

Revealing existing and potential partnerships: affinities and asymmetries in international collaboration and mobility

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Abstract

This study provides a preliminary analysis of the international profiles in collaboration and mobility using the seven countries indicated in the US executive order of January 27, 2017. The objective of this research is to analyze the flow of knowledge between countries and the relative importance of specific countries in order to inform evidence-based science policy. The work serves as a proof-of-concept of the utility of asymmetry and affinity indexes for collaboration and mobility. Comparative analyses of these indicators can be useful for informing immigration policies and motivating collaboration and mobility initiatives. Our analysis reinforces many of the established understandings of collaboration and mobility relationships—emphasizing the importance of geographic and cultural similarities. The analysis also explores the varied lenses on the importance of particular countries, when viewed from egocentric and relational perspectives. Our analysis suggests that comparisons of collaboration and mobility from an affinity perspective can identify gaps for mobility initiatives, given established scientific relationships. This approach can inform international immigration policies, but can also serve to identify potential partnerships at other levels of analysis (e.g., institutional, sectoral, or by state/province).

Conference Topic

Science communication; Science policy

Introduction and Background

Immigration is heralded as the key contemporary policy issue (Duncan, 2016; Bildt, 2017). Across the globe, political leaders are proposing and implementing nationalistic policies that restrict global mobility. One notable example is the executive order signed by United States President Trump on January 27, 2017 temporarily suspending entry of individuals from seven countries (i.e., Iran, Iraq, Libya, Somalia, Sudan, Syria, and Yemen) and placing restrictions on visa renewals for an additional 38 countries. Scientists home and abroad decried the executive order as impeding science, providing anecdotes of students, postdocs, and researchers who were trapped either home or abroad and unable to continue in their scientific activities (Morello & Reardon, 2017). However, there was little research on the scientific relationships among these countries and the implications of the policies for the scientific community.

Previous analysis showed the exponential growth of scientific connections at the global level over the last two decades (Adams, 2013; Wagner et al., 2015), primarily measured through collaboration (or co-authorship) (Newman, 2001; Barabási et al., 2002; Glanzel & Schubert,

2004; Leydesdorff & Wagner, 2008; Perianes-Rodríguez et al., 2009; Chinchilla-Rodríguez, et al., 2010; Gazni, et al., 2012; Wagner, Park, & Leydesdorff, 2015). Less understood is how scientists create relationship among countries through mobility. The use of bibliometric methods, in particular, has received scant attention, with a few notable exceptions (Moed & Halevi, 2014; Sugimoto, Robinson-Garcia, & Costas, 2016). However, there are traces of international relationships embedded in publication data: Scholars' co-author publications with scholars from other countries, they co-affiliate in multiple countries, and they change countries across their publication career. This data, however, has not been effectively harnessed to inform policy.

We provide here a proof-of-concept analysis, demonstrating the utility of bibliometric data to inform our understanding of the scientific relationship between countries, by using the countries indicated in the so-called “immigration ban” of January 2017. We present an approach that measures proportional production and probabilistic affinities for both collaboration and mobility, to describe the relationship in the context of the global scientific system. Furthermore, we compare these two indicators of international connectivity—collaboration and mobility—to provide a more refined understanding of the role of certain countries in the global knowledge network.

The vast differences in the volume and research capacities of different countries is a topic of concern for constructing valid indicators of international collaboration. In general, the more countries differ in scientific size, the larger the difference in relative terms (Luukkonen, Tijssen, Persson, & Silvertsen, 1993). Furthermore, the existence of collaboration and mobility between two countries implies reciprocity, but may not be symmetric. This is well-understood in network science: the degree of reciprocity is determined not by the definition of the link but by the extent to which two nodes report the same relationships with one another and two nodes exhibit proportional relationships based on overall performance of each one or of all nodes in the network (Tichy, Tushman, & Fombrun, 1979). Several indices exist to measure network asymmetries (Luukkonen et al., 1993; van Eck & Waltman, 2009). Among them, two particular indices—Affinity Index (AFI) and Probabilistic Affinity Index (PAI)—have been used to measure the relative strength of networking science. The first one is size-dependent and the latter is size-independent. AFI allows for the calibration of relative importance and asymmetries between countries, measuring the amount of collaborative papers published jointly and the total number of international collaborations of each country and also, the number of active authors and the number of mobile authors. In a similar way, taking into account all the potential partners in the network and by removing the size dependency, PAI reveals the affinities that are largely dependent upon different drivers of scientific collaboration and mobility. In particular, the PAI is highly sensitive and reveals the limit of the scientific sizes as a predictor of relationships. Previous studies have employed AFI and PAI (e.g., Zitt et al., 2000; Finardi & Buratti, 2016) to analyze collaboration, but no previous study has, to our knowledge, applied these measures to analyze the connections constructed through mobility.

We examine, for each of the seven countries for which visas were temporarily suspended as well as the United States, four dimensions: (a) asymmetry of collaboration, (b) asymmetry of mobility, (c) affinity for collaboration, and (d) affinity for mobility. We provide collaboration and mobility in parallel to highlight the different insights that can be gained by examining these indicators in concert, rather than independently. Our objective is to provide bibliometric tools to bring scientific evidence to arguments of anecdote in this time of heightened concern over globalization.

Data and Methods

By using affiliation data from scientific publications, it is possible to track the trajectory of individual scientists and analyze collaboration and mobility at the level of research groups,

subject areas, and countries (Moed & Halevi, 2014; Sugimoto, Robinson-Garcia, & Costas, 2016). In this study, we use co-authorship as a measure to examine international collaboration and the number of affiliations of scholars with different countries as a proxy of international mobility in a sample composed of the seven countries involved in the immigration ban--Iran, Iraq, Libya, Somalia, Sudan, Syria and Yemen--and the United States.

The data is drawn from a curated version of the Web of Science housed at CWTS (Leiden University). Author data from 2008 to the present has been disambiguated using an author disambiguation algorithm developed by Caron and van Eck (2014), wherein individuals are matched with distinct publication records based on similarities in co-authorship networks and affiliation information. The use of a disambiguation algorithm is necessary to identify mobility at the individual level. We therefore restrict our data to the period 2008-2015, to utilize this disambiguated data (14,097,939 publications). We further refine our data only to those links which contain at least one of the countries of interest in our sample and include only those individuals who have at least 2 publications (n=3,521,797). These nation-to-nation links were associated with 8,168,640 publications (2008-2015) across 216 countries. For collaboration, we considered all authors listed on the papers and their connections to countries. Reprint affiliations have been included for both collaboration and mobility analysis and all document types were included.

Country names were cleaned and standardized (e.g., merging Timor-Leste and East Timor, Congo and Republic of Congo as well as Zaire and the Democratic Republic of Congo). The cleaning resulted in 213 countries. We then enriched this data by adding additional classifications. Every country was assigned to one of eight geographical regions: North America, Latin America and the Caribbean, Africa, Asia, the Middle East, the Pacific Region, Eastern Europe, and Western Europe. Income level category, as defined by the World Bank (2016) was used as a proxy for economic capacity. The Scientific Technological and Capacity Index (Wagner et al., 2001) was used as an indicator of scientific capacity. This index categorizes countries into four groups of unequal sizes: advanced (n=22), proficient (n=24), developing (n=22), and lagging (n=80). In the present study, an additional group ("other") is added to account for the 66 countries that were not placed in the Wagner et al. (2001) classification.

Full-counting is used to attribute the credit to authors for collaboration and mobility. Thus, the sum of publications and authors exceeds the total number of publications. From these data, we calculate the following indicators:

- total number of publications per country (# papers);
- position in the ranking of the number of publications at the international level (Rank # papers);
- number of publications with international collaboration (#papers in international collaboration);
- proportion of papers with foreign partners (% international collaboration);
- number of countries involved in international collaboration (# collaborators countries);
- percentage of countries reached in international collaboration with respect the total number of potential collaborators (% collaborators countries);
- number of authors per country (# authors),
- number of international mobile authors per country (# authors in international mobility);
- percentage mobile authors with respect the total authors (% mobile authors);
- number of countries with mobility connections (#mobility countries),
- percentage of countries reached in international mobility with respect the total number of potential countries (% mobility countries),
- ratio of the proportion of collaborators countries among all potential collaborators;

- and the proportion of the countries with mobility connections among all potential countries (Ratio collab-mobil). For example, Yemen is collaborating with 109 out of 212 countries reaching around 50% of potential collaborators, at the same time is reaching around the 12% of potential mobile connections. That means that Yemen multiplies by four the number of countries in collaboration respect those with mobility (Table 1).

To measure the asymmetry in collaboration and mobility patterns, we use a pair of inclusion indexes, $AFI(i, j)$, and counterpart, $AFI(j, i)$, with one-way normalization. AFI is a measure of the links between a given country (i) with another country (j), compared to the total links country (j) with the entire world during the same period. $AFI(i, j)$ is calculated as:

$$AFI(i, j) = \frac{n(i, j)}{\sum_j n(i, j)}$$

where $n(i, j)$ is the volume of links between countries i and j. This index is size-dependent given that the preference for partner j in $AFI(i, j)$ is influenced by the global size of j (conversely, preference is dependent upon the size of i for $AFI(j, i)$). This index highlights the important partners in terms of quantity and demonstrates the asymmetry in partnerships.

To normalize by the size of both countries, we employ the Probabilistic Affinity Index (PAI), widely used in science policy to demonstrate the degree to which proximity (both material and immaterial) contributes to scientific relationships among the countries (Zitt et al., 2000). The index is capable of demonstrating strong relationships with small countries and presents the strength of relationships in their *global context*. For PAI, we refer to Zitt et al. (2000)'s algorithm and apply it to calculate the relationships between countries for both collaboration and mobility:

$$PAI(i, j) = \frac{[n(\dots)n(i, j)/n(i)n(j)]^2 - 1}{[n(\dots)n(i, j)/n(i)n(j)]^2 + 1}$$

where $n(i) = \sum_j n(i, j)$ and $n(\dots) = \sum_{i \neq j} n(i, j)$. PAI is normalized into [0,1] in order to make it comparable with AFI.

Each indicator yields a different lens on the international portfolio of a given country. The affinity index reveals asymmetries, demonstrating that collaborations with country i might constitute a large portion of the total collaborations of country i, but a small proportion of the collaborations of country j. It simultaneously provides an indicator of the main collaborators in the global network. PAI, on the other hand, highlights the strengths of countries that might not have high output, but have disproportionately strong connections in the global environment. We present, for both collaboration and mobility, the 50 main and preferred partners for the countries in our sample, according to the AFI and PAI.

Results

Overview of collaboration and mobility

The seven countries differ in both economic and scientific dimensions. Iran, Iraq, and Libya are economically considered as upper-level income countries, whereas Sudan, Syria, and Yemen are in the lower-middle income bracket for countries. Somalia is in the lowest income level. Somalia is also distinct in terms of the profile of scientific output and the size of the scientific workforce—having the lowest of both for the seven (Table 1). Iran is the most prolific country in the set—contributing 1.8% of the share of world publications, placing it in 17th place worldwide in terms of scientific output. The next most productive country in the set is Iraq, which is ranked 82nd globally in terms of production and produces 0.05% of the world output.

The general international profile of the countries also differs—nearly all publications from Somalia are authored with an international partner, whereas only a fifth of publications from Iran are the result of international collaboration. Iran and Sudan have the widest collaboration portfolios in terms of number of international partners—reaching 76 and 75% (respectively) of potential collaborative partners in this dataset. Somalia has the fewest, reaching less than 20% of potential partnerships, likely as a result of the low output. Mobility provides a different lens on international partnerships. For example, Iraq has one of the lowest rates of collaboration, yet nearly half of the researchers in Iraq have some degree of mobility and reaches nearly a quarter of all potential partners. Iran is the only country that remains stable across the two lists—appearing as both the least collaborative and the country with the lowest percentage of mobile researchers. However, even with the lower degree of mobility, it still reaches nearly 40% of potential mobility countries, second in this set only to the United States (at 88%). These results suggest that collaboration and mobility indicators present different images of the international profiles of countries. A comparison of the indicators suggests that mobility is a more selective indicator: in all countries, the ties between collaborative countries is higher than the ties established through mobility. In a way, mobility is a costlier (particularly from a human, social and economic point of view) event than collaboration, thus explaining the prominence of collaboration over mobility.

Table 1. Percentage of international collaboration, collaborators countries, authors in mobility and mobility countries.

Country Code	Rank # papers	# papers	COLLABORATION				MOBILITY					
			# papers in international collaboration	% international collaboration	# collaborators countries	% collaborators countries	# authors in mobility	% mobile authors	# mobility countries	% mobility countries	ratio collab-mobil	
USA	1	2292220	753271	32.86	212	100.00	816408	79967	9.8	188	88.68	1.13
IRAN	17	146883	31695	21.58	165	76.39	57481	4752	8.3	85	40.09	1.91
IRAQ	82	3759	2508	66.72	114	52.78	1389	662	47.7	49	23.11	2.28
SUDAN	99	1853	1487	80.25	161	74.54	734	288	39.2	46	21.70	3.44
SYRIA	103	1575	1122	71.24	134	62.04	542	195	36.0	40	18.87	3.29
YEMEN	117	1075	948	88.19	109	50.46	305	152	49.8	27	12.74	3.96
LIBYA	119	1002	841	83.93	119	55.09	438	217	49.5	33	15.57	3.54
SOMALIA	194	40	39	97.50	39	18.06	20	3	15.0	2	0.94	19.14

The dominant partners for both collaboration and mobility are scientifically “advanced” countries (Table 2). Yemen is an exception, collaborating predominately with “lagging” countries. All countries have a demonstrable share of connections with lagging countries, when compared to “developing” and “proficient” countries showing homophily in their international relationships.

Table 2. Percentage of collaboration and mobility with countries by S&T Capacity Index

S&T Index	IRAN		IRAQ		LIBYA		SOMALIA		SUDAN		SYRIA		YEMEN	
	Mobility	Collab												
Advanced	74.75	54.99	44.10	39.70	55.29	42.94	0.00	50.78	35.56	39.84	68.91	43.56	17.68	14.92
Proficient	10.27	23.02	10.95	14.88	7.06	13.95	0.00	10.94	24.92	15.45	5.04	12.16	12.15	4.88
Developing	2.47	8.95	7.54	10.92	5.88	13.85	0.00	8.59	3.65	8.94	5.46	14.30	12.71	9.12
Lagging	12.12	10.49	36.42	32.08	29.41	25.16	100.00	29.69	33.74	33.48	19.75	26.52	56.35	66.33
Others	0.40	2.55	1.00	2.41	2.35	4.09	0.00	0.00	2.13	2.29	0.84	3.46	1.10	4.75

Western Europe is also a dominant partner, but with some exceptions (Table 3). For example, the plurality of Iraq’s mobility and collaboration partners come from the Middle East. Somalia’s mobility is limited to Africa and Asia; and Sudan and Yemen have mobility largely with Asian countries.

Table 3. Percentage of collaboration and mobility with countries by geographic region

Regions	IRAN		IRAQ		LIBYA		SOMALIA		SUDAN		SYRIA		YEMEN	
	Mobility	Collab												
% Africa	0.72	1.85	0.71	4.31	0.78	8.57	66.67	23.44	13.68	19.30	4.20	10.31	2.21	4.82
% Asia	18.87	17.63	44.81	31.52	12.94	14.66	33.33	8.59	32.52	17.82	6.30	13.11	48.07	15.47
% Eastern Europe	2.85	13.46	2.84	5.21	1.57	4.74			0.30	3.35	0.42	6.66	0.55	1.20
% Latin America & Caribbean	0.81	4.07		3.04	0.78	3.45		4.69		4.10	0.42	4.12		0.58
% Middle East	2.64	6.90	8.96	16.89	27.06	23.81		7.81	20.67	16.21	18.91	21.91	32.60	26.61
% Northern America	30.76	16.66	9.39	8.82	7.45	6.84		10.16	5.17	7.71	9.66	8.57	4.97	5.19
% Pacific Region	7.34	5.10	6.26	3.71	4.71	3.39		3.13	1.52	2.13	1.68	3.33		0.48
% Western Europe	36.01	34.33	27.03	26.50	44.71	34.54		42.19	26.14	29.38	58.40	31.99	11.60	8.95

Country-specific analysis

Iran. High producing and advanced countries, such as the United States and Canada, lead in terms of the top connections for both collaboration and mobility, when considering the AFI for Iran (Figure 1A). For example, Iran publishes more than 22% of internationally-collaborative publications with the US and 20% of Iranian researchers (those for whom their first publication was in Iran) have been affiliated with the US. However, Iran also has a strong connection with Malaysia—a scientifically lagging country with upper middle income. Among the countries with the strongest ties, collaboration is stronger with the US, Germany, and the United Kingdom than mobility, whereas the inverse is true with Canada and Malaysia. Overall, using AFI as the measurement, Iran tends to have stronger relationships in terms of collaboration than mobility.

PAI presents a very different portfolio in terms of international connections. The strongest partners using this index include Azerbaijan, Malaysia, Armenia, and Iraq—reinforcing the importance of geographical, linguistic, and cultural ties. Canada also remains highly ranked according to this index. The United States, however, drops considerably in the ranking and the United Kingdom show a negative index in terms of mobility. As with AFI, the connection with the US on the PAI is stronger with collaboration than mobility. This preference is invariable across the 50 preferred partners for Iraq. Several countries have a very high probability index for collaboration, but negative ranks for mobility. These include several Latin American (i.e., Brazil, Mexico, Chile) and Middle Eastern (i.e., Pakistan, Saudi Arabia, Egyptian) countries. This may suggest potential avenues for mobility programs.

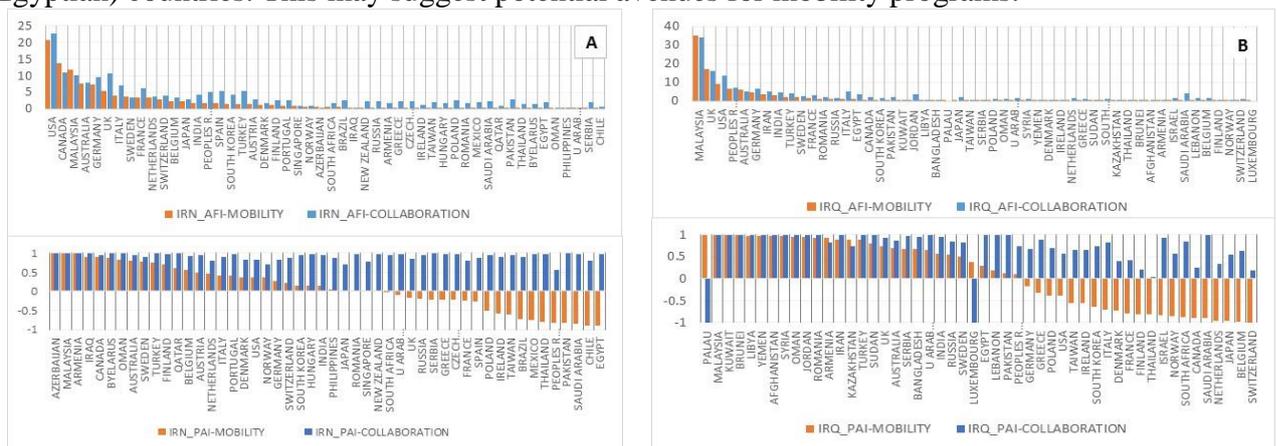


Figure 1. Main partners of Iran (left A) and Iraq (right B) in mobility and in collaboration according to AFI (top) and preferred partners in PAI (bottom).

Legend: AFI reflects the size of countries in terms of the percentage of international publications (blue columns) or mobile researchers (orange columns) of Iran with their 50 main partners. PAI removes size effect, their values range between 1 and -1 denoting that the bigger value, the strongest partner a country is among all potential ones in the network. The same below.

Iraq. Iraq collaborates with 115 countries and has researchers with mobility connections with 50, including Palau and Luxembourg, with whom there are no collaborations in common (Figure 1B). As measured with AFI, Malaysia captures the largest share of collaboration and mobility relations with Iraq, followed by the UK, the US, and China. Countries such as the US Italy, Jordan, and Saudi Arabia have demonstrably higher AFI indexes in collaboration than mobility; however, for the most part there is an evenness in the collaboration and mobility patterns for Iraq according to AFI.

Taking into consideration all potential partners with PAI, the strongest relationships are with Malaysia, Kuwait, Brunei, Libya, Yemen, Afghanistan, Syria, Oman and Jordan (PAI 0.99 and 0.95 in collaboration and mobility). Among the most developed countries only the United Kingdom, Australia, and Sweden are preferred partners (with PAI values of 0.75 and 0.7 in mobility and 0.93 and 0.87 in collaboration). In contrast, Iraq shows low affinities with China, Germany, and the USA. This suggests that some scientifically developed countries located in Europe, the Pacific region, and Asia are acting as bridges of enhancing the connectivity of Iraqi

science. As with Iran, the comparison between collaboration and mobility using PAI reveals gaps in partnerships. For example, Iraq has strong affinities for collaboration with Saudi Arabia and Israel (0.99 and 0.93, respectively), but no mobility. There are, of course, political explanations for these discrepancies, but the measurement provides a neutral way to identify communities that have demonstrated scientific affinities (i.e., through collaboration) which could be explored in further policy initiatives.

Sudan. As seen in Figure 2, Sudan has mobility with 46 countries (39%) and collaborates with 161 (74.5%), a similar figure to the one observed in Iran despite the difference in number of publications. In terms of size, Sudan's main partners in mobility are Saudi Arabia, China, Malaysia, Germany, South Africa, the United Kingdom and the USA (5.5%); while the collaborative partners are different—the US is the top collaborative partner followed by Saudi Arabia, the United Kingdom, Germany, and China. Similar to Iran, collaboration tends to be much higher in all cases than mobility, as measured by AFI.

When correcting for size, the strongest partners are Eritrea, Bahrain, Brunei (in mobility, but not collaboration), Saudi Arabia, Malaysia, South Africa, Uganda, Yemen, Cote Ivoire, Ethiopia, Zambia, Oman, and Kenya. In the case of Sudan, neighbors and language matters in the strength of the relationships with the exception of Malaysia. The United States has a fairly high collaboration PAI, but is low in terms of mobility, similar to other advanced countries, such as France, Switzerland, and Canada. This may indicate avenues for potential collaboration between these advanced countries and Sudan, a lagging country.

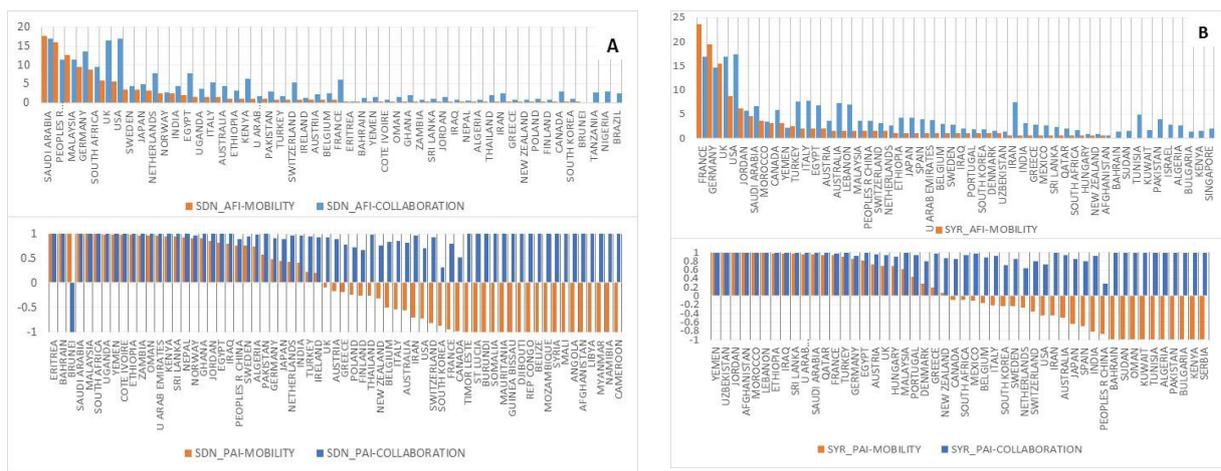


Figure 2. Main partners of Sudan (left A) and Syria (right B) in mobility and in collaboration according to AFI (top) and preferred partners in PAI (bottom).

Syria. Nearly three-quarters of Syria's output (71.2%) is the result of international collaboration, written in collaboration with 134 countries. More than a third of Syrian authors have mobility, linking Syria with 40 countries. As with Sudan, Syria does not have a parallel relationship between collaboration and mobility—the US, for instance, is highest in collaboration by AFI, but is ranked fourth by mobility. France, Germany, and the UK are strong partners on both dimensions. Across the top 50 countries, Syria has a pronounced emphasis on collaboration over mobility.

PAI again demonstrates the importance of socio-cultural factors in establishing collaborative ties. Syria's preferred partners in this index include Yemen, Uzbekistan, Jordan, Afghanistan, Morocco, Lebanon, Ethiopia, Iraq, Sri Lanka, United Arab Emirates, Saudi Arabia, and Qatar. A second preferential zone is formed by European countries—including France, Turkey, Germany, Austria, the United Kingdom, Hungary, and Portugal. The US is not a preferred partner, demonstrating low degrees of mobility, despite fairly high levels of collaborative affinity. Syria has several countries in its profile with extreme differences in

affinity between collaboration and mobility, including Oman, Tunisia, Algeria, Pakistan, Serbia, Argentina, and Israel.

Yemen. Yemen collaborates with 109 countries and has mobility connections with 27 countries. (these are not entirely overlapping units, as there is mobility, but no collaborative publications with Madagascar). The strongest partners in terms of size include Malaysia, Saudi Arabia, and Egypt. By the AFI, the US is ranked fourth in terms of collaboration and sixth by mobility. Yemen demonstrates higher degree of collaboration than mobility by AFI.

There are stronger similarities between preferred partners by AFI and PAI. Using PAI, the strongest ties are with Syria, Malaysia, Saudi Arabia, Egypt, Qatar, and Sudan. When considering the entire global context, Yemen has several countries for whom there are less than expected values for both mobility and collaboration, including South Korea, Sweden, Canada, Japan, Australia, and Spain.

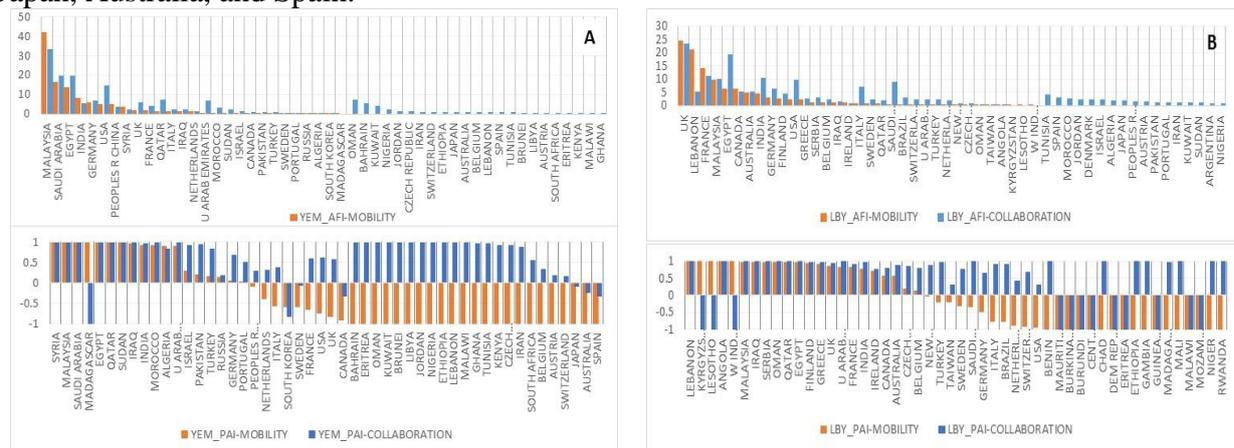


Figure 3. Main partners of Yemen (left A) and Libya (right B) in mobility and in collaboration according to AFI (top) and preferred partners in PAI (bottom).

Libya. Libya has collaborative partnerships with 119 countries and mobility with 33 countries (including Lesotho, Kyrgyzstan, and the West Indies with which Libya has no collaborative papers). In gross volume, the main partners in collaboration are the United Kingdom, Egypt, France, India, Malaysia, and the USA (9.8% in collaboration and 2.3% in mobility). Collaboration is the dominant form of connection.

The preferred partners are Lebanon, Angola, Malaysia, Iraq, Serbia, Oman, Qatar, Finland, and Greece. The second zone of influence comprised the United Kingdom, United Arab Emirates, France, and India. The United States is not a preferred partner. Libya's collaboration and mobility ties with many African countries are much lower than would be expected, given the global scientific network.

Somalia. Somalia has the lowest rate of publication across the seven countries, with collaborative ties with 40 countries and mobility ties with only two—Kenya and Malaysia. The US is the fourth most important partner in AFI, after Kenya, Malaysia, and the United Kingdom. Somalia is outperforming expected collaboration rates in all countries, but is underperforming expected values of mobility in all countries save Kenya and Malaysia.

United States. Given that our proof-of-concept study focuses on the relationship of the US with the seven countries in the executive order, it is necessary to also take an egocentric analysis of the US for context. The US has one of the lowest levels of international collaboration due to size and scientific capacity, but serves as the dominant collaboration for nearly all countries across the world. We provide both the top 50 connections, but also the countries in examination (the fact that these do not overlap suggests the comparatively weaker relationship between these countries from the perspective of the US). According to AFI, the strongest partners include (in order of importance) China, the UK, Germany, Canada, France, Italy, Japan, South Korea, and Switzerland. Collaboration rates are higher than mobility rates for all countries except for China and Iran, countries with the exception of China and Iran where the percentages are slightly

higher (China: 18 % for collaboration and 19% mobility; Iran 1% for both collaboration and mobility).

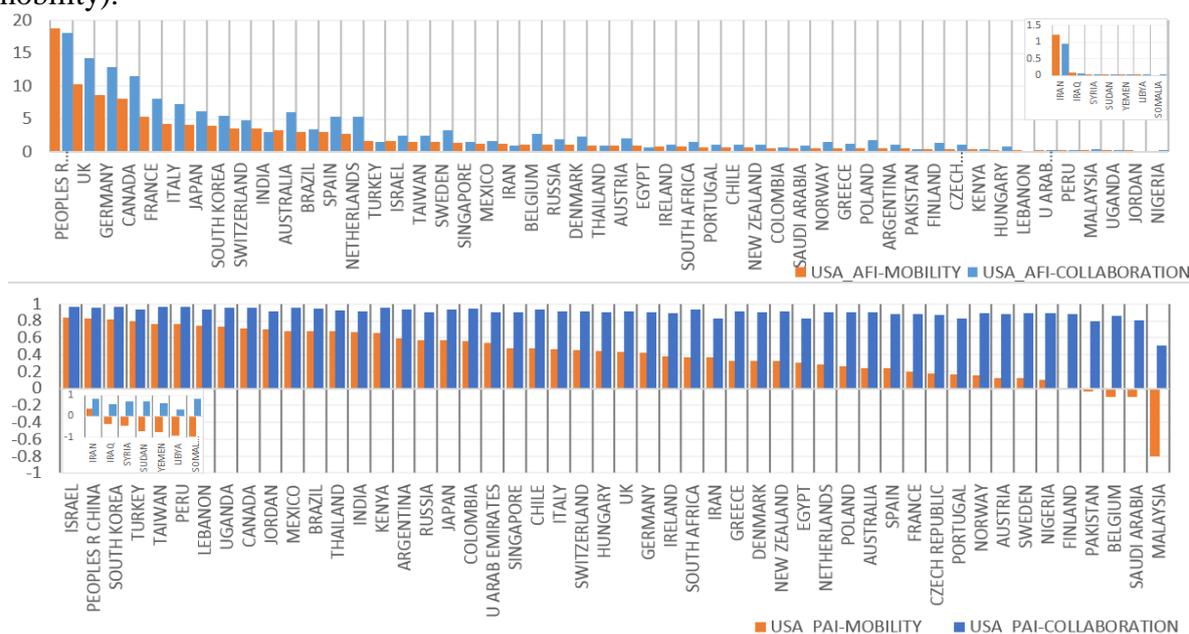


Figure 4. Main partners of USA in mobility and in collaboration according to AFI (top) and preferred partners in PAI (bottom).

When size dependence is removed, Israel is the main collaborative partner with the US, followed by China, South Korea, Turkey, Taiwan, Peru, Lebanon, Uganda, and Canada. Unlike the other countries studied, Malaysia is not a preferred partner. In the global market, the US is outperforming in terms of collaboration across all the countries. However, it has lower than expected values in terms of mobility with Pakistan, Belgium, Saudi Arabia, and Malaysia (within the top 50 countries) and with six of the seven countries (Iran is the exception).

Discussion and Further Research

This work presents a case study of the application of asymmetry and affinity measures to better understand the implications of migration policies. Using the countries suspended in the 2017 US executive order, we present an egocentric view of each country involved in order to analyze the strength and reciprocity of the relationships of each of the various countries with the US and with other preferred partners. Although affinity indexes have long been used to analyze international collaboration, this is the first analysis to explore the insights gained when mobility and collaboration are analyzed in parallel. For the case under study, we demonstrated an asymmetrical relationship between each of these countries and the US—the US was a dominant country in terms of collaboration and mobility for the seven countries, though they represented a small fraction of the share of US scientific relationships. Of the seven, Iran was the most important scientific country for the US, with higher than expected amounts of collaboration and mobility. Across the countries, Malaysia was a consistently preferred partner—a particularly striking relationship given the low affinity between the US and Malaysia.

Internationalization of science affects the research performance of countries and in certain degree depends on the attractiveness of a partner in the global network. The country with which the scientific relationship is established is important for indicator construction, given unequal magnitude of contributions between partners. The results of this study demonstrate that, despite the low volume of international publications and mobile researchers for many countries, the number of countries reached is relatively high. This internationalization presents policy challenges and opportunities, particularly for developing and lagging countries that are simultaneously confronted with critical internal conditions that often isolate them from

countries with high scientific capacity. Despite these barriers, international collaboration seems to respond to the dynamics created by the self-interests of individual scientists rather than to other structural, institutional, or policy-related factors (Leydesdorff & Wagner, 2008). This is evident in the degree of internationalization of the countries in our sample.

Previous studies have revealed different drivers underlying the formation of collaborations networks such as geographical and cultural proximity, thematic similarity, regional partnership, as well as the reputation and attractiveness of the receiving partner (Zitt, Bassecoulard, & Okubo, 2000; Archambault, Beauchesne, Côté, & Roberge, 2011; Adams et al. 2014; Finardi & Buratti, 2016). Our results confirmed these pre-existing notions: AFI demonstrated the asymmetries and preferential attachments to countries with high reputation and scientific capacity. PAI reinforced the importance of geographic and linguistic proximity. Large countries, like the US, have extremely high breadth across the scientific network—serving as a collaborative partner with all and a mobile partner for many. Smaller countries, in turn, rely upon international collaboration for a large share of their output. However, there is a distinct lack of reciprocity in terms of mobility. Whereas there are established scientific similarities, on the basis of patterns of collaboration, this does not necessarily lead to increased mobility. Mobility, therefore, is a more selective indicator; while collaborations can be established without colocation, mobility—even in the case of co-affiliation—(i.e., researchers with a double appointment with two or more international institutions but keeping ties with their country of origin) often requires some degree of travel and human interaction, having a higher social, human, and economic cost. Mobility is thus likely to be heavily influenced by political environments. Given that the countries in our sample have experienced embargos, invasions, civil wars, and revolutions in the course of the time period under investigation, these are likely to have influenced mobility rates (Moed, 2016).

Scientific relationships are highly resource-dependent (Pouris & Ho, 2014). However, our analysis has demonstrated the potential utility of combining collaboration and mobility indicators to identify preferred partners, inform policies, and identify potential areas for establishing mobility programs. This method could be extended to multiple levels of analysis, for example, to the institutional level, to examine intra- and inter-national collaboration networks. Further research should investigate the degree to which mobility and collaboration initiatives are successful in facilitating relationships between partners, particularly those that are not already established as preferred or dominant partners, and how to enhance the attractiveness of countries in the global scientific system.

Limitations and further analysis

This study requires further analysis in order to overcome some of the limitations and respond to other important questions related to the capacities and influences of countries in science. The data examines only those authors whose first publication occurred in or after 2008. This provides only limited diachronic analysis. More data and analysis are necessary to further inform a longitudinal analysis of collaboration and migration patterns, especially due to the inflationary effect on the traditional measurements of collaboration based on affiliations, that creates some overlaps when we are comparing collaboration and mobility. There is a major general limitation of collaboration analysis based on author affiliations and further analysis should be done to minimize this effect. In further research, we intend to complement our analysis with a time component, allowing us to analyze some key points such as authors' choices regarding institution address selection from publication data. This will facilitate the analysis of causal relationships, examining the relationship between collaboration and migration as well as the effects of policies and political action (Hottenrott and Lawson, 2017). We also plan to analyze positions occupied in the bylines of co-authorship, the impact of publications as a result of these relationships, the institutional reputation of destinations, and

the degree to which topic changes occur as a result of these interactions. At the methodological level, approaches with different counting methods (Perianes-Rodríguez et al., 2016) and scale-adjusted metrics will be explored in order to assure an accurate comparison of relational capacities of countries with different sizes and capacities (Archambault et al., 2011; Finardi & Buratti 2016). There are also several other elements, such as the thematic specialization of science, which should be taken into account when analyzing collaborative preferences between countries (Glanzel 2000; Radosevic & Yoruk 2014).

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