 and

Brazilian institution with up to a one-year-long period abroad, seeking the benefits of mobility while requiring the return and maintaining strong ties with the original home institutions. http://www.cienciasemfronteiras.gov.br/web/csf-eng/home

2013, Moed et al., 2013; Moed and Halevi, 2014; Science Europe and Elsevier, 2013; Conchi and Michels 2014), alone or in combination with other data sources (Jonkers and Cruz-Castro, 2013; Baruffaldi and Landoni, 2012). Bibliometrics-based work on scientist mobility further seeks to shed light on the incidence and consequences of brain circulation. The focus may be on a defined group of scientists in a country such as those who are doctorate holders (Pierson and Cotegrave, 2000), those in a specific scientific domain (Laudel, 2003) or the whole population of scientists in a specific set of countries (Weinberg, 2011; Moed et al., 2013; Science Europe and Elsevier, 2013; Conchi and Michels 2014). International scientist collaboration tends to occur more frequently than international scientist migration (Science Europe and Elsevier, 2013). The increase in scientific collaboration is well documented, but it is not clear whether scientist mobility is outpacing collaboration or failing to keep up with it. Compared to other population groups, the relative magnitude of skilled migration has increased over time (UN-DESA and OECD, 2013b and 2014b; Docquier and Rapoport, 2009 and 2012). Despite their potentially far reaching implications for international knowledge creation and diffusion, empirical evidence about the drivers and impact of scientist mobility remains scarce.

The findings of empirical work on inventor mobility (Trajtenberg, 2005; Trajtenberg et al., 2006; Hoisl, 2007; Breschi and Lissoni, 2009; Miguélez and Moreno, 2013; Miguélez and Fink, 2013; Breschi et al., 2014) may provide some first indication of which factors potentially influence international scientist mobility patterns, as there may be a non-negligible degree of overlap between the populations of patenting inventors and publishing scientists. Inventor mobility studies highlight the role of inventor productivity as well as geographical, social and technological distance between origin and destination country in shaping their international mobility patterns. Mobility is generally found to be positively associated with inventor productivity as proxied, for example, by the education level of the inventor and the use of external sources of knowledge such as university research or scientific literature (Hoisl, 2007).

Geographic proximity between regions is also found to encourage inventor mobility (Miguélez and Moreno, 2013). Economic (e.g. transportation costs) and social factors such as cultural and linguistic similarities and personal linkages may explain this phenomenon, in particular as co-invention networks and interpersonal formal ties of inventors (Breschi and Lissoni, 2009) tend to be regional in nature. Mobility of researchers provides a principal way of knowledge diffusion, facilitating access to localised knowledge spillovers (Jaffe et al. 1993; Audretsch and Feldmann, 1996, 2004) or to a leading international scientific collaboration network. While mobility can induce scientific collaboration, new or existing collaboration ties may also drive mobility decisions, i.e. the link between mobility and collaboration is likely to run in both directions. Furthermore, the same set of factors may impact mobility and collaboration decisions in a similar fashion. The technological proximity of regional scientific undertakings, for instance, proves to encourage both mobility and collaboration (Miguélez and Moreno, 2013).[4]

3. A framework for analysing the determinants of scientist mobility flows

This report adopts an empirical gravity model of international flows to describe and analyse new aggregate, bilateral data on international scientist mobility. The gravity framework has been applied to several types of models in the social sciences, in particular in dealing with trade and foreign direct investment (Baldwin and Taglioni, 2006; Bergstrand 1985, De Groot et al., 2004; Jansen and Piermartini, 2009; Kleinert and Toubal, 2010; Linders and De Groot, 2006; Rose, 2007; Zwinkels and Beugelsdijk, 2010; Neumayer, 2011) and in the analysis of migration (Clark et al., 2007; Karemera et al, 2010 and Mayda, 2010). It has also been used more recently by Miguélez and Moreno (2013) and Fink et al. (2013) in the study of inventor mobility. Gravity models predict bilateral flows based on the attributes of origin

4. Miguélez and Moreno (2013) measure technological similarity as the un-centred correlation between regional vectors of technological patent classes (Jaffe, 1986).

and destination economies for the phenomenon under investigation, and measures of the distance between the two economies that can bear upon the costs and incentives for flows to arise. Empirical gravity models can be consistent with theoretical models of constrained utility-maximising migration choices.[5]

The model ultimately can be simplified into a regression framework in which the log of flows of scientists from country (i) to country (j), namely y_{ij}, can be written as a function of characteristics of the origin and destination country, m_i and w_j, respectively, as well as a number of measures of the link between origin country (i) and destination country (j), including measures of proximity z_{ij} and other bilateral linkages x_{ij}, and allowing for an error term ε_{ij}.

$$\ln y_{ij} = \alpha \ln x_{ij} + \beta \ln z_{ij} + \theta m_i + \pi w_j + \varepsilon_{ij}$$

Since it is impossible to identify and capture the full range of attributes of origin (m_i) and destination (w_j) locations that may be relevant for the phenomenon of mobility, it is a common approach in the literature to apply fixed effect estimation methods that control for unobserved, potentially correlated and systematic features related to both origin (u_i) and destination country (v_j). Because the available measure of scientist mobility used in this paper is time-invariant – it reflects the aggregated affiliation flows of a highly specific population over an extended period of time – the identification stems from the cross-sectional variation in destinations (origins) for each origin (destination) economy.

$$\ln y_{ij} = \alpha \ln x_{ij} + \beta \ln z_{ij} + u_i + v_j + \varepsilon_{ij}$$

The empirical analysis proceeds in a staged approach. It starts with a basic model that accounts for a set of standard variables employed in empirical gravity models such as geographical, cultural and economic proximity, to which further explanatory variables are subsequently added:

- **Model 1** controls for the effect of geographical distance, the existence of a common border, common official language and trade service flows. It also seeks to estimate how scientific dissimilarity and collaboration, international tertiary student and migrant stocks affect the patterns of bilateral scientist mobility over the 1996–2011 period.

- **Model 2** accounts for two distinct categories of service trade flows as well as indicators for travel visa restrictions to provide evidence on the effect of knowledge intensive services and visa policies on bilateral scientist mobility and collaboration over the period 1996-2011.

The distinction between distance (dissimilarity) variables z_{ij} and those that capture the linkages between origin and destination countries x_{ij} reflects the fact that distance-related measures z_{ij} are by construction symmetric ($z_{ij} = z_{ji}$), whereas "oriented flow" variables such as trade or migration are asymmetric. This is relevant for the identification of a number of potential effects in this empirical model of bilateral scientist mobility.

- **Model 3** explores the effect of the counter-flows of international students and migrants to shed light on the magnitude and nature of international brain circulation. For example, we are interested in understanding whether the flow of students (migrants) from (j) to (i) has a different

5. Gravity models are regularly used to impute missing bilateral flows in trade and migration databases. This can pose problems in further analysis if no account is made for potential data construction endogeneity. This problem does not apply to our analysis as our dependent variable has been created entirely separate from the explanatory variables.

impact on scientist flows from (i) to (j), relative to student (migrant) flows from (i) to (j). The following specification is estimated, where the coefficients α and γ would not be separately identified if $x_{ij} = x_{ji}$.

$$\ln y_{ij} = \alpha \ln x_{ij} + \gamma \ln x_{ji} + u_i + v_j + \varepsilon_{ij}.$$

- **Model 4** accounts for changes in the relative scientific and economic conditions between origin and destination country alongside changes in scientist collaboration, international student and migrant stocks to explore the effect of convergence in science and economic factors that may influence scientists' mobility decisions.

Another approach to control for unobserved heterogeneity is to explore only the variation within each set of country pairs (dyads). Thus, if we take model 3 as reference, the difference in log flows applying within dyad <i,j> is as follows:

$$\ln y_{ij} - \ln y_{ji} = (\alpha - \gamma)(\ln x_{ij} - \ln x_{ji}) + (u_i - v_i + v_j - u_j) + (\varepsilon_{ij} - \varepsilon_{ji}).$$

- **Model 5** implements this approach, which identifies $\alpha - \gamma$ under some basic conditions by means of a dyad fixed-effects regression. This not only accounts for unobserved heterogeneity concerning the bond between a given pair of countries, but also helps infer the dominant influencing factor in the presence of feedback effects (i.e. whether $\alpha > \gamma$ or $\alpha < \gamma$). The following specification is estimated:

$$\ln y_{ij} = \psi \ln x_{ij} + \mu \ln w_j + \varphi_{<i,j>} + \varepsilon'_{ij},$$

where the dyad fixed effect is defined such that: $\varphi_{<i,j>} = \varphi_{<j,i>}$ and $\psi = \alpha - \gamma$, reflecting the net effect.

In this case, symmetric variables are not identified. Furthermore, identification of additional, idiosyncratic origin and destination fixed effects cannot be completed for both origin and destination countries at the same time. It is however possible to identify the role of either origin or destination country features (μ).

This exploratory analysis seeks to document some new and policy-relevant relationships between scientist mobility and a number of fundamental science-related and socioeconomic variables. The estimated relationships may not necessarily reflect causal effects. Clearly, a number of variables such as scientist collaboration, international student and migrant stocks are likely to be endogenous, being possibly influenced by scientist mobility or common unobserved underlying factors. Our econometric analysis is based on aggregate data on scientist mobility and its potential drivers.[6] It relies on cross-sectional variation in data and thus indicates average effects over the reference period. Future work may be able to explore natural experiments within our sample.

The empirical models presented in this paper are implemented in a negative binominal regression framework to account for zero flows in the dependent variable. We verify the robustness of econometric results to the choice of estimator and specification. Some robustness checks are implemented on the logged regressors by instead applying the log transformation to one plus the relevant variable when the zeroes are genuine, rather than missing observations. To avoid overstating the precision of our estimates and take into account the correlation within dyads, standard errors are clustered by dyad.

6. Sufficiently broad time windows are required to observe at least two publication events and a potential change in affiliation. As a result, the scope for confining the analysis to shorter time-spans is rather limited.

4. Data sources and variables used

The analysis of international scientist mobility relies on multiple data sources, including bilateral scientist mobility, collaboration, international student stock, proximity, travel visa policy, R&D intensity and economic data. This section describes the construction of the analytical database and variables used in the regression analysis.

Bilateral international scientist flows

Bilateral scientist flows have been derived by OECD using bibliometric data on publications published between 1996 and 2011. Authors of peer-reviewed publications indexed in Elsevier's Scopus Custom Data (OECD licensed version of May 2012) are identified by a unique author ID assigned by Elsevier. Episodes of international mobility and general mobility profiles can be inferred from authors with at least two publications over the reference period, based on the sequence of changes in institutional affiliation revealed in those publications. Bibliometric indicators can provide a complementary picture of scientist mobility at global level. First developed by Elsevier (2011), they are experimental and require careful interpretation (Moed et al., 2013; Moed and Halevi, 2014).[7] Implied mobility records are less accurate for less prolific authors and for those who move from and into roles for which disclosure in scholarly journals is not the norm, as is often the case of researchers working in industry or researchers in some domains using books as the main scholarly communication vehicle.

We chose to base our analysis on authors with at least two publications over the reference period 1996-2011, rather than restrict the analysis to the most prolific authors, in order to obtain the largest possible sample and minimise the impact of publication bias restricting the analysis to the most productive authors. The bilateral mobility indicators used in this analysis are solely based on the very first and very last reported publication for each individual author. They can be consulted online. [8] This means that a scientist moving from country (i) to country (j) and then from (j) to (k), as implied by her affiliation record, would only count towards the calculation of flows from (i) to (k), thus netting out interim mobility flows. In previous, separate work, the OECD has developed indicators that tease out more detailed mobility patterns that reflect for example returning individuals, but not on a bilateral basis.[9]

The choice of reference period and observation windows can also have an impact on the derived indicators. Reported institutional affiliations may indicate the status at the time of publishing and may not reflect where the research took place, but do reflect some form of "intellectual presence". A practical challenge faced in identifying mobility through affiliations is the apparently increasing incidence of multiple affiliations. In line with other related work using this source, publication-author records with

7. A number of studies lend some qualified support to the use of these data for tracking mobility. Laudel (2003) and Conchi and Michels (2014) compared scientist mobility records derived from bibliometric data with those derived from alternative data sources, including CV and self-reported data from scientist surveys. Moed and Halevi (2014) evaluate the potential and limitations of the bibliometric approach in terms of author profile accuracy and interpretation, looking at the coherence between related statistics and scientist mobility as implied in Scopus publication records for authors in 17 countries. The authors conclude that the bibliometric approach is promising, but that its outcomes should be interpreted with care, and ideally combined with complementary data sources such as scientist surveys or CV data.

8. A simplified version of the bilateral flow indicators are publicly available from the interactive charts published alongside the 2013 OECD Science, Technology and Industry Scoreboard (OECD, 2013a), using the Tableau ® software application. http://www.oecd.org/sti/scoreboard-2013-interactive-charts.htm. The dynamic chart sits under "Researchers on the move", with the heading "Bilateral flows".

9. These related indicators are available on the same link, under the heading "Mobility and impacts".

affiliations in multiple countries were removed from the database on which the mobility indicator was calculated, as the seemingly least harmful option.[10]

Failure to assign author identification numbers (IDs) consistently over time can also distort mobility estimates by understating mobility when an individual has multiple IDs or overstating it for individuals with common names which are not correctly disambiguated.[11] Changes in academic status from a Ph.D. to a post-doc position or from associate to full professorship cannot be identified based on the information available. The same limitation applies to information about the nationality of mobile scientists. No attempt has been made to classify the institution to which the scientist is affiliated according to institutional sectors, but evidence available elsewhere points to most records coming from individuals affiliated to academic institutions, followed by government and health, with only a minority from the private/business sector.[12]

A significant pitfall of the Scopus version used (May 2012) concerns indexing gaps in the early 2000s, immediately before the launch of Scopus in November 2004. For this period, Scopus performed a range of backfill activities and material already present in the databases that fed into other Elsevier systems. Two such databases, namely EMBASE and Compendex, did not capture complete article data for over the period 2001-2003. In a number of cases only the first author's identity and affiliation were captured.[13] Visual inspection of the data shows a short-lived increase in the share of single-author publications over that same period that is consistent with the lack of co-author profiles for a significant subset of the population. Using simple interpolation assumptions, the number of documents with missing non-corresponding authors could be as large as 25% of the total number of documents indexed. Because missing authors in one document can be picked up in another article published in the same year, the severity of this problem will be less pronounced. Indeed, looking at the number of unique authors over time, the author coverage gap appears to be in the order of 10% or less, still significant but much less pronounced.[14] Overall, this implies that mobility records for individuals who are not first authors will be incomplete through this short spell, but only provided that their first or last publication goes missing as a result of this coverage gap. This may bias downwards the measurement of bilateral flows, particularly understating flows from and to countries that are less likely to host first in line authors who in some fields tend to be the leading and first listed authors. The direction of this bias and its potential implications for the analysis cannot be easily gauged without further investigation. Scopus has been undertaking further efforts to address the indexing gap and it is hoped that future versions of the database will allow for a more accurate analysis.

Despite their many limitations, the experimental indicators on mobility enable a highly relevant and unique perspective on the size and direction of bilateral research scientist flows. The top nine international bilateral flows (**Figure 1**) as measured by sum of bilateral flows between two countries (total bilateral flows) involve exchanges featuring the United States. While the total inflow exceeds the outflow, more scientists who start by publishing in the United States move to affiliations in China and Korea than vice versa, the respective net flows from the United States (outflow minus inflow) to China and Korea as

10. Approaches for dealing with the multiple affiliation phenomenon would require additional assumptions that cannot be tested with the data at-hand. Alternatively, the implied observed "mobility" from a move from (i) to (j) when (i) is retained as affiliation could have been dealt with by weighting such flow as 0.5 as opposed to a full count, but in the interest of simplicity this approach was not pursued at this stage.

11. A non-profit global initiative – the open researcher and contributor ID (ORCID) – seeks to deal with this problem by assigning unique identifiers linkable to an individual's research output. Elsevier's Scopus database, used in this study, is linking its data to ORCID IDs. http://orcid.org

12. See for example: http://www.scimagoir.com/index.php

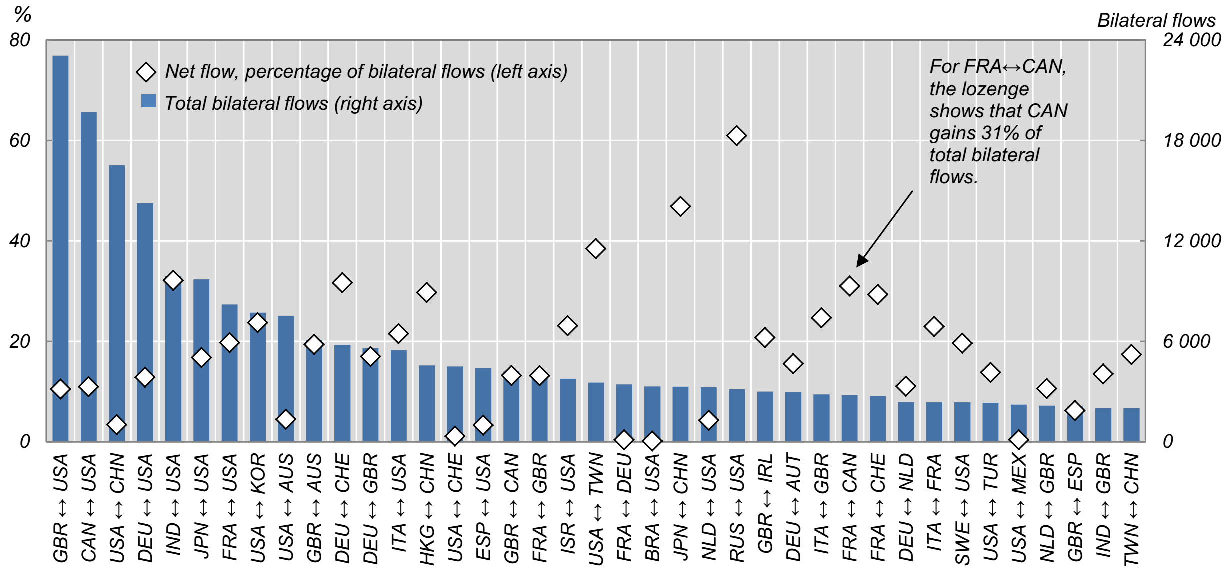
13. Personal communication between one of the authors and Elsevier staff.

14. Diagnostics are available from the authors upon request.

percentage of bilateral flows amounting to 3.4% and 23.7% respectively. German-based researchers moving to Swiss affiliations account for the largest flow between non-English speaking countries. Table A in the Annex contains for the three top destination countries – United States, United Kingdom and Germany – a list with the top ten source countries. The United Kingdom is the second most connected economy in terms of mobile scientists. These statistics do not account for the mobility of individuals before their first publication, e.g. as students. As a result, many of these flows may represent foreign nationals returning to their home countries.

Figure 1. International flows of scientific authors, 1996-2011

Largest bilateral flows, by first and last affiliation

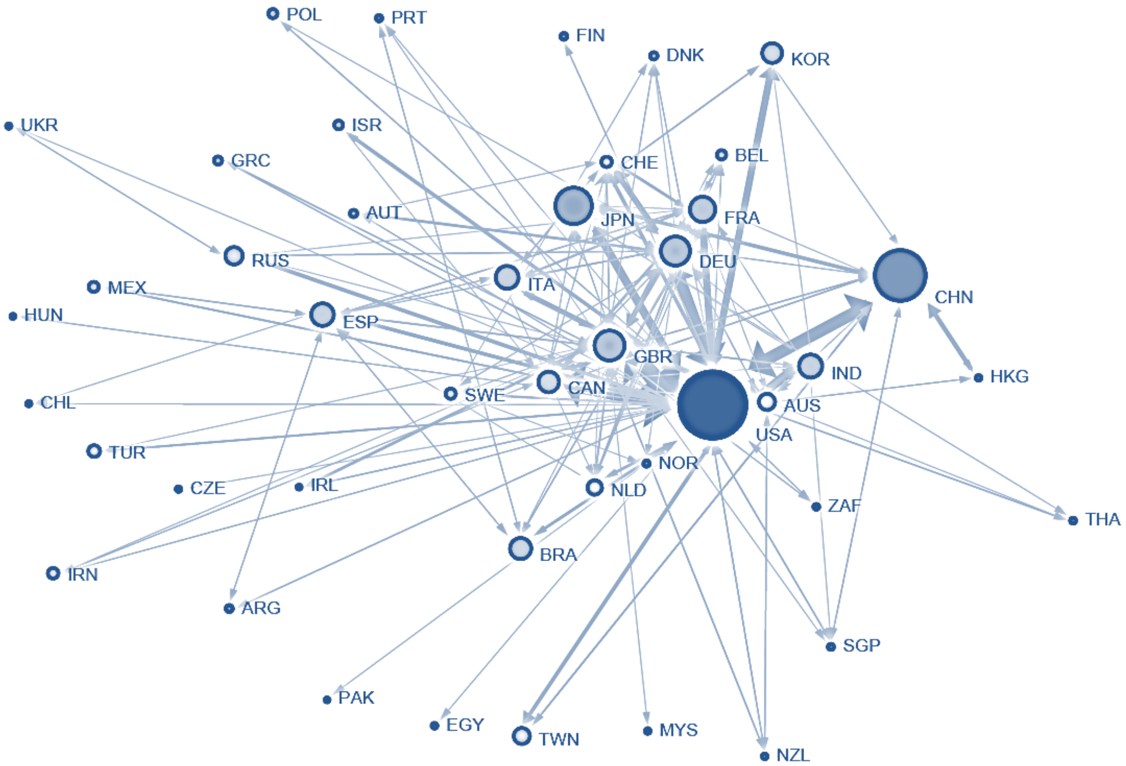


Source: OECD (2013), *OECD Science, Technology and Industry Scoreboard 2013*, based on OECD calculations applied to Scopus Custom Data, Elsevier, version 5.2012. http://dx.doi.org/10.1787/888932891511

Although leading research economies tend to attract more scientific authors from abroad to offset outward flows, flows within each pair tend to be of a similar order of magnitude in both directions, suggesting the existence of complex patterns of knowledge circulation representing the mobility of individuals at different stages of their careers, from students to established professors. The implied international mobility network of scientists (**Figure 2**) also displays a number of interesting patterns that reveal affinities between different economies based on linguistic, historical as well as political and cultural linkages. The recent GlobSci survey study by Franzoni et al. (2012), for some specific fields of science, provides some confirmatory evidence for these descriptive findings. A high share of foreign-raised scientists study and work in a number of countries. The survey also shows that many countries, not only the United States, rely strongly on foreign talent. By contrast, there are some countries – including India, Italy, Japan, Brazil and Spain – where foreign scientists and engineers are relatively rare.

Figure 2. International mobility network of scientific authors, 1996-2011

Counts of bilateral flows, by first and last affiliation



Source: OECD (2013), *OECD Science, Technology and Industry Scoreboard 2013*, based on OECD calculations applied to Scopus Custom Data, Elsevier, version 5.2012.

Note: The position of selected economies (nodes) is determined by the number of bilateral flows of publishing scientific authors from 1996 to 2011. A visualisation algorithm has been applied to the international mobility network to represent the linkages in a two-dimensional layout where distances reflect the combined strength of mobility forces between economies.[15] Bubble sizes are proportional to the number of scientific authors who stay in the economy. The thickness of the arrows joining the nodes represents the number of moves between each pair. A difference in the size of the arrow tip within each pair denotes a marked difference in the volume of flows in each direction.

Some of these countries exhibit average mobility rates according to the new OECD indicator, thus suggesting that many of those mobile researchers are returning former students or academics. Consistently with the OECD bibliometric results, this survey also finds considerable variation in migration patterns across economies. Swiss and Indian scientists are the most mobile; while those from the United States the least. The survey also documents that, as is the case in the CDH study, for virtually all the core countries studied, the United States is the dominant destination country.

Scientific collaboration

Mobility can be an important conduit to expand collaboration networks, but it can also be an outcome of mobility episodes. International scientific collaboration is a proven mechanism for promoting excellence

15. The algorithm simulates a system of forces defined on an input graph and outputs a locally minimum energy configuration. Nodes resemble mass points repelling each other and the edges simulate springs with attracting forces. The algorithm tries to minimize the energy of this physical system of mass particles. The result has been visualised using the Kamada-Kawai (Kamada and Kawai, 1989) force algorithm, and has been implemented using the *Sci*^{2} tool (*Sci*^{2} Team, 2009).

in scientific research. Scientists collaborate across borders for a variety of reasons: to bring together the most talented and qualified individuals, to pool intellectual, technological and financial resources, and to effectively address scientific questions that transcend geographical and political boundaries. Evidence presented in the 2013 Science, Technology and Industry Scoreboard (Annex: Figure B.1 and B.2) shows that economies with higher international collaboration rates tend to have higher average citation rates and top-cited publications are more likely to involve scientific collaboration across institutions (especially international) than “average” publications. International collaboration appears to allow economies to attain higher citation impact rates than they would have otherwise achieved.

The collaboration indicator measures the total number (whole counts) of co-authored documents between pairs of countries as calculated based on Scopus Custom Data, Elsevier, version of April 2014, for the 1996-2011 period, through an update of the version reported in OECD (2013a).[16] The analysis relies on the average number of collaborations over the period, while averages are also calculated at the 3-year sub-periods at the beginning and end of the reference period to investigate whether scientist flows are related to changes in collaboration. As expected, the scientific collaboration and mobility networks documented in this publication show a high degree of similarity. This paper investigates the extent to which different factors influence these networks in a comparable or distinctive fashion.

International and foreign students (tertiary-level)

According to Freeman (2010), the international mobility of students is one way through which the globalization of scientific and engineering talent proceeds. We look at the distribution of tertiary-level international (mobile) students and foreign (non-citizen) students by destination and source country and by year, as a potential predictor of scientist flows. If highly skilled individuals tend to move in the same direction, the student flows from (i) to (j) should strongly correlate with scientist flows in the same direction. Conversely, student flows from (j) to (i) can contribute to the stock of future scientists in (i) with a potential interest in returning to country (j) (and the attributes required doing so, such as language, etc.). This provides a potential basis for testing competing hypothesis regarding the nature of international knowledge flows through people. The number of students enrolled refers to the count of tertiary-level[17] students studying in the reference period. Because time series before 2004 are only available for foreign (non-citizen) students, we combine for analytical purposes such data with more recent data on international (mobile) students which better capture student mobility.[18] Data are only available for 40 reporting

16. For the aggregate analysis, the indicator is computed on the entire available population. The population is thus not constrained to match the same population from which the mobility indicator is computed, as would be required for an analysis at the individual micro-level.

17. A better approximation could be potentially achieved by looking only at PhD level students.

18. Each student enrolled in the education programmes covered by the corresponding category is counted only once. National data collection systems permitting, the statistics reflect the number of students enrolled at the beginning of the school / academic year. Students are classified as foreign students (non-citizens) if they are not citizens of the country in which the data are collected. While pragmatic and operational, this classification is deemed inappropriate by OECD and other international bodies for capturing student mobility because of differing national policies regarding the naturalisation of immigrants. Countries that have lower propensity to grant permanent residence to its immigrant populations are likely to report second generation immigrants as foreign students. Therefore, for student mobility and bilateral comparisons, interpretations of data based on the concept of foreign students should be made with caution. Students are classified as international students if they left their country of origin and moved to another country for the purpose of study. Depending on country-specific immigration legislation, mobility arrangements, and data availability, international students may be defined as students who are not permanent or usual residents of their country of study or alternatively as students who obtained their prior education in a different country, including another EU country.

“destination” countries, while the number of countries of origin exceeds 200. The United States is the top destination location for international students between 1996 and 2011.[19]

Degree of proximity

Scientific proximity and distance

Science proximity is defined as the Pearson correlation of the vector of the scientific output for each country aggregated by the 28 two-digit All Science Journals Classification (ASJC) categories. Scientific output is measured by total number of indexed documents from publicly available SCImago indicators (SCImago 2007) for the 1996-2012 period which were developed based on Scopus data. This follows a similar approach to framework adopted by Miguélez and Moreno (2013) to measure technological similarity. Scientific dissimilarity or distance is then obtained by subtracting Scientific proximity from one.

Geographic and linguistic distance

Data on contiguity, physical distance and commonly spoken (official) languages were obtained from the CEPII distance database (Mayer and Zignago, 2011). These variables are commonly employed in gravity models of bilateral trade and foreign direct investment flows, reflecting dyadic migration costs and strength of bilateral linkages. Whereas contiguity indicates the presence of a common border between the bilateral counterparts, physical distance between the two countries reflects the bilateral distance between the largest cities of countries within a dyad (based on their latitude and longitude), using the cities’ shares in the total population (in 2004) as weights to obtain a more nuanced measure of bilateral distance. These data also provide two indicators of language commonality, one indicating whether two countries have the same official primary language, the other specifying whether one language is spoken by at least 9% of the population in both countries.

Economic proximity: service trade flows

The analysis focuses on service trade flows as opposed to general trade flows comprising goods in order to avoid potential distortions caused by raw materials, fuel and other commodities that are unrelated to knowledge circulation. Service trade data were kindly provided by the OECD Directorate for Trade and Agriculture based on an internal working version of the OECD Trade in Services[20] database used as input for the ‘OECD/WTO TiVA database’. Different categories of services trade can be distinguished according to the 2002 Extended Balance of Payments Services classification (EBOPS 2002). We thus explore the role of trade in more knowledge intensive services such as computer and information services and other business services with respect to scientist flows and collaboration over 1996-2011.

Policy levers

Migration policies can help shape international migration flows, their magnitude, direction and nature. Migration policies related to the skills of migrant populations tend to be non-bilateral in nature (OECD, 2014b), i.e. they are not specific to a given pair of countries.[21] Given the lack of systematic data on

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19. The 2014 OECD International Migration Outlook (OECD, 2014b) shows that the U.S. remains to attract the highest proportion of foreign students in 2012, yet other countries are becoming increasingly popular, 16% of students looking for education abroad choosing a U.S. college in 2012, comparing to 25% in 2000.

20. http://www.oecd-ilibrary.org/trade/data/oecd-statistics-on-international-trade-in-services/trade-in-services-by-partner-country_data-00274-en?isPartOf=/content/datacollection/tis-data-en

21. For information on trends about international migration flows and policies, see OECD (2013b and 2014b).

national policies that may directly or indirectly influence migration decisions, there is currently only little evidence on how migration, skills-based and other policies[22] in sending and receiving countries affect international migration. Czaika and de Haas (2014) find that travel visa policies significantly decrease bilateral inflow and outflow dynamics in the general population. [23]

Travel visa restrictions

Information on tourist visa policies provide basic insights into how travelling restrictions affect bilateral migration flows, notwithstanding the fact that tourist visa policies differ from those for skilled professionals in terms of eligibility requirements, scope and time limit. Nevertheless, travel visa restrictions may reduce the probability of scientist mobility and collaboration across two countries where either bilateral or unilateral visa restrictions are in place, impeding personal contacts across borders by raising the cost of travel. The analysis draws on data on bilateral and unilateral visa restrictions from the November 2004 edition of the International Civil Aviation Association's Travel Information Manual (IATA, 2004) as collected by Neumayer (2011). The manual provides authoritative information on existing visa restrictions. Data are available for 205 countries, i.e. 41,820 country pairs. Visa restrictions are a fairly common phenomenon. Only about 17% of those country pairs are entirely free of such restrictions. As the measure of unilateral visa restrictions solely states whether one of the two countries imposes visa restrictions on the other country, but not vice versa, it is not possible to identify the direction of restrictions within a given dyad. As both visa restriction measures are symmetric, visa restriction effects cannot be identified in a dyad fixed-effects regression context.

Bilateral migration trends

Scientist flows between countries are to some extent related to the bilateral migration flows within dyads. Data on bilateral migration stocks from the World Bank Global Bilateral Migration Database were used to control for the general migration pattern between two countries. The database provides a comprehensive picture of bilateral migrant stocks for the period 1960-2000, covering 226 economies across the five continents based on decennial census information. General bilateral migration data reveal that the global migrant stock increased from 92 to 165 million between 1960 and 2000. The United States remains the most important migrant destination in the world, home to one fifth of the world's migrants and the top destination for migrants from no less than sixty sending countries. As the empirical analysis of scientist flows covers the time period 1996 to 2011[24], variables denoting the migrants stocks for 1990 and 2000 were included in the regressions.

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22. For example, Moretti and Wilson (2014) estimate that the state-based provision of subsidies for biotech employers in the United States over the period 1990-2010 encourages the mobility of star biotech scientists to the State providing the incentive. Cervantes and Goldstein (2008) point to the role of labour and product market regulations, entrepreneurship, education and immigration policies in shaping high-skilled migration in OECD regions.

23. At the time of submitting this draft, the DEMIG (Determinants of International Migration) project at the University of Oxford was in the process of compiling new migration and policy databases to provide evidence on the impact of sending and receiving countries' migration policies on international migration. http://www.imi.ox.ac.uk/pdfs/projects/demig/briefing

24. The OECD migration databases provide tables with annual series on migration flows and stocks in OECD countries from the 1990s onwards as well as comprehensive and comparative information on a broad range of demographic and labour market characteristics of immigrants living in OECD countries (http://www.oecd.org/els/mig/oecdmigrationdatabases.htm).

Research resources and economic factors

R&D intensity

R&D efforts by countries may shape bilateral scientist mobility and collaboration flows as the highly skilled seek new opportunities to work with peers in other economies dedicating substantial resources to scientific research. Data on gross domestic expenditures on R&D (GERD) as a percentage of gross domestic product (GDP) were obtained from the OECD Main Science and Technology Indicators and the UNESCO Institute for Statistics (UIS) R&D databases. We have extracted this indicator for 152 countries to investigate the degree to which scientist mobility and collaboration between two countries are related to the R&D intensity in the receiving (or sending) country and differences in the relative R&D intensity ratio of origin versus destination country over time.

Economic development

Economic factors are also likely to play a major role in driving observed mobility patterns. Evidence from the OECD/UNESCO/Eurostat study on the Careers of Doctorate Holders (CDH) shows that median gross annual earnings, converted in purchasing power parities (PPPs), vary greatly across economies, ranging from 18 306 US dollar PPPs in the Russian Federation to 93 000 in the United States. Doctorate holders are least well paid in Central and Eastern European countries (with the exception of Slovenia), while the highest median gross annual earnings are found in the United States and the Netherlands. Although with a different target population, a study conducted by the European Commission in 2007 (EC, 2007) also notes a large variation in the remuneration of researchers across countries. While it captures the immediate years after the onset of the global financial crisis, our paper deals with the entire 1996-2011 period as the object of analysis, thus capturing a general trend. For some countries, this general trend may have recently switched in the opposite direction, for example as a result of deteriorating economic conditions or fiscal consolidation policies reducing public funding of science and technology in specific countries.[25]

The analysis includes information on the income and population size of countries to account for the economic well-being as well as basic demographic developments in origin and destination economies. Data on annual population size and gross domestic product (GDP) per capita (in constant USD 2005 million) over 1996-2011 were extracted for 252 countries from the World Development Indicators Database. The indicator of total population denotes the number of residents regardless of legal status or citizenship (except for refugees not permanently settled in the country of asylum, who are generally considered part of the population of their country of origin). As a measure of the convergence of dyad countries in terms of economic performance, we compute the difference in the relative GDP per capita ratio of origin versus destination country at the end of the reference period (2009-2011 average) and the onset of the observation period (1996-1998 average), thus minimizing the effect of annual fluctuations in economic performance in the analysis.

The previous sources are combined into an analytical data set. Some analyses are confined to a reduced sample for which data on all required variables are available. Lack of information on some bilateral trade flows is the factor that accounts for the largest reduction in sample size. Also, analyses investigating the relationship between scientist mobility and international student stocks are by construction limited to a small set of destination countries for which foreign students were recorded. Summary statistics, reporting on the number of countries and dyads for which relevant data are available are provided in Annex Table C.1. Annex Table C.2contains a list of definitions and data sources for the variables used in this analysis. Whenever possible, we document the sensitivity of results to the choice of

25. A general picture of migration in the aftermath of the economic crisis is available in Arslan et al. (2014).

sample when introducing additional controls in the econometric specification. This shows that differences in the composition of original and retained sample do not by themselves account for the observed results.

5. Empirical results

The estimates displayed in **Table 1** show results from negative binomial regressions of the number of scientist flows on a set of distance measures and linkage variables as well as origin and destination fixed effects.[26] Geographic, cultural, economic and scientific distance measures relate to the indicator of bilateral scientist flows in the expected way (column 1). For example, countries or economies with similar specialisation profiles tend to exhibit higher flows between them, all else being equal. Column (2) shows that there are no major systematic differences between the full sample and the restricted sample for which additional information on migration and international students are available.[27]

In our bilateral scientist mobility database, data may be available for both countries in the dyad (complete dyad) or only one ordered pair (one-way-only dyad). As the estimation sample is restricted to observations with available data, the share of one-way dyads in the estimation sample tends to increase, as shown in the bottom panel. Column (3) introduces migration related variables, separating overall migration stocks in 1990 (pre-dating the reference period) and the average stock of tertiary-level international students over the reference period. Both variables are statistically significant and have the expected sign. As one could hypothesise, the student ‘migration’ variable exhibits a stronger relationship with scientist flows than general migration.

After controlling for the number of scientific collaborations, it is possible to note that the elasticity between collaborations and scientist flows is close to one. The significance of several proximity variables vanishes (e.g. common official language) or even gets turned around (e.g. geographical distance and scientific dissimilarity) once the scientific collaboration variable (columns (4) and (6)) is added to the regression, suggesting that collaborations and mobility are co-determined (endogenous). In this paper, we do not try to estimate the structural relationship between these two variables and the potential direction of causation between them. Additional specification checks are reported in columns (5) and (6) – accounting for zeroes in the migration, international student and collaboration variables confirm the robustness of these results.

Although highly correlated (correlation=0.93), collaboration and mobility linkages exhibit some noteworthy differences. Mobility flows are more concentrated than collaborations –the Gini index for the distribution of mobility flows is 0.91 against 0.87 for collaboration. On average, the main mobility partner accounts for 46% of all bilateral flows, while the comparable figure for collaboration stands at 38%, with medians at 37% and 26%, respectively. Inspecting individual countries, there is no single country with an output of more than 1 100 publications in 2010 where mobility is less concentrated than collaboration: neither is there one where the top partner in scientific collaborations accounts for a bigger share than the top mobility partner in mobility.[28]

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26. The results do not appear to be particularly sensitive to the choice of estimator. Re-estimating the main specifications in Tables 2 to 4 using the fixed effects estimator we obtain results that are very similar in a qualitative and quantitative basis. Results are available from the authors upon request.

27. The model specification in columns (1) and (2) is identical and applied to data sets of different sizes to gauge the mere effect of a sample size reduction. In column (2) the model is applied to a sample where migration information is available for at least one of the two countries in the dyad (see column (3)).

28. This pattern may be due in part to the use of whole counts for collaborations which may involve more than two countries while a mobility episode is constrained to be between a given pair of countries.

Table 1. International scientist flows, 1996-2011

Negative Binomial Regression with Fixed Effects (FE)

Number of scientist flows (i → j)	(1)	(2)	(3)	(4)	(5)	(6)
Contiguity (i↔j) (0/1)	0.303	0.010	-0.149	-0.033	-0.193	-0.043
	(0.153)*	(0.145)	(0.100)	(0.068)	(0.109)	(0.072)
Log (Geographical distance (i↔j))	-0.535	-0.322	-0.061	0.133	-0.114	0.103
	(0.044)**	(0.060)**	(0.043)	(0.039)**	(0.044)*	(0.036)**
Common official language (i↔j) (0/1)	0.923	0.776	0.275	0.139	0.342	0.164
	(0.126)**	(0.136)**	(0.112)*	(0.087)	(0.109)**	(0.087)
Common language (i↔j) (0/1)	0.608	0.582	0.336	0.198	0.340	0.197
	(0.114)**	(0.120)**	(0.100)**	(0.072)**	(0.098)**	(0.071)**
Log (Service exports) (i→j)	0.336	0.467	0.204	0.086	0.223	0.086
	(0.033)**	(0.049)**	(0.036)**	(0.031)**	(0.035)**	(0.029)**
Scientific dissimilarity (i↔j)	-12.390	-10.965	-5.215	3.388	-3.684	3.175
	(1.839)**	(2.722)**	(2.383)*	(1.945)	(2.221)	(1.792)
Log (Migrants1990 (i→j))			0.069	0.034		
			(0.012)**	(0.010)**		
Log (International students (i→j))			0.369	0.160		
			(0.019)**	(0.017)**		
Log (Collaborations (i↔j))				0.968		
				(0.034)**		
Log (1+Migrants1990 (i→j))					0.061	0.038
					(0.011)**	(0.008)**
Log (1+International students (i→j))					0.346	0.156
					(0.019)**	(0.016)**
Log (1+Collaborations (i↔j))						0.979
						(0.033)**
Origin economy FE	yes	yes	yes	yes	yes	yes
Destination economy FE	yes	yes	yes	yes	yes	yes
Chi2-statistic	14,874.4	12,409.3	20,178.1	34,461.0	19,995.4	33,791.9
Log-likelihood	-16,509.0	-8,689.0	-8,270.0	-7,790.0	-9,278.0	-8,762.0
Number of observations	8,010	2,583	2,583	2,583	3,310	3,310
Number of dyad clusters	4005	2058	2058	2058	2603	2603
<Complete dyads>	4005	525	525	525	707	707
<One-way-only dyads>	0	1533	1533	1533	1896	1896

*Note: * p<0.05; ** p<0.01; heteroscedasticity-robust standard errors clustered by dyad.*

Table 2 investigates in more detail the factors that contribute to explaining observed mobility (a) and collaboration patterns (b). Column (2a) introduces more detailed information on specific, knowledge-intensive categories of service trade. The incremental effect of this type of trade in services is positive but not statistically significant at the 5% level. It is interesting to see that no such effect is found in the case of collaborations (column 2b). Columns (3a) and (3b) explore the impact of visa restrictions, which turn out to have statistically significant negative effects on both scientist flows and collaborations. In the case of bilateral restrictions, collaborations can decrease by as much as 50%. This higher impact on collaboration may be due to the fact that short visits to build up and support the collaboration are more sensitive to the baseline tourist visa restrictions that underpin the indicator, while longer spells that result in affiliation changes may require other types of visa which are not captured in the indicator.

The larger effect of bilateral restrictions is also a plausible result, but it must be noted that there can be attenuation bias impacting on the unilateral visa variable because it has been constructed to equal one regardless of the direction in which the unilateral visa applies, and zero otherwise. Future analysis should aim to reconstruct this indicator to account for this asymmetry and complement it with additional information on the types of skill-related visa requirements that most likely apply to the mobility episodes captured by our indicator. While collaboration may occur on a remote basis, interactions may only be enabled by short term visits for which a normal visa can be more relevant. In contrast, common language and distance appear to have a stronger impact on mobility than collaboration. This may relate to the higher emotional, travel and opportunity costs associated with the move to a distant country with no common official language.

Table 2. Comparing international scientist flows and collaborations, 1996-2011

Negative Binomial Regression with Fixed Effects (FE)

	Number of scientist flows (i→j)			Number of scientific collaborations (i↔j)		
	(1a)	**(2a)**	**(3a)**	**(1b)**	**(2b)**	**(3b)**
Contiguity (i↔j) (0/1)	-0.149	-0.135	-0.155	-0.113	-0.116	-0.120
	(0.100)	(0.101)	(0.098)	(0.062)	(0.062)	(0.056)*
Log (Geographical distance (i↔j))	-0.061	-0.052	-0.074	-0.228	-0.230	-0.236
	(0.043)	(0.044)	(0.043)	(0.025)**	(0.025)**	(0.024)**
Common official language (i↔j) (0/1)	0.276	0.284	0.274	0.170	0.169	0.162
	(0.112)*	(0.112)*	(0.113)*	(0.071)*	(0.071)*	(0.071)*
Common language (i↔j) (0/1)	0.336	0.341	0.337	0.127	0.127	0.130
	(0.100)**	(0.100)**	(0.101)**	(0.061)*	(0.061)*	(0.062)*
Scientific dissimilarity (i↔j)	-5.204	-5.225	-4.520	-9.586	-9.572	-8.790
	(2.384)*	(2.385)*	(2.431)	(1.305)**	(1.309)**	(1.366)**
Log (Migrants1990 (i→j))	0.069	0.070	0.067	0.038	0.038	0.036
	(0.012)**	(0.012)**	(0.013)**	(0.007)**	(0.007)**	(0.007)**
Log (International students (i→j))	0.370	0.368	0.364	0.199	0.199	0.191
	(0.019)**	(0.019)**	(0.019)**	(0.011)**	(0.011)**	(0.010)**
Log (Service exports (i→j))	0.203	0.159	0.195	0.092	0.105	0.086
	(0.036)**	(0.051)**	(0.036)**	(0.018)**	(0.025)**	(0.018)**
Log (Computer/info service exports) (i→j)		0.033			-0.002	
		(0.019)			(0.012)	
Log (Other business services export) (i→j)		0.016			-0.013	
		(0.033)			(0.019)	
Bilateral visa restrictions (i↔j) (0/1)			-0.345			-0.504
			(0.137)*			(0.109)**
Unilateral visa restrictions (i↔j) (0/1)			-0.081			-0.144
			(0.061)			(0.039)**
Origin economy FE	yes	yes	yes	yes	yes	yes
Destination economy FE	yes	yes	yes	yes	yes	yes
Chi2-statistic	20,218.2	20,519.6	20,379.8	58,563.9	58,604.7	60,785.5
Log-likelihood	-8,272	-8,270	-8,265	-10,582	-10,582	-10,540
Number of observations	2,603	2,603	2,603	2,603	2,603	2,603
Number of dyad clusters	2078	2078	2078	2078	2078	2078
<Complete dyads>	525	525	525	525	525	525
<One-way-only dyads>	1,553	1,553	1,553	1,553	1,553	1,553

*Note: * p<0.05; ** p<0.01; heteroscedasticity-robust standard errors clustered by dyad.*

A third set of analytical results is available in **Table 3**, documenting the statistical association between flows that operate in opposite directions within a dyad. The research question in this case has to do with the way in which scientist flows interact with other population flows. For example, a potential driver of mobility from country (i) to country (j) is the stock of population in country (j) with personal ties to country (i), e.g. by virtue of permanent residence or nationality. Such stocks depend on flows from country (j) to country (i) and build up over time. If that is the case, we can consider a more developed notion of brain circulation that goes beyond the specific group of publishing scientists. We focus in particular on the role of tertiary international students – a rather imperfect proxy for flows of advanced degree and PhD students. We attempt to control for other confounding factors by comparing the impact of such flows, with those for a broader population group as implied by the stock of migrants at the beginning of the period. The results indicate a very significant elasticity of scientist flows to student flows in the opposite direction. This elasticity is of similar magnitude (10%) to the elasticity found in the same direction of the flow. In contrast, for the general stock of migrant population, we do not find evidence for such an effect. We interpret this as evidence of a significant brain circulation effect. This is a plausible explanation for the observation that there are often more scientists ‘moving’ from highly developed countries to emergent and developing economies than otherwise.

Table 3. The role of population counter-flows in explaining scientist flows, 1996-2011

Negative Binomial Regression with Fixed Effects (FE)

Number of scientist flows (i→j)	(1)	(2)	(3)	(4)	(5)
Contiguity (i↔j) (0/1)	-0.033	-0.012	-0.014	-0.019	-0.109
	(0.058)	(0.062)	(0.062)	(0.061)	(0.084)
Log (Geographical distance (i↔j))	0.133	0.227	0.227	0.232	0.078
	(0.035)**	(0.036)**	(0.036)**	(0.035)**	(0.039)
Common official language (i↔j) (0/1)	0.139	0.218	0.216	0.194	0.268
	(0.078)	(0.089)*	(0.090)*	(0.089)*	(0.106)*
Common language (i↔j) (0/1)	0.198	0.083	0.085	0.078	0.149
	(0.066)**	(0.062)	(0.062)	(0.060)	(0.083)
Log (Service exports) (i→j)	0.086	0.108	0.107	0.094	0.193
	(0.029)**	(0.033)**	(0.034)**	(0.034)*	(0.037)**
Scientific dissimilarity (i↔j)	3.388	1.162	1.316	-0.682	-23.740
	(1.880)	(4.905)	(5.037)	(5.020)	(6.530)**
Log (Collaborations (i↔j))	0.968	1.210	1.207	1.103	
	(0.033)**	(0.061)**	(0.062)**	(0.061)**	
Log (Migrants1990 (i→j))	0.034	0.043	0.040	0.033	0.039
	(0.009)**	(0.013)**	(0.016)**	(0.016)*	(0.021)
Log (International students(i→j))	0.160	0.126	0.124	0.116	0.248
	(0.017)**	(0.024)**	(0.023)**	(0.022)**	(0.024)**
Log (Migrants1990 (j→i))			0.008	-0.005	-0.003
			(0.016)	(0.016)	(0.019)
Log (International students)(j→i)				0.092	0.224
				(0.018)**	(0.022)**
Origin economy FE	*yes*	*yes*	*yes*	*yes*	*yes*
Destination economy FE	*yes*	*yes*	*yes*	*yes*	*yes*
Chi2-statistic	40,834	25,753	25,870	27,506	17,595
Log-likelihood	-7,790	-4,343	-4,343	-4,326	-4521
Number of observations	2,583	1,050	1,050	1,050	1,050
Number of dyad clusters	2058	525	525	525	525
<Complete dyads>	525	525	525	525	525
<One-way-only dyads>	1,533	0	0	0	0

*Note: * p<0.05; ** p<0.01; heteroscedasticity-robust standard errors. Standard errors are not clustered by dyad to ensure the full rank of the covariance matrix and computation of Chi2 statistics. Heteroscedasticity-robust standard errors clustered by dyad do not vary significantly from those reported. Results are available from the authors upon request.*

An additional, complementary hypothesis is considered in **Table 4**. This further set of results provides a test of the role of convergence across countries on a number of indicators that may reflect on the relative attractiveness as residence locations for scientists. The results indicate that a reduction in the relative R&D intensity and GDP per capita gap between countries (i) and (j) – e.g. country (i) moving from having a tenth of country (j)’s GDP per capita to half – is associated with a lower level of scientist flows from (i) to (j). The effect of convergence in R&D intensity is only statistically significant once the level of collaboration is controlled for. While the cross sectional correlation with collaboration is very strong over the period, we observe, however, no such relationship between changes in collaboration over 1996-2011and the level of bilateral scientist flows in that period.

Table 4. International scientist flows and other changes over the period, 1996-2011

Negative Binomial Regression with Fixed Effects

Number of scientist flows (i→j)	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**
Log (Service exports (i→j))	*0.179*	*0.198*	*0.174*	*0.056*	*0.049*
	*(0.043)***	*(0.043)***	*(0.038)***	*(0.030)*	*(0.030)*
Scientific dissimilarity (i↔j)	*-5.367*	*-8.291*	*-9.310*	*0.797*	*2.740*
	*(2.716)**	*(2.706)***	*(3.612)***	*(2.522)*	*(2.495)*
Log (Migrants1990 (i→j))	*0.070*	*0.070*	*0.029*	*0.024*	*0.034*
	*(0.015)***	*(0.015)***	*(0.014)**	*(0.011)**	*(0.013)***
Log (International students (i→j))	*0.331*	*0.325*	*0.398*	*0.118*	*0.118*
	*(0.025)***	*(0.026)***	*(0.028)***	*(0.021)***	*(0.021)***
Change in relative R&D intensity ratio (i→j)	*0.077*	*0.087*	*-0.065*	*-0.213*	*-0.224*
	(0.076)	*(0.075)*	*(0.099)*	*(0.065)***	*(0.065)***
Change in relative GDP per capita ratio (i→j)		*-0.386*	*-0.505*	*-0.529*	*-0.488*
		*(0.123)***	*(0.125)***	*(0.090)***	*(0.087)***
Log (Change in intl. student stock (i→j))			*-0.040*	*0.017*	*0.008*
			(0.023)	*(0.018)*	*(0.017)*
Log (Collaborations (i↔j))				*1.080*	*1.084*
				*(0.045)***	*(0.045)***
Log (Change in collaboration (i↔j))				*-0.042*	*-0.052*
				(0.038)	*(0.038)*
Log (Change in migrant stock (i→j))					*0.021*
					(0.013)
Origin economy FE	*yes*	*yes*	*yes*	*yes*	*yes*
Destination economy FE	*yes*	*yes*	*yes*	*yes*	*yes*
Chi2-statistic	*14,748.2*	*14,925.9*	*13,771.0*	*29,658.9*	*29,697.5*
Log-likelihood	*-5,153*	*-5,048*	*-3,867*	*-3,582*	*-3,512*
Number of observations	*1384*	*1358*	*953*	*937*	*918*
Number of dyad clusters	*1048*	*1022*	*761*	*745*	*729*
<Complete dyads>	*336*	*336*	*192*	*192*	*189*
<One-way-only dyads>	*712*	*686*	*569*	*553*	*540*

*Note: * p<0.05; ** p<0.01; heteroscedasticity-robust standard errors clustered by dyad. Other symmetric controls not reported include contiguity dummy, geographical distance and common language.*

To complete the presentation of empirical results, **Table 5** reports the analysis of mobility focusing on the variation in scientist mobility flows within country dyads, which restricts the set of dependent variables to non-symmetric and destination (or sending) country-specific variables. The results are consistent with previous findings, in particular the negative coefficient associated with international student flows, in contrast to the positive coefficient found for overall migration. The mobility of students in a given direction has predictive power on the observed mobility of scientists in the opposite direction, thus lending support to the knowledge circulation paradigm. It is likely that this result reflects how flows from a country to another may be partly driven by the subset of students originally coming from the latter and returning to their homes to continue their careers. These results are robust to the inclusion of further controls on the characteristics of destination countries.

Table 5. Scientist flows within "country pairs" or dyads, 1996-2011

	OLS		Negative Binomial Regression		
	Log (Scientist flows (i→j))		Counts of scientist flows (i→j)		
	(1)	(2)	(3)	(4)	(5) [a]
Log (Migrants1990 (i→j))	*0.072*	*0.058*	*0.075*	*0.073*	*0.076*[a]
	*(0.021)***	*(0.023)**	*(0.009)***	*(0.010)***	*(0.009)***
Log (International students (i→j))	*-0.021*	*-0.035*	*-0.028*	*-0.021*	*-0.029*[a]
	(0.023)	*(0.025)*	*(0.010)***	*(0.010)**	*(0.010)***
Log (Service exports (i→j))	*0.085*	*0.094*	*0.068*	*0.079*	*0.068*
	(0.066)	*(0.056)*	*(0.028)**	*(0.023)***	*(0.028)**
Log (GDP per capita (j))		*0.277*		*0.202*	
		*(0.087)***		*(0.034)***	
Log (GERD/GDP(j))		*-0.226*		*-0.236*	
		*(0.064)***		*(0.024)***	
Log (Population (j))		*-0.066*		*-0.071*	
		*(0.022)***		*(0.009)***	
Dyad fixed effect <i,j>	*yes*	*yes*	*yes*	*yes*	*yes*
F-statistic / Chi2-statistic	*5.2*	*8.9*	*4,474,713*	*14,075,168*	*4,609,496*
R-squared / Log-likelihood	*0.94*	*0.95*	*-3,986*	*-3,875*	*-3,985*
Number of observations	*966*	*966*	*1,050*	*1,050*	*1,050*
Number of dyad clusters	*483*	*483*	*525*	*525*	*525*
<Complete dyads>	*483*	*483*	*525*	*525*	*525*
<One-way-only dyads>	*0*	*0*	*0*	*0*	*0*

*Notes: Fixed effect regressions for each dyad <i,j>. * p<0.05; ** p<0.01; F- and R-squared statistics and heteroscedasticity-robust standard errors clustered by dyad are reported for the OLS regression. Chi2- and log-likelihood statistics and robust-standard errors are reported for the negative binomial regression. . Standard errors are not clustered by dyad to ensure the full rank of the covariance matrix and computation of Chi2 statistics. Heteroscedasticity-robust standard errors clustered by dyad do not vary significantly from those reported. Results are available from the authors upon request. a. As a robustness check, specification (5) uses Log (1+Migration1990 (i→j)) and Log (1+International students (i→j)) instead of the simple log transformation.*

This evidence on the brain circulation paradigm is consistent with separate OECD analysis on the same underlying data. Such work shows (Annex: Figure D.1 and D.2) not only a significant degree of temporary mobility in the form of scientists returning to their original country of affiliation, but also a remarkable difference in the status of the journals that mobile scientists publish in relation to those who are not observed to be internationally mobile (OECD, 2013a). Mobile scientists publish in journals with higher citation impact rankings. Interestingly, that work also shows, for a majority of countries, a large similarity in the status of journals across different types of mobile scientists, i.e. inflows, outflows and returnees. Returnees contribute significantly to raising the average publishing profile for the near totality of countries. Our analysis here confirms the view that brain circulation is a complex and multi-directional phenomenon, particularly linked and most likely drawing upon flows of tertiary-level students in the opposite direction.

6. Conclusions and further remarks

The research presented in this paper provides an initial, exploratory contribution to the analysis of the factors that drive the international mobility of research scientists. The findings from this work lend support to a knowledge or brain circulation perspective of scientist flows rather than a more traditional view of brain gain/brain drain in which some countries win at the expense of others' loss of high potential individuals. Scientist mobility appears to occur in the context of a wider, more complex network of mobile, highly educated and skilled individuals that provides the basis for training and collaboration. We find that mobility flows are statistically related to policy-related variables such as bilateral and unilateral travel visa restrictions and to changing economic and research conditions. Furthermore, our analysis shows that convergence between countries is associated with increased mobility towards the countries that are catching up, at least in relative terms.

The implications of this work can be far reaching but need to be considered in the context of the broader evidence on mobility and highly skilled migration. Policy makers need to evaluate which are the policies that make most effective use of complex international networks and mobility opportunities that individuals appear to be increasingly willing to use. They should also be aware of the potential reversibility of some of the observed flows if the conditions change, for example, if the R&D catching up process comes to a halt and the conditions or expectations that first attracted scientists cease to apply.

There are several possible avenues for future research. Firstly, it is important to go beyond the analysis of aggregate mobility patterns to explore in more detail mobility episodes at the micro (scientist) level. This is a necessary step in order to understand whether mobility has a genuine impact on scientific collaboration and the productivity of researchers (e.g. as measured by citations), or whether it is the more collaborative and productive researchers that are more likely to identify mobility opportunities. This is also necessary for understanding how mobile researchers contribute to national and global scientific performance. Micro-based analysis should also help provide improved evidence on the dynamic processes that result in individual scientists being matched to positions and the efficiency of this largely global and unique marketplace.

The study of scientist mobility also requires paying more attention to specific science policies that bear on mobility. In that respect, there are potential avenues to begin exploring, e.g. what bilateral collaboration and mobility agreements for scientists are in place, and what level of resources are dedicated to promote the overseas training of students and scientists as well as to open up inbound flows. Our analysis has used a very crude estimate of visa restrictions as applicable to tourists, which can provide cover for short term stays and collaborations. The regimes that govern the granting of student and work visas can be more instrumental for shaping more lasting flows. Other policy aspects such as the recognition of foreign tertiary degrees, the administrative burdens involved in applying for positions and the openness of the process to outsiders can clearly shape mobility patterns. Pursuing further research in this area requires a conscious effort to build up accurate databases that trace policy changes over time.

It is equally important to work on developing new tools and instruments to trace mobility of the highly skilled. This paper has used a rather new application of bibliometric data to trace scientist mobility, but this approach is limited to those researchers that keep publishing in scholarly journals. Flows to business or other activities where publishing is not the norm can bias the overall picture. Excess emphasis on a given, easy to measure, population such as publishing scientists may obscure the relevance for policy of flows into other sectors and types of STI activity that do not necessarily entail scholarly publishing.

Other complementary statistical approaches can be brought in to complement the picture presented in this work and may be further integrated in the future. For example, the motivations underpinning mobility decisions or informal linkages with home institutions can be gauged from targeted, linked surveys. This information can be useful for policy makers wishing to design outward mobility incentives that generate real benefits to the domestic economy. Developing the tools and the analysis for better understanding the nature and impact of knowledge flows through people is part of the agenda of the OECD and its measurement work on science, technology and innovation.

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ANNEX

Table A. International scientist flows to the three countries with highest number of inflows, 1996-2011

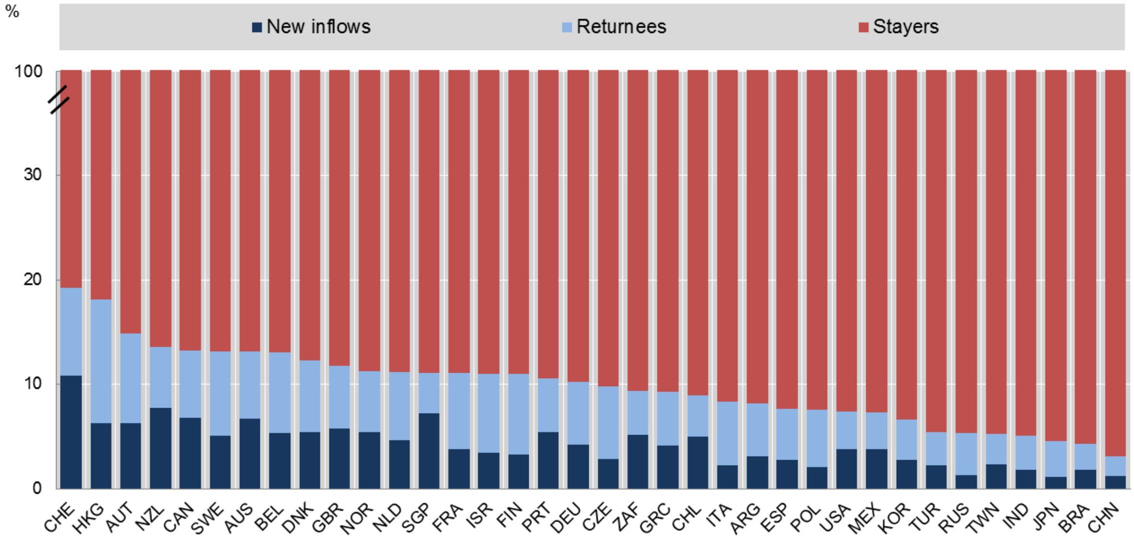
Top 10 Source Countries

	USA			GBR			DEU		
#	Source Country	Scientist flow	%Total	Source Country	Scientist flow	%Total	Source Country	Scientist flow	%Total
1	GBR	12739	13%	USA	10323	28%	USA	6210	24%
2	CAN	10932	11%	DEU	3283	9%	GBR	2330	9%
3	DEU	8042	8%	AUS	2455	7%	CHE	1979	8%
4	CHN	7978	8%	FRA	2212	6%	FRA	1726	7%
5	IND	6550	6%	CAN	1829	5%	AUT	1265	5%
6	JPN	5668	6%	ITA	1764	5%	ITA	1090	4%
7	FRA	4913	5%	NLD	1199	3%	NLD	1060	4%
8	AUS	3596	4%	IRL	1192	3%	RUS	1049	4%
9	ITA	3331	3%	IND	1142	3%	CAN	614	2%
10	KOR	2942	3%	ESP	991	3%	ESP	592	2%
Total		101,463	66%		37,491	70%		25,839	69%

Source: OECD calculations applied to Scopus Custom Data, Elsevier, version 5.2012, http://www.oecd.org/sti/scoreboard-2013-interactive-charts.htm#researchers (bilateral flows option). Charts for other countries, as well as outflows, can be obtained from the same source.

Figure B.1. International mobility of scientific authors, 1996-2011

As a percentage of authors with two or more publications, by last reported affiliation

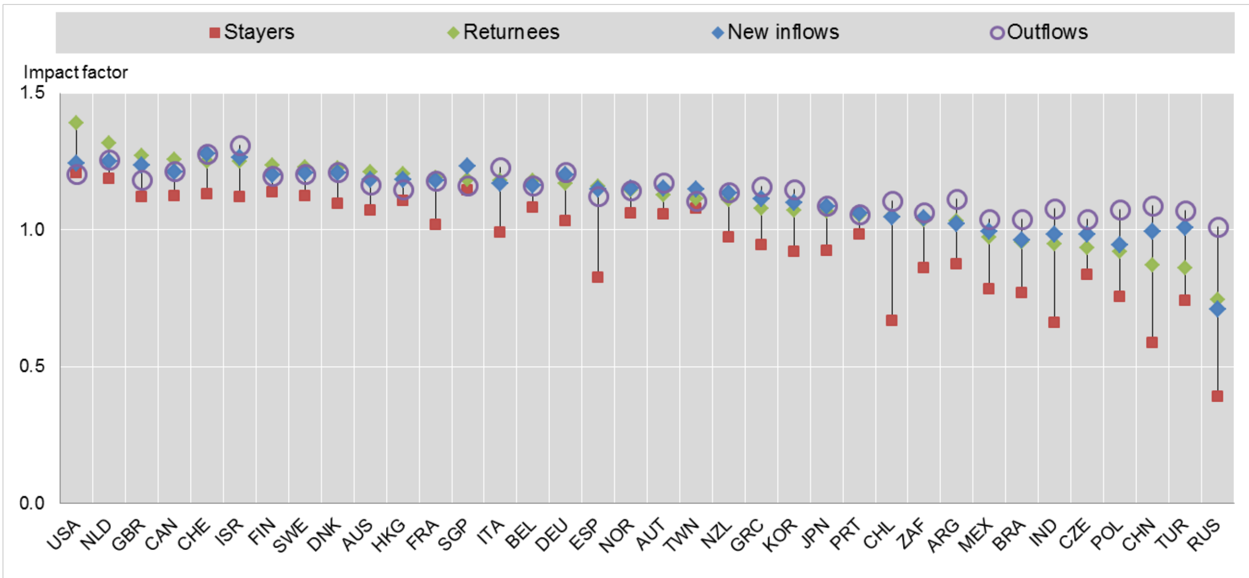


Source: OECD (2013a), *Science, Technology and Industry Scoreboard 2013*, calculations based on Scopus Custom Data, Elsevier, version 5.2012, May 2013. http://dx.doi.org/10.1787/888932891530

Notes: International mobility of scientific researchers is inferred from authors listed in the Scopus Custom database of peer-reviewed scientific publications, with at least two documents over the reference period, based on changes in the location of their institutional affiliation. Stayers maintain an affiliation in a given reference country over the period. Outflows are defined on the basis of the first affiliation. New inflows are defined on the basis of the final affiliation and exclude individuals who "return" to their original country of affiliation. The latter group are defined as "returnees". The minimum threshold per economy is over 25 000 scientific authors in the stayer category. The minimum threshold per economy is over 25 000 scientific authors in the stayer category.

Figure B.2. Impact of scientific authors, by category of mobility, 1996-2011

Based on the median source-normalized impact per paper (SNIP)



Source: OECD (2013a), *Science, Technology and Industry Scoreboard 2013*, calculations based on Scopus Custom Data, Elsevier, version 5.2012, and SNIP2 Database, www.journalmetrics.com, Elsevier, Scimago and University of Leiden. May 2013. http://dx.doi.org/10.1787/888932891549.

Notes: A proxy measure of scientific impact for researchers with different mobility patterns is estimated by calculating, for each author and mobility profile, the median across the relevant journals' Source-Normalized Impact per Paper (SNIP) over the entire period. A SNIP impact value that is higher than one means that the median attributed SNIP for authors of that country/category is above average.

Table C.1. Summary Statistics

Variable	Source countries	Destination countries	Dyads (complete)	Dyads (total)	N	Mean	Median	Min	Max	SD
Scientist flows (i→j)	253	253	31,864	31,864	63,728	6.65	0.00	0.00	12739.00	135.73
Collaborations (i↔j)	253	253	31,864	31,864	63,728	13.26	0.00	0.00	12125.13	184.05
Log(Collaborations (i↔j))	248	248	12,817	12,817	25,634	-0.21	-0.69	-2.77	9.40	2.33
Change in collaboration (i↔j)	218	218	4,957	4,957	9,914	1.70	1.63	-4.49	6.12	1.11
Log(International students (i→j))	210	39	608	2,865	5,729	3.01	2.93	-1.61	11.55	2.57
Change in international student stock (i→j)	193	24	236	1,416	2,832	1.07	0.93	-4.32	7.28	1.27
Scientific dissimilarity (i↔j)	236	236	27,730	27,730	55,460	0.08	0.06	0.00	0.51	0.07
Contiguity (i↔j) (0/1)	221	221	24,306	24,306	48,612	0.01	0.00	0.00	1.00	0.11
Log(Geographical distance (i↔j))	221	221	24,306	24,306	48,612	8.83	9.00	4.11	9.89	0.76
Common official language (i↔j) (0/1)	221	221	24,306	24,306	48,612	0.17	0.00	0.00	1.00	0.38
Common language (i↔j) (0/1)	221	221	24,306	24,306	48,612	0.17	0.00	0.00	1.00	0.37
Bilateral visa restrictions (i↔j) (0/1)	193	191	18,145	18,336	36,672	0.48	0.00	0.00	1.00	0.50
Unilateral visa restrictions (i↔j) (0/1)	193	191	18,145	18,336	36,672	0.35	0.00	0.00	1.00	0.48
Log(Migrants1990 (i→j))	226	225	6,909	10,866	21,731	3.75	3.14	0.00	15.47	2.85
Change in migrant stock (i→j)	226	225	6,159	10,001	20,001	0.35	0.19	-7.24	8.28	1.21
Log(Service exports (i→j))	91	91	4,095	4,095	8,190	2.92	2.88	-5.42	10.64	2.33
Log(Computer/info services exports (i→j))	91	91	4,095	4,095	8,190	-2.53	-2.52	-16.03	8.05	3.71
Log(Other business services exports (i→j))	91	91	4,095	4,095	8,190	0.57	0.56	-9.20	9.72	2.81
Log(GERD/GDP (j))	131	131	8,514	16,500	32,999	-0.96	-0.87	-3.78	1.42	1.21
Change in relative R&D intensity ratio (i→j)	68	68	2,192	2,192	4,384	0.42	0.00	-42.56	55.74	3.98
Log(Population (j))	210	210	21,945	26,453	52,906	15.14	15.50	9.17	20.98	2.31
Log(GDP per capita (j))	198	198	19,503	24,941	49,882	8.14	8.03	4.93	11.75	1.65
Change in relative GDP per capita gap ratio (i→j)	180	180	16,110	16,110	32,220	-0.83	0.00	-583.00	285.03	13.20

Source: OECD calculations based on linked data on bilateral scientist mobility flows (Scopus Custom Data, Elsevier, version 5.2012).

Notes: As information on dyad linkages is available only on an aggregate basis for the time period 1996-2011, linkages related to country reformations (e.g. breakup of former Yugoslavia) cannot be identified separately and are dropped as within country linkages from the analysis. This concerns overall 28 country pair linkages, resulting in overall 63,728 country pair observations. The column "Dyads (complete)" denotes the number of dyads in case of which data are available for both countries in the dyad.

Table C.2. Summary description of variables used in the regression analysis

Variable	Definition	Source
Scientist flows (i→j)	*Number of publication authors reporting an affiliation based in country/economy (i) at the outset of their publication spell and an affiliation in (j) in their latest recorded publication between 1996 and 2011.*	*OECD analysis, based on Elsevier custom Scopus ® database.*
Collaborations (i↔j)	*Average yearly number of scientific collaborations (whole counts) implied by publication co-authorship within the (i→j) dyad between 1996 and 2011.*	
Change in collaboration (i↔j)	*Ratio of Collaborations (i↔j) averaged over 2009-2011 to Collaborations (i↔j) averaged over 1996-1998.*	
International students (i→j)	*Number of international students from country (i) residing in country (j) averaged over 1996-2011. International student status is based on non-residency. Where not available on that basis, data based on foreign citizenship.*	*OECD Education Database, UNESCO-OECD-Eurostat (UOE) data collection on education statistics (Bilateral stock of international students)*
Change in international student stock (i→j)	*Ratio of international students (i→j) averaged over 2009-11 to international students (i→j) averaged over 1996-98.*	
Scientific dissimilarity (i↔j)	*Defined as 1 minus similarity measure of scientific publication patterns, based on the Pearson correlation of vectors of published documents by All Science Journal Classification (ASJC) categories.*	*Own calculations, based on data published by SCImago (2007).*
Contiguity (i↔j) (0/1)	*Dummy variable =1 if economies (i) and (j) share a common border, else zero.*	*CEPII distance database (Mayer and Zignago, 2011)*
Geographical distance (i↔j)	*Population-weighted distance between country (i) and (j) in km. Bilateral distances between the largest cities of country (i) and(j) are weighted by their shares in the total population of country (i) and (j) respectively.*	
Common official language (i↔j) (0/1)	*Dummy variable =1 if countries (i) and (j) share common official primary language, else zero.*	
Common language (i↔j) (0/1)	*Dummy variable =1 if a language is spoken by at least 9% of the population in both country (i) and (j), else zero.*	
Bilateral visa restrictions (i↔j) (0/1)	*Dummy variable =1 if bilateral visa restrictions are in place between countries (i) and (j) as of Nov. 2004, else zero.*	*Neumayer (2006, 2011), based on Nov 2004 edition of IATA's Information Manual*
Unilateral visa restrictions (i↔j) (0/1)	*Dummy variable =1 if unilateral visa restrictions are in place between countries (i) and (j) as of Nov. 2004, else zero.*	
Migrants1990 (i→j)	*Number of migrants from economy (i) reported in economy (j) as of 1990.*	*World Bank Global Bilateral Migration Database (Bilateral migrant stocks)*
Change in migrant stock (i→j)	*Ratio of stock of migrants (i→j) in 2000 to stock of migrants (i→j) in 1990.*	
Service exports (i→j)	*Service exports from country (i) to country (j) in constant USD2005 million averaged over 1996-2011.*	*OECD Trade in Services Database (EBOPS (2002): Extended Balance of Payments Services classification)*
Computer/info services exports (i→j)	*Computer and information services exports (EBOPS class: 6) from country (i) to country (j) in constant USD2005 million averaged over 1996-2011.*	
Other business services exports (i→j)	*Other business services exports (EBOPS class: 7) from country (i) to country (j) in constant USD2005 million averaged over 1996-2011.*	
GERD/GDP (j)	*Gross domestic expenditures on R&D (GERD) as percentage of gross domestic product (GDP)*	*UNESCO (UIS) database; OECD MSTI Main Science and Technology Indicators data base*
Change in relative R&D intensity ratio (i→j)	*Average relative GERD/GDP ratio over 2009-2011 (GERD/GDP of country (i) over GERD/GDP of country (j)) minus average relative GERD/GDP ratio over1996-1998.*	
Population (j)	*Population of country (j) averaged over 1996-2011.*	*World Development Indicators Database World Bank*
GDP per capita (j)	*GDP per capita in constant USD2005 million averaged over 1996-2011.*	
Change in relative GDP per capita ratio (i→j)	*Average relative GDP per capita ratio over 2009-2011 (GDP per capita of country (i) over GDP per capita of country (j)) minus average relative GDP per capita ratio over1996-1998.*	