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Exploring the Nature and Dimensions of Scientific Mobility:
Insights From ORCID Database - A Visualization Approach

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ABSTRACT

Comprehending the characteristics or potential benefits of global mobility of scientists has been inadequate from academic/practical perspectives. The authors attempt to fill a theoretical gap by focusing on the nature/dimensions of the mobility of highly educated people to other countries. They analyze data from the Open Researcher and Contributor ID-ORCID database and examine the characteristics of scientists as well as the propensity of these highly qualified individuals to migrate. Using 6000 migration records of PhDs from 194 countries, the authors utilize visual analytics to explore the various dimensions of scientists and their movements. Results show that the largest numbers of researchers reside in developed countries; there is net inflow of PhD researchers to developed countries. Also, scientific immigration is impacted not only by the availability of research positions in academic institutions, but also by economics (supply/demand) as well as contemporary immigration policies and social trends.

KEYWORDS

Education, ORCID, Scientific migration, Scientific mobility, Visualization

1. INTRODUCTION

Mobility of skilled labor—highly talented and productive individuals with the potential to earn high wages—is a well-documented phenomenon (Gibson & McKenzie, 2012). The globalization of knowledge has contributed to skilled mobility at an international level (Saint-Blancat, 1990) by facilitating highly educated people with innovative mindsets and knowledge-based skillsets to become primary drivers of economic and social development (Boc, 2020; Saint-Blancat, 2019). It's therefore not at all surprising that global competition for highly qualified researchers, such as PhDs, is increasing rapidly as their role in economic development is being recognized, and as countries

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look to address skill gaps. Attracting researchers from wherever they are located only makes sense (Gibson & McKenzie, 2012; Gonzalez et al., 2008; POST, 2008). Several factors, including quality of life, monetary benefits, and perception of benefits in the destination country, are important in driving scientific mobility (Khan, 2021; Li et al., 2021; Torrisi & Pernagallo, 2020; Vega-Muñoz et al., 2021). One sees that, across the world, the scenario varies widely, with Eastern and Southern European countries losing scientists and engineers (S&Es) to Western Europe and the US (Gaule, 2014; Geuna, 2015; Mahroum, 2000a).

Available data indicate a net flow of S&Es from developing to developed countries. The familiar term 'brain drain' aptly describes the damaging impact of this migration (POST, 2008; Mahroum, 2000b). And yet, there is evidence that migration may be beneficial to both the 'sending' and 'receiving' countries by fostering positive knowledge transfer. Therefore, it may very well be more appropriate to use the term 'brain circulation' in place of brain drain (Balaz & Williams, 2004; Balaz et al., 2004; Beine et al., 2008, 2010; Benassy & Brezis, 2013; Bhagwati & Hamada, 1974; Czaika & Orazbayev, 2018a, 2018b; Dohlman et al., 2019; Gomez et al., 2020; Saxenian, 2005). Additionally, scientists tend to be attracted by countries with strong research systems.

Simultaneously, in the United States, the number of international students—most of them undergraduates—has been trending upward, increasing by 32% since 2000 to 2010. While 2018 to 2019 set a new all-time high for overseas students in the United States, the Institute of International Education data shows small dips in intake over the years spanning 2016 to 2019, coinciding with the election and presidency of Donald Trump (Open Doors, 2020). The situation is similar in the United Kingdom, which has the largest population of foreign-born PhD students in all of Europe (Edler et al., 2013; Franzoni et al., 2012; Gagliardi, 2011; Galgoczi et al., 2016). In 2012, 47% of U.S. doctoral students came from abroad (European Commission, 2014; Lanka, 2022; Lawson et al., 2015).

The international mobility of scientists contributes to the creation and diffusion of scientific knowledge. To extrapolate, it is hoped that scientific mobility nudges science-deprived societies forward, toward the frontier of technological progress, innovation, and economic development (Abel & Sander, 2014; Brockmann & Helbing, 2013; Furukawa et al., 2011; Gaillard & Gaillard, 1998; Gorodnichenko & Roland, 2011; Kapur & McHale, 2005; Kerr, 2008; Netz & Jaksztat, 2017; Nussenzveig, 1969). Attracting high-level academics and researchers, therefore, is an objective of many countries and institutions around the world (Czaika & Orazbayev, 2018a, 2018b; POST, 2008), and not just those in Western Europe and the United States. Studying the reasons for scientific mobility and migration is important for supporting policy changes, such as those which could help countries develop incentives to draw migrants or retain talent within their own countries. Overall, given the lack of consensus on the reasons for migration, as well as the dearth of recent empirical evidence, there is, to date, no agreement on the interpretation of the phenomenon of scientific migration (Ackers, 2008; Appelt et al., 2015; Canibano et al., 2011; Dao et al., 2018; Grubel & Scott, 1966; Sly, 1972; Van Bouwel, 2010). Some attempts have been made to characterize this mobility in recent years (Auriol et al., 2013; Chang & Milan, 2012; Guena, 2015; Moguérou & Di Pietrogiacomo, 2008) for example, reports on the various research studies into scientists' mobility within and across countries, thereby providing the first comprehensive analysis of this increasingly important phenomenon. Prior literature has assessed scientists' motivations to migrate, in terms of intentionality and causality; the pull factors indicate how scientists are attracted by opportunities in a host country, and the push factors reflect the national conditions that propel them to leave their home country. Most of these studies address such questions as what characterizes national and international mobility researchers and what factors motivate migration and mobility. While there is some availability of statistics and studies in scientific mobility, the scarcity of relevant data has made research scant. Over the past decade, the Open Researcher and Contributor ID (ORCID) database has gathered sufficient data to make deeper study of the scientific mobility phenomenon possible. We therefore update the findings of past studies by offering a more contemporaneous view of scientific mobility with data from ORCID. The aim of the current study is to use empirical data from the ORCID database and explore the nature of scientific mobility along with its dimensions by deploying a visualization methodology. In this manner, we aim to shed light on the characteristics and magnitude of scientific mobility and offer policy implications and recommendations. The following research questions are addressed:

What are the dimensions of scientific mobility? and
What is the current state of scientific mobility around the world?

Our research is significant in many ways. First, while most studies on scientific mobility and migration have been done based on a bibliometric analysis (Gomez et al., 2020; Guruyev et al., 2020; El-Ouahi et al., 2021; Sweileh et al., 2018) and have indirectly used the publication data of scientists (Arrieta et al., 2017; Azoulav et al., 2017; Bohannon & Doran, 2017, 2018; Chinchilla-Rodriguez et al., 2018; Robinson-Garcia et al., 2019; Scellato et al., 2015; Stokstad, 2017), this research is one of the few to use vast amounts of empirical data from the newly available ORCID database (www.orcid.org) to explore the nature and dimensions of scientific migration and mobility. Remarkably, this merged dataset includes data on approximately 194 countries, making it fairly comprehensive. In this manner we are adding to the empirical body of work on scientific mobility and migration. Second, our research utilizes a descriptive analytics visualization methodology. It analyzes the available data as is, from a historical perspective. The goal is to study the dimensions and nature of scientific mobility and portray an effective story (Keim, 2001; Kohlhammer et al., 2011). The premise of the methodology is to let the data speak rather than analyze with preconceived notions. In this manner, the data drives the analysis (Thomas & Cook, 2005). Due to the limited availability of data, however, predictive analysis is not feasible. Third, our findings offer significant implications for future research and policymaking. With the analysis of scientific mobility data, countries can frame policy decisions relating to how mobility can enhance knowledge exchange and contribute to economic development. Fourth, an analysis of the distribution patterns of scientific mobility offers insight for governments to analyze the educational infrastructure in a country to attract skilled S&Es.

The remainder of this paper is structured as follows: Section 2 provides background information on the phenomenon of scientific migration and mobility, Section 3 outlines the methodology, Section 4 presents the results and analysis of visualization, and Section 5 shares the scope and limitations of the study. Section 6 covers a comprehensive discussion, and finally, Section 7 provides our conclusions with implications for future research.

2. RELATED WORK

Scientific migration (movement by scientists from one country to another) and mobility (movement by scientists across jobs/careers, income levels, etc.) have been the focus of numerous research articles and conference presentations (Geuna, 2015). In fact, the number of publications on the theme of 'brain drain' grew from 34 in 2000 to more than 100 in 2011 (Beine et al., 2010). As this brain drain phenomenon induces migration, several facets—including the economic differences among the countries, net effect, and culture—play critical roles in migration (Clark et al., 2007; Cohen et al., 2008; Nguyen et al., 2014). A large number of studies that focused on highly educated or skilled people, or on the incidence and causes and effects of migration, have relied on different data sets. Important results emerged regarding turnover among technology talents, in which scholars carried out detailed theoretical analyses and conducted empirical studies. The variables examined in these studies are grouped into the following five categories: personal characteristics, such as age, gender, career length, and education level as proposed by Spencer and Steers (1981); organizational factors, such as price summary, organization team harmony, equitable salary distribution, and gaining the support of superiors and colleagues (Lee & Mowday, 1987; Mahroum, 2000b; Price, 2001); work factors, such as working conditions, consistency of work and expectations, work intensity, and work autonomy; environmental factors, such as Woodward's focus on employment opportunities and unemployment rate (Woodward, 1975); and the psychological factors, such as work achievement, organizational commitment, work integration (Lee & Mowday, 1987), and focus on work safety (Sousa-Poza et al., 2002). These variables are usually at the micro and individual level.

Other studies focus on the impact of scientific mobility on economic development and knowledge diffusion between home countries and immigrant countries at the macro level (Abel & Sander, 2014; Belot et al., 2012; Blume-Kohout, 2016; Bogue, 1977; Gomez et al., 2020; Jons, 1975; Kambourov et al., 2012). Most of these studies focus on migration during the financial crisis, inter-regional migration, or migration in specific countries (Dyachenko, 2017; Findlay et al., 2005; Hawthorne, 2008; Kahanec, 2013; Koikkalainen, 2013; Krisjane et al., 2013; Lowell et al., 2001). Note that some studies classify migrants as skilled and unskilled based on the extent of formal education and overlook the skill sets that are attained through job and life experiences (Hagan et al., 2015; Teichler, 2015).

Even though cross-sectoral or career-mobility are not new phenomena, changes in research systems—internationalization, increased inter-sectoral collaboration, and diversification of career and job roles—make researchers' mobility more relevant to the dynamics of knowledge creation and dissemination (Henning & Hovy, 2011). Ghoddusi and Siyahhan (2010) developed a 'real immigration option' model to analyze brain drain and educational choices. This study emphasizes the uncertainty that exists with regard to the extent of labor market integration, wage differential, and cultural proximity between the immigrating and emigrating countries. Other studies discuss the circumstances of migration in specific regions. For example, Nussenzveig (1969) references the causes of migration in Latin America to be complicated and changeable. Scott (2015), on the other hand, explores academic mobility in terms of two broad frameworks namely hegemonic internationalization and fluid globalization. The former denotes scientific migration from the periphery to an evolving core, while the latter looks at scientific mobility within the broader context of social movements, global communities, and economic issues.

This research contributes to the body of research on scientific mobility in several significant ways. For one, this is one of the few studies to use the ORCID database as a source. Also, this paper takes a novel approach, studying researchers' distribution and migration in different countries and tries to understand the features and factors influencing researchers' distribution in those different countries. The research aims to depict a macro distribution of researchers worldwide and then drills down to analyze PhD researchers and non-PhD researchers in different countries. It then identifies the placement of these researchers: Do they work mostly in academia, or in other organizations? The study also provides insight into the migration (mobility) patterns of both PhD and non-PhD researchers. Lastly, our study updates the prior studies and findings with a more state-of-the-art view of scientific mobility.

3. METHODOLOGY

Our methodology includes the stages of data collection and variable selection, data preparation, analytics platform and tool selection, and analytics implementation.

3.1 Data Collection

Data in this research was collected in summer 2019 from the public dataset of ORCID for the period 1970 to 2017. Due to the lag in entering data into the ORCID system, the period through 2017 offers the most up to date data. The ORCID organization offers an open and independent registry of details regarding scientists, procured by way of their publication records and biographical data. Specifically, we downloaded data from the following link: https://support.orcid.org/hc/en-us/articles/360006897394-How-do-I-get-the-public-data-file-#02-a. Upon graduation all students, especially PhD students, have the option to register themselves in the ORCID database—for example PhDs can conveniently find their information in the ORCID database to add as an author for the manuscript that they would like to submit in any journal or conference paper submission portal. Given the high popularity of the use of ORCID by PhDs, we use this database for our study.

Scientists, academic authors, and contributors are uniquely identified via a persistent digital identifier. Our data relates to 194 countries and approximately 6,237 PhD movement records. This virtually universal coverage of scientists provides a rich dataset for exploring the nature of scientific mobility. The key variables examined in this research are listed in Table 1.

3.2 Visualization

This data-driven study uses a visualization approach with primarily descriptive analytics (Börner, 2019; Sun et al., 2013) to obtain a panoramic insight into scientific mobility procured from the ORCID dataset. Visualization enables researchers and policymakers to analyze large datasets, while acting on the results in real time (Keim, 2001; Keim et al., 2008; Kohlhammer et al., 2011; Raghupathi & Raghupathi, 2020; Thomas & Cook, 2005; Wong & Thomas, 2004). Visualization allows one to discover unexpected patterns and insights that can lead to innovative and novel solutions (Kohlhammer et al., 2011; Thomas & Cook, 2005; Tufte, 2001; Tukey, 1977) and allows one to understand a phenomenon in depth (Keim, 2001; Keim et al., 2008; Kohlhammer et al., 2011; Raghupathi & Raghupathi, 2020; Thomas & Cook, 2005). Also, visualization scales the hurdle of information overload by translating information into viable insight and by enabling examination of results and processes that lead to those results (Keim, 2001; Thomas & Cook, 2005; Wong & Thomas, 2004). The goal of this study is to convey a cohesive story using one of the three pillars of data science, namely visualization (Keim, 2001; Kohlhammer et al., 2011). Descriptive analytics relies on the premise of describing data as is with no preconceived assumptions. It is primarily more data driven and enables comprehending past and current patterns and data trends, as well as using the insight for informed decision-making (Kohlhammer et al., 2011; Thomas & Cook, 2005). Information is depicted visually in the form of meaningful charts and reports, utilizing the techniques of categorization, characterization, and aggregation or classification of data to gain insight to make business decisions (Kohlhammer et al., 2011; Thomas & Cook, 2005). In the context of scientific mobility, we utilized visualization with descriptive analytics. We explored the data and let the data

Table 1. Variables in the research

Variables	Description
Orcid_id	Unique open digital identifier
Country	The country or territory in which the research organization is located
Affiliation_type	Organizational affiliation of the researcher, whether with an academic institution or an industry
Earliest_year	Year of the degree
Earliest_country	Country of the degree
End_year	End date of relationship with the organization, e.g., the date that the researcher was awarded the degree
Has_migrated	Has researcher migrated to another location?
Has_phd	Does researcher have a PhD?
Organization_name	Name of the organization
Phd_country	Country where the PhD researcher received the degree
Phd_year	Year in which the PhD researcher received the degree
Start_year	Start date of relationship with the organization, e.g., the date that the researcher started the degree program

inform the findings in a bottom-up approach. Based on Van Wijk's (2005) value of visualization, we adopted an explorative empirical approach via visualization to address our research questions. The following section discusses the results of the analyses.

4. RESULTS AND ANALYSIS

Since we aim to compare countries on different dimensions and to examine trends over time, we mainly used histograms, line charts, pie charts, map charts, and tree maps.

4.1 The Geographic Distribution of PhD Researchers Among Different Countries

We explored the geographic distribution of PhD researchers among different countries (Figure 1).

The intensity of the color denotes a higher concentration of PhDs in the country. The United States has the highest number of PhD researchers registered in ORCID, with 52,499, or approximately 16% of the total. The United States (US) is followed by Brazil (BR), Great Britain (GB), China (CN), India (IN), Spain (ES), and Australia (AU). By contrast, island countries such as Marshall Islands (MH), Wallis and Futuna Islands (WH), Fiji (FJ), Mauritius (MU), French Polynesia (PF), Bermuda (BM), Falkland Islands (FK), Grenada (GD), and Guam (GU) each have a significantly fewer PhD researchers, at fewer than 20 PhD researchers per country. In this context, it is relevant to point out that some of the countries that show a relatively low number of PhDs are ones that are characterized by an economy that is more based on tourism. It is also possible that some countries may not have researchers registering in ORCID as regularly.

4.2 The Geographic Distribution of Non-PhD Researchers Among Different Countries

In Figure 2, we explored the geographic distribution of non-PhD researchers across different countries. The distribution of non-PhD researchers is analogous to that of the PhD researchers (Figure 1), except for Russia (RU) and Brazil (BR). The United States, again, has the highest number of non-PhD researchers (36,431, which is about 9%), while Russia (RU) (11,196) and Brazil (BR) (23,502) have

Figure 1. Distribution of PhD researchers in ORCID in different countries

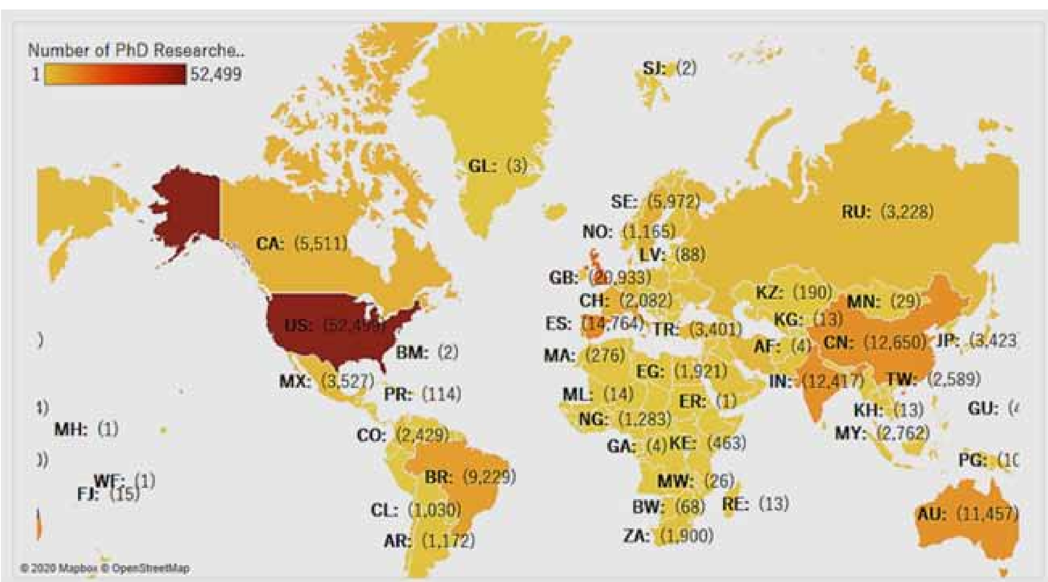
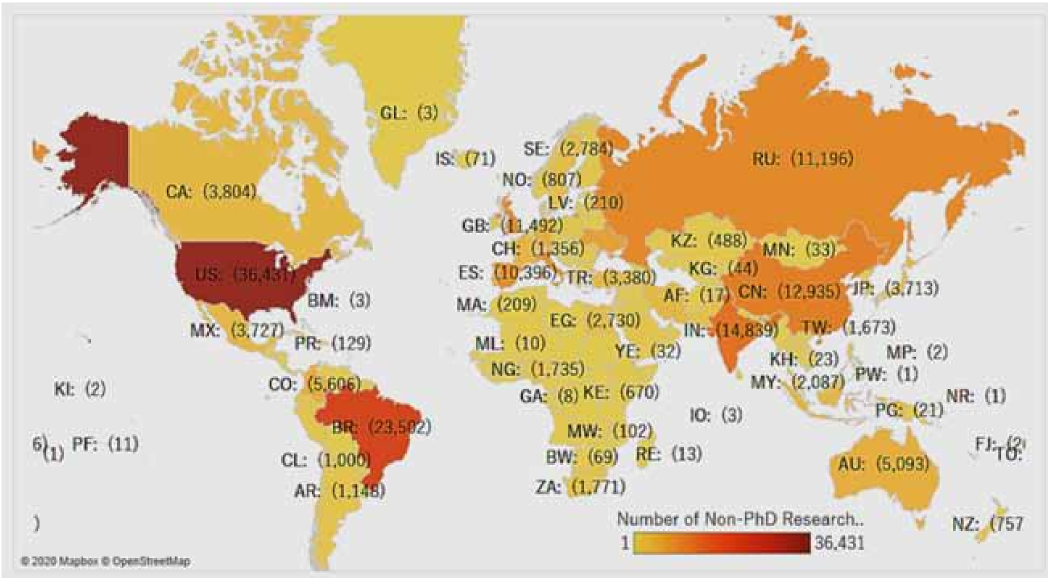


Figure 2. Distribution of non-PhD researchers in ORCID in different countries

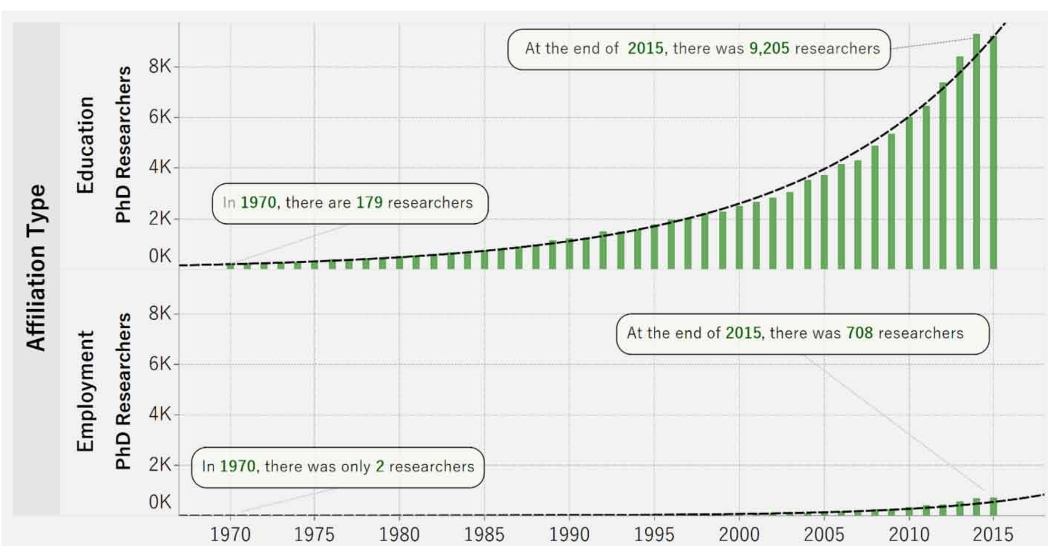


relatively higher numbers of non-PhD than PhD researchers. Australia (AU) has half the number of non-PhD researchers (5,093) as PhD researchers (11,457).

4.3 Number of Researchers by Affiliation Type for the Years 1970 to 2015

We explored the data to see if PhD researchers were affiliated with academia (shown as education) or industry (shown as employment). Figure 3 shows the trend of the number of researchers by affiliation type for the years 1970 to 2015. It shows that the number of PhD researchers in academia

Figure 3. The trend of PhD researchers over the years by affiliation type



is significantly higher than that in industry. The trends for both types indicate an increasing pattern showing that the number obtaining a PhD increased over the years at a significant rate. From 1970 to 2015, the number of PhD researchers in academia increased from 179 to 9,205, while the number in industry increased from 2 to 708. The increasing pattern shows promise and opportunity for PhD researchers in industry as well as academia worldwide. Researchers can help make economies more productive and innovative by advancing knowledge across academia and industry (Hutt, 2019).

4.4 PhD Migration Over Time From 1968 to 2015

Figure 4, a stacked bar chart, displays PhD migration over time, from 1968 to 2015. The orange bar represents the number of PhD researchers who had migrated, while the blue bar shows the number of PhD researchers who had not migrated. The total height represents the cumulative number of researchers. The overall number of PhDs shows an increasing trend, with a peak in the year 2014. In 2015, the number of PhD researchers dropped slightly, to 16,911 from 17,385 the previous year. The total number of migrated PhDs also experienced an increasing trend over time from 1968 to 2013. The numbers dropped slightly in 2014 and 2015. This could be an effect of increasing participation in higher education globally. Also, since ORCID data is self-reported, the increasing trend may be a reflection of the popularity of ORCID among researchers.

4.5 The Top Five Affiliation Roles and the Top Five Degrees

In addition to affiliation type, we also looked at the top 5 affiliation roles (Lecturer, Assistant Professor, Associate Professor, Professor, and Researcher) and the top 5 degrees (Masters, MD, MSc, PhD student, and PhD researcher) as shown in Figure 5. Being a descriptive study, this would help us get an idea into the trajectory of scientists in terms of education as well as career. In terms of affiliation roles, the highest number of researchers are in the role of Assistant Professor (23,519) and Professor (23,336). This is followed by Associate Professor, Lecturer, Researcher, and Research Assistant. In terms of degree, the highest number of researchers is in the PhD degree (102,905). The other degrees of Masters, Doctor of Medicine (MD), Master of Science (MSc), and PhD Student have fewer than 10,000 each, or one-tenth the number of PhDs.

Figure 4. Trend of the number of PhD researchers and migrated PhD researchers

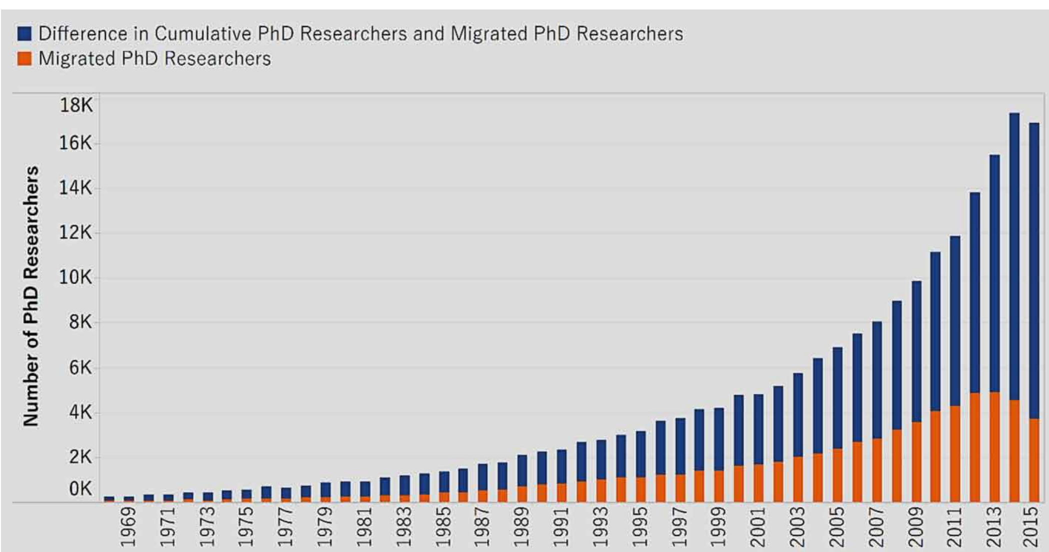
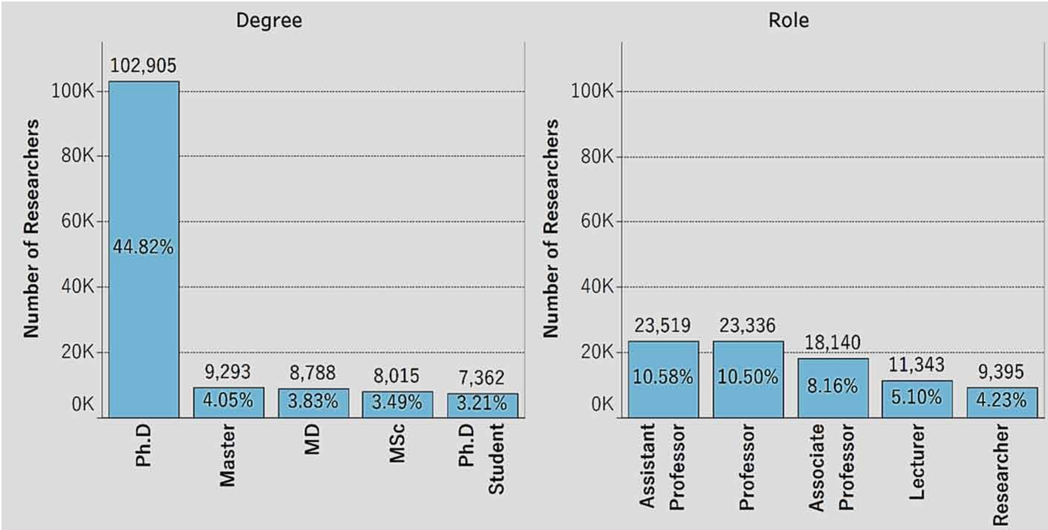


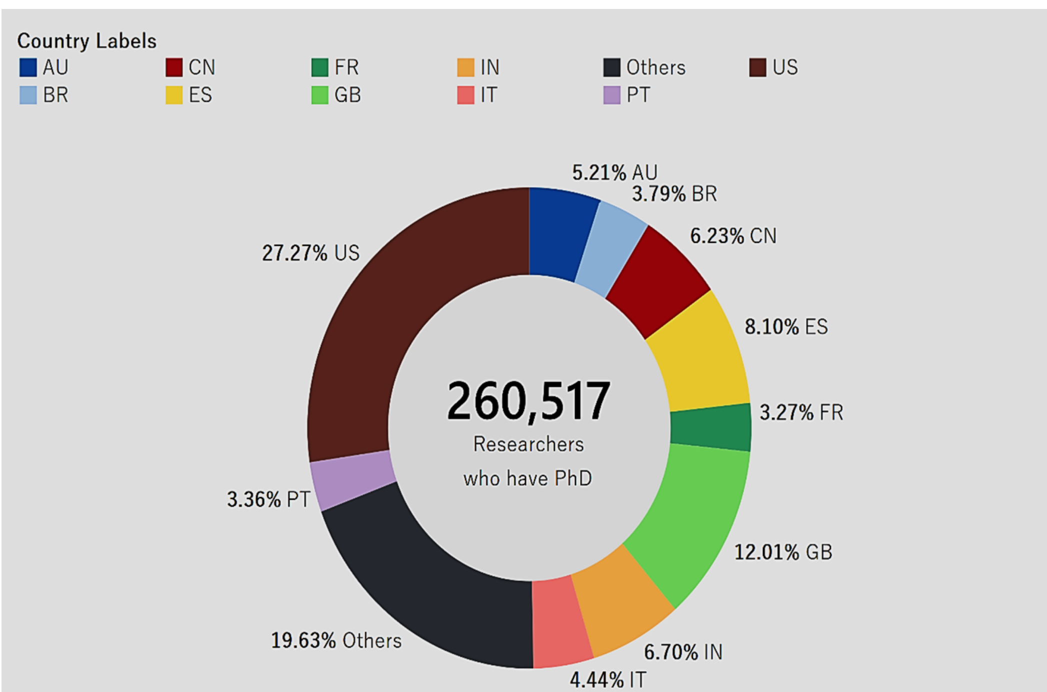
Figure 5. Distribution of researchers across affiliation roles and degrees



4.6 The Distribution of PhD Researchers by Country

Figure 6 depicts the distribution of PhD researchers by country. The chart highlights the top 10 countries with the highest number of researchers registered in ORCID. The United States has the most PhD researchers in the world with approximately 30%, followed by Spain (ES), Great Britain

Figure 6. Percentage of PhD researchers by country



(GB), and India (IN). Some countries, like Brazil, train a higher number of PhD researchers, while others, such as China, train fewer.

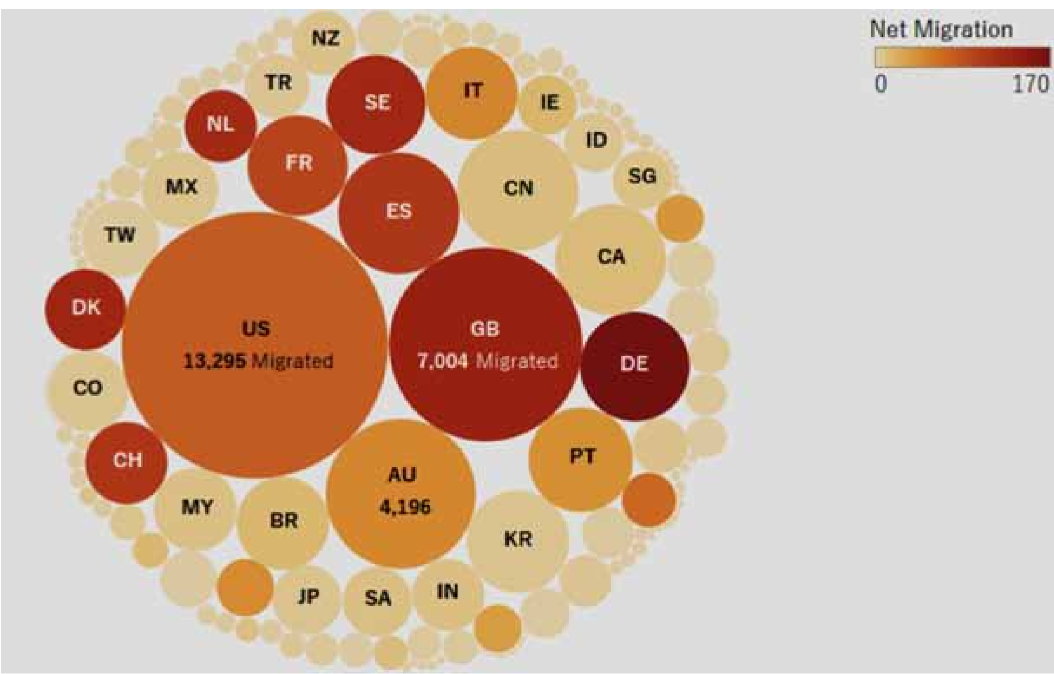
Not only does the United States produce the highest number of PhDs, but it also attracts a large percentage of PhDs from other countries, contributing to mobility but also to a possible brain drain in the country of origin. Given that the United States produces the highest number of PhDs, it follows that it provides a sound infrastructure for higher education.

4.7 The Migration Patterns of PhD Researchers Between Countries

Next, we explored the migration patterns of PhD researchers between countries.

Figure 7 depicts a bubble chart showing the migration patterns of PhD researchers in various countries. The size of the bubble reflects the number of PhDs who migrated from different countries. The larger the bubble, the greater the number of migrants. Meanwhile, the intensity of the color represents the net migration, or the difference between the number that migrates into, and the number that migrates out of, a country. The darker the bubble, the larger the number of PhDs migrating into the country. Figure 7 shows that the United States (US) had the highest number of migrated PhDs, with 13,295 researchers (18%), followed by Great Britain (GB), with 7,004 researchers (9.5%). These two countries have relatively high numbers of PhDs overall. The fact that approximately one-third of PhD researchers in the United States come from other countries can be a large contributing factor to global scientific mobility. On the other hand, countries such as the Netherlands (NL), Denmark (DK), Belgium (BE), Finland (FI), Austria (AT), and Norway (NO), have a higher number of PhDs but a lower number of net migrations. Note that the majority of PhD researchers in Europe earned their degrees in their home country. It is natural that these countries attempt to offer incentives to attract more doctoral candidates, such as charging lower fees or recognizing them as employees rather than as students (Hutt, 2019). It is clear that further investigation is needed to explore the reasons for migration.

Figure 7. Distribution of PhD migrations between countries



4.8 Number of PhDs Who Migrated From the United States During the Period 2000 to 2016

Figure 8 depicts the number of PhDs who migrated from the United States during the period 2000 to 2016. The trend shows that the number migrating out of the United States shows a marked increase in 2003 and a decrease in 2012; the year 2016 had the lowest number of PhD migrations. Among the more popular countries that American PhD researchers were likely to migrate to were China, Great Britain, and Canada. However, the total number of researchers migrating to these countries also decreased rapidly from 2012. This is the period in which the United States economy experienced significant economic growth.

4.9 Number of PhD Researchers Who Migrated to the United States From the Top 10 Countries

Figure 9 shows the number of PhD researchers who migrated to the United States from the top 10 countries. The chart shows that migrations in general began to decline in 2016. Among these 10 countries, China, Canada, Great Britain, and India have the highest number of PhDs migrating to the United States. A comparison of Figures 8 and 9 shows that for some countries the number of PhDs migrating to the United States is relatively higher than the number of PhDs migrating from the United States, such as for India and China. This implies that at the time during which the data was gathered, these countries were facing brain drain. It is also possible that there is lack of self-reported data in ORCID for the year 2016.

4.10 The Migration Pattern of Researchers in Educational Organizations within the United States

In Figure 10, we take a closer look at the migration pattern of researchers in educational organizations within the United States. As shown, the University of California at Berkeley has the highest number of PhD researchers (about 14%), followed by the University of Michigan (about 12%), and MIT (about 11%). Other institutions, such as the University of Pittsburgh (6.11%), Colorado State University, Boulder (5.04%), and the University of California, Irvine (0.26%) show relatively lower numbers of

Figure 8. Drill down analysis of PhD migrations from the United States from 2000 to 2016 (top ten countries)

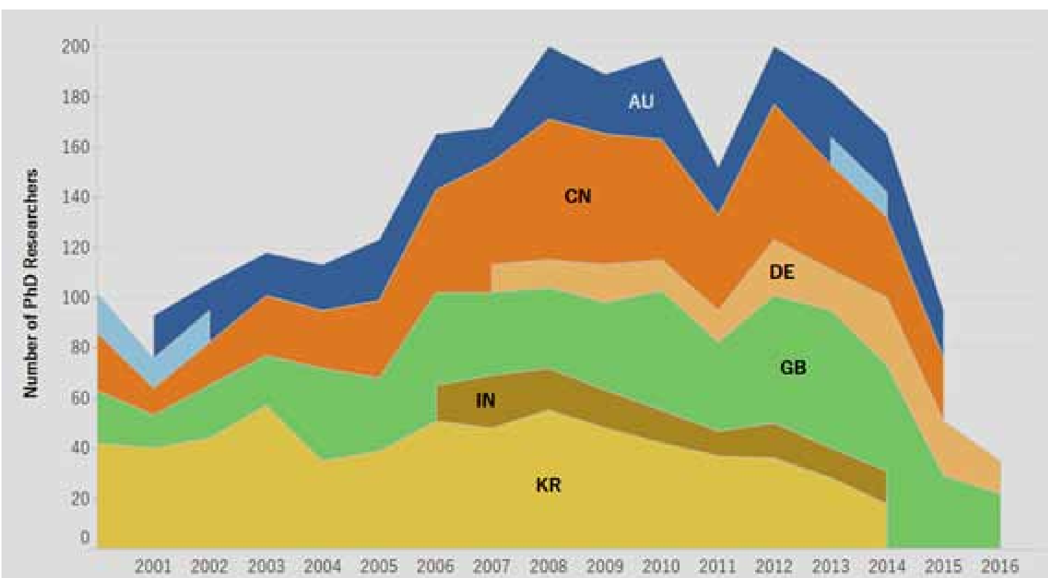
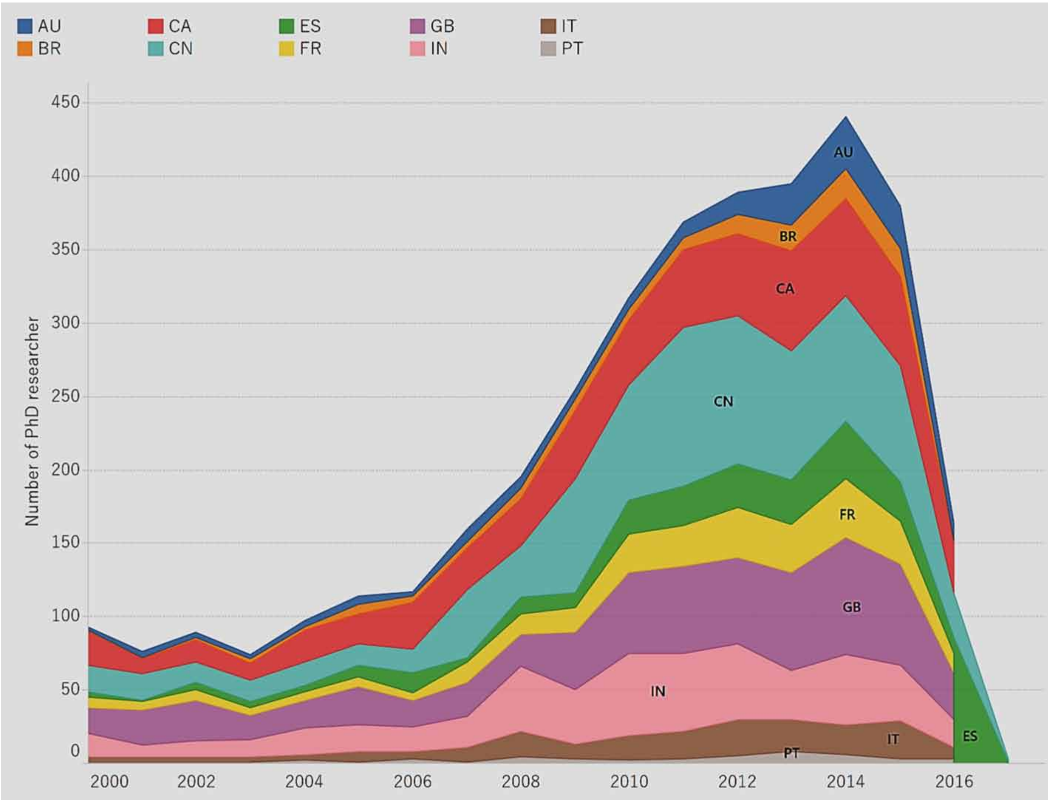


Figure 9. Analysis of PhD migrations to the United States between 2000 and 2016 (top ten countries)



PhD researchers. This gives us an idea of which American institutions are more research-oriented and/or attract more doctoral candidates. Future research can follow the patterns of international versus national student distribution in these institutions to offer further insight into reasons for migration.

4.11 The Top 25 Research Organizations in 2016

In Figure 11, we drill down into the top 25 organizations worldwide with the highest numbers of PhD-educated researchers in the year 2016. The United States has the highest number of organizations in the top 25 list (headed by Texas A&M), followed by Spain and Great Britain. On the other hand, despite having relatively high numbers of PhD researchers, other countries, such as Russia and China, do not appear among the top 25 organizations. It is natural that developed countries, such as the United States and Great Britain, have an advantage over others in terms of infrastructure and resources for higher education. Private funding for higher education is an important dimension that may also account for differences.

4.12 The Top Seven Countries With the Most Researchers in Academia in 2016

Figure 12 shows the top 7 countries in terms of the number of researchers in academia in 2016. The X-axis shows the university ID and the mark shows the university name. The Y-axis represents the number of researchers. As shown in Figure 12, Spain had the highest numbers of academic PhD researchers worldwide in 2016, particularly at Complutense University of Madrid (UCM), Universidad de Sevilla, and University of Barcelona. Following Spain, Brazil and Italy also show high numbers of academic PhD researchers in 2016.

Figure 10. Drill down analysis of PhD researchers' migration within the United States (top ten)

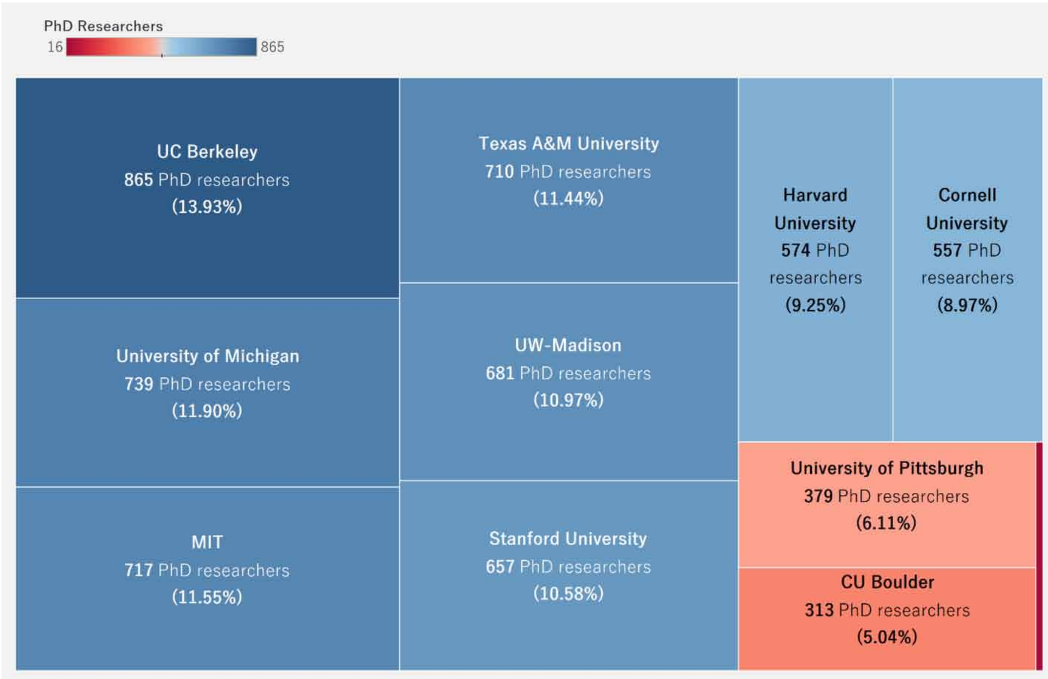
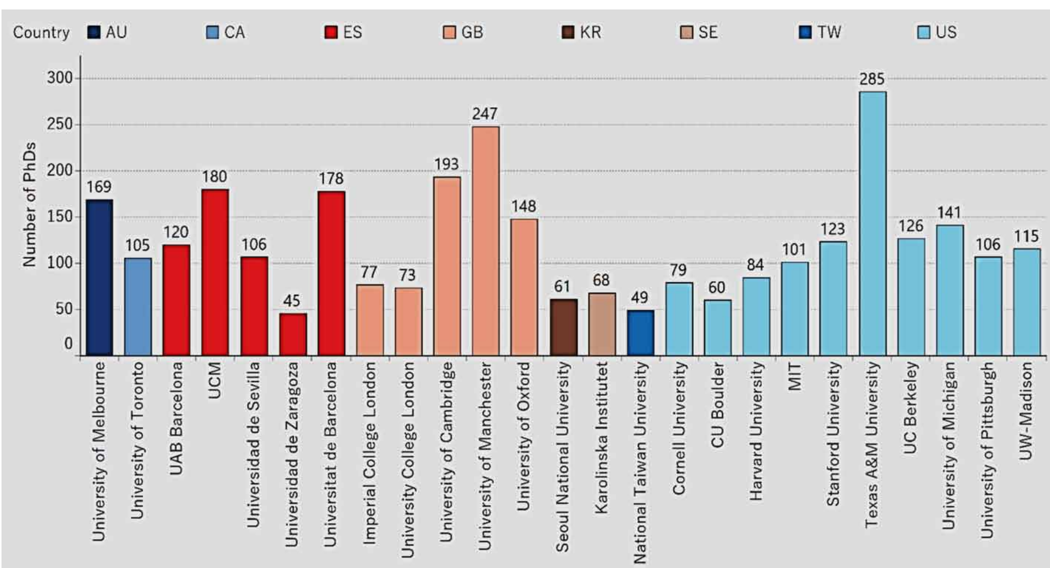


Figure 11. Distribution of PhDs in key organizations worldwide in 2016



4.13 The Distribution of Non-PhD Researchers Across the World

Figure 13 shows the distribution of non-PhD researchers across the world. It focuses on the top 10 countries with the highest numbers. As shown, the United States has the highest number of non-PhD researchers, followed by Brazil, China, Spain, Great Britain, and India, in that order. Compared to

Figure 12. Analysis of top seven countries with the number of PhD researchers in academia in 2016

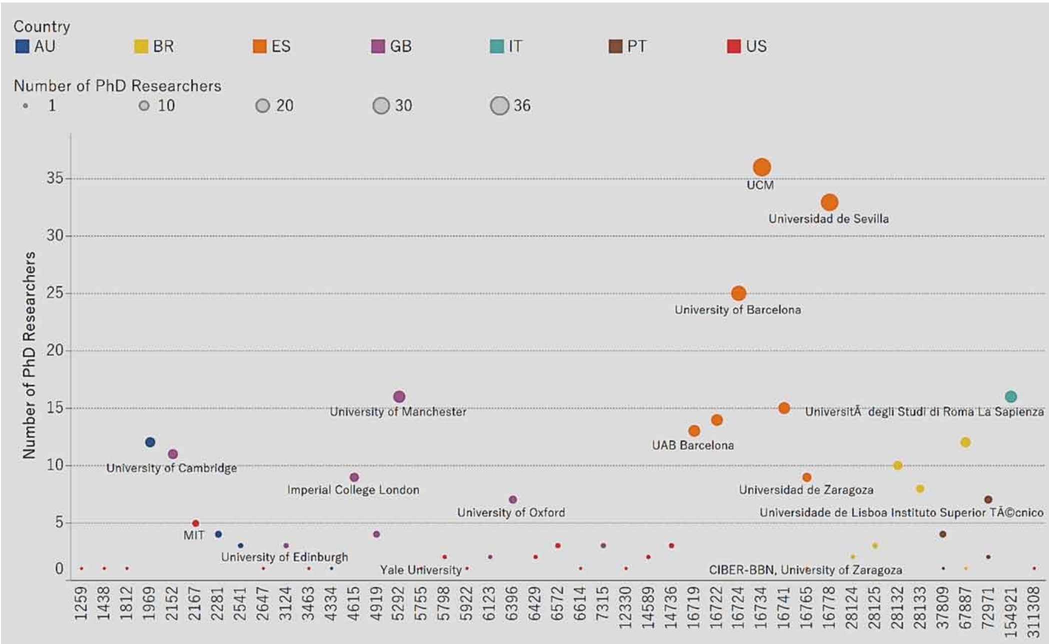


Figure 13. Distribution of non-PhD researchers by country (top ten countries)

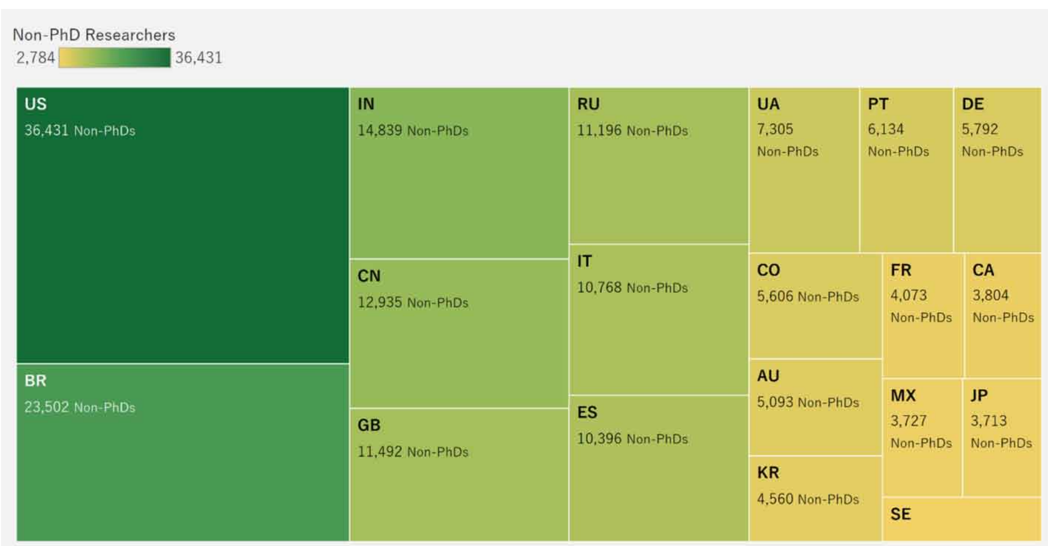


Figure 2, countries such as Brazil and China have more non-PhD than PhD researchers. The United States seems to have a high number of PhD as well as non-PhD researchers, reflecting the priority given to research nationwide.

4.14 Migration of Non-PhD Researchers for the Top 20 Countries With the Most Non-PhD Researchers

Figure 14 shows the percentage of migration of non-PhD researchers for the top 20 countries that has the highest number of non-PhD researchers. Compared to PhD researchers, the percentage of non-PhD researchers who have migrated is significantly lower. This could be because non-PhDs have a relatively less competitive advantage in the international research market when compared with PhDs. Additionally, some countries stipulate the PhD as a prerequisite for some research positions.

It would appear that non-PhD researchers prefer to stay in their home countries rather than look for opportunities in foreign countries. This can be a balance to the phenomenon of brain drain.

In Figure 13, the number of non-PhD researchers in Brazil, Ukraine, Iran, and Russia is greater than the PhD researchers (> 97%), and those non-PhDs rarely migrated to other countries. A possible reason for the low migration could be the kind of academic climate that is reinforced by the national leaders of countries such as Iran. For example, the election of Iranian President Hassan Rouani resulted in a more progressive and international academic national climate when compared to his predecessors such as Mahmoud Ahmadinejad (ICEF Monitor, 2021).

4.15 Non-PhD Researchers by Affiliation Type and Organization

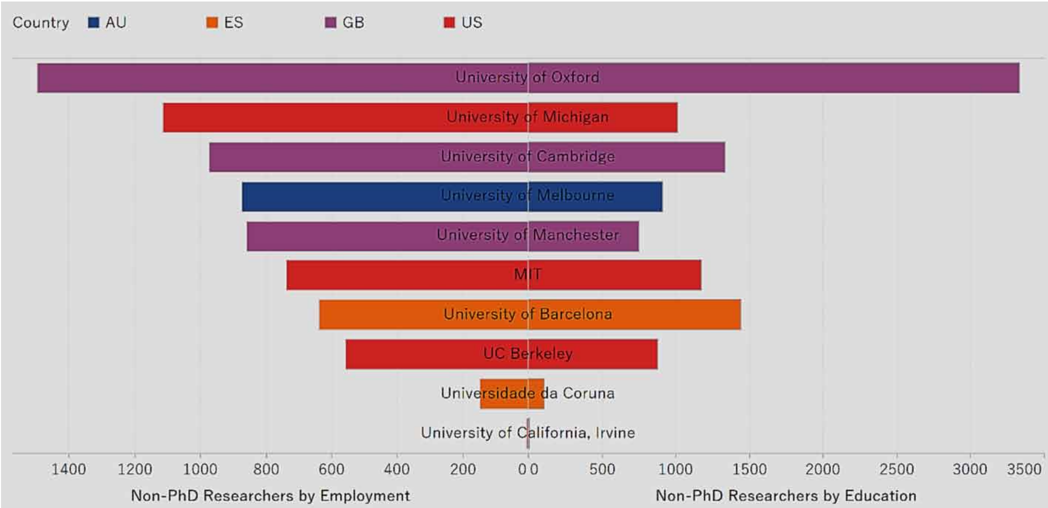
Figure 15 shows the number of non-PhD researchers by affiliation type of academia (education) versus industry (employment), and by organization. The number of non-PhD researchers at the University of Oxford far exceeds others. In general, it appears that the number of non-PhD researchers in academia (education) exceeds that in industry (employment). Even though countries like Brazil (BR), China (CN), India (IN), and Russia (RU) have relatively large numbers of non-PhD researchers (as seen in Figure 2), these countries do not appear in Figure 15. We can therefore infer that these countries do not have large organizations with big contingents of non-PhD researchers. Typically, non-PhD researchers in these countries tend to be dispersed across multiple organizations.

Figure 14. Migration of non-PhD researchers in various countries (top 20 countries)

Country 2016	Country Name	Not Migrated	Has Migrated
US	United States	90%	10%
UA	Ukraine	98%	2%
SE	Sweden	88%	12%
RU	Russia	97%	3%
PT	Portugal	91%	9%
MX	Mexico	91%	9%
KR	The Republic of Korea	87%	13%
JP	Japan	91%	9%
IT	Italy	95%	5%
IR	Iran	97%	3%
IN	India	97%	3%
GB	Great Britian	89%	11%
FR	France	90%	10%
ES	Spain	94%	6%
DE	Belgium	86%	14%
CO	Colombia	89%	11%
CN	China	94%	6%
CA	Canada	83%	17%
BR	Brazil	97%	3%
AU	Australia	85%	15%

Percentage of Researchers 0.0% 100.0%

Figure 15. Non-PhD researchers by affiliation type and organization

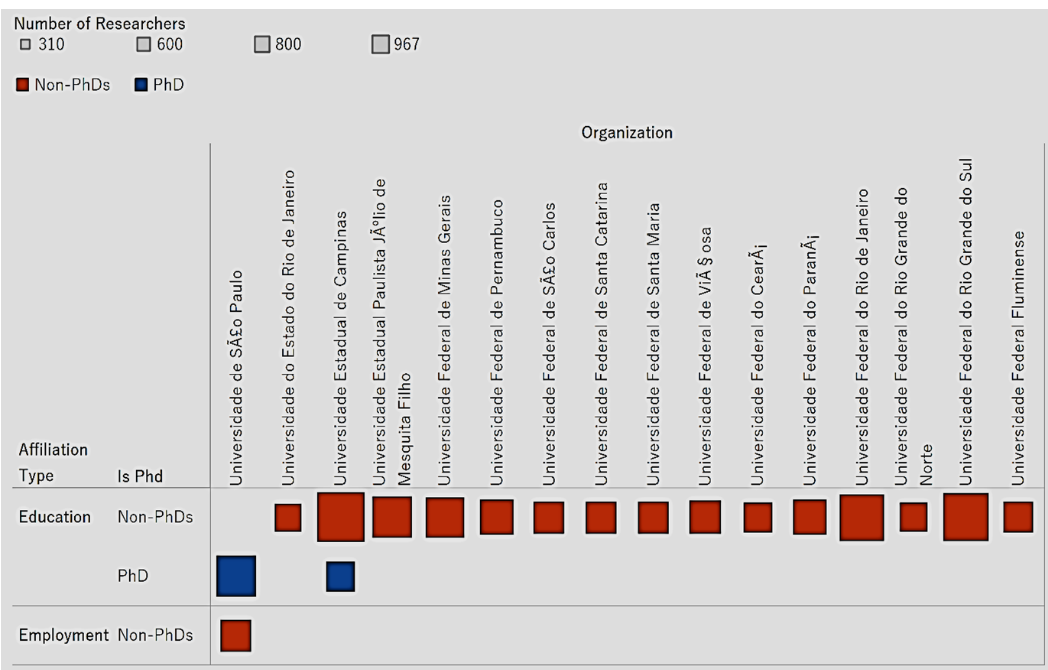


With this in mind, we explored further the distribution of researchers in countries like Brazil, Russia, China, India, and the United States.

4.16 The Distribution of PhD and Non-PhD Researchers in Brazil

Figure 16 shows the distribution of PhD and non-PhD researchers in Brazil (BR) across different organizations by affiliation type—academia (education) vs. industry (employment). The size of each

Figure 16. Distribution of researchers in Brazil by affiliation type



square represents the relative number of researchers. The data is drilled down to the total number of researchers, which is roughly 300. In academia (education), there is a tremendous number of non-PhD researchers that are distributed across different organizations, except for Universidade de São Paulo. In contrast, Universidade de São Paulo has the highest number of PhD researchers, more than 800, followed by Universidade Estadual de Campinas. In industry (employment), there are no researchers with a PhD in Brazil, but there are approximately 600 non-PhD researchers who are registered under ORCID. Overall, Brazil has a significant number of non-PhD researchers and a smaller number of PhD researchers, with the majority of researchers being in academia.

4.17 The Distribution of PhD and Non-PhD Researchers in Russia

Figure 17 depicts the distribution of PhD and non-PhD researchers in Russia by affiliation type. The color and size of squares represent the number of researchers in different organizations. The data is drilled down to the total number of researchers, which is approximately 100. As the figure displays, the number of researchers in large organizations in Russia is fewer than in Brazil, thus the concentration of researchers is less. There are no PhD researchers at large education or employment affiliations, and most non-PhD researchers are affiliated with educational institutions.

4.18 The Distribution of PhD and Non-PhD Researchers in China

Figure 18 depicts the distribution of PhD and non-PhD researchers by affiliation type in China. The color shows the number of researchers in various organizations. Data is filtered by the total number of researchers, which is approximately 300. The figure indicates that most researchers in China are non-PhD academic (educational) researchers. Tsinghua University has the most researchers, including PhD researchers. Peking University also has a large number of non-PhD researchers compared to PhD. Zhejiang University does not have many researchers, but it has both PhD and non-PhD researchers.

4.19 The Distribution of PhD and Non-PhD Researchers in India

Figure 19 depicts the distribution of PhD and non-PhD researchers in India by affiliation type. The color shows the number of researchers in various organizations. Data is filtered by the total number

Figure 17. Distribution of researchers in Russia by affiliation type

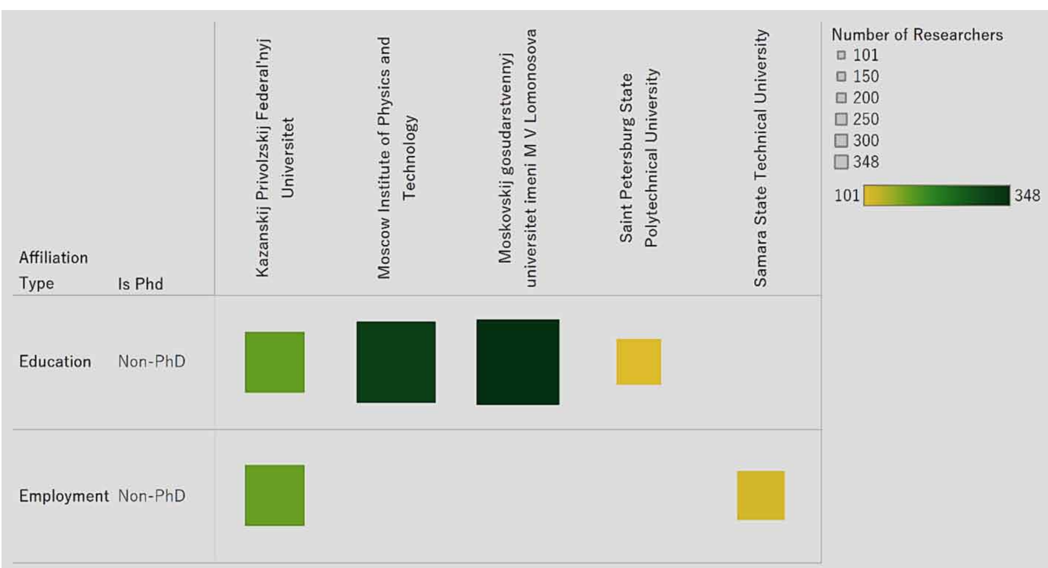
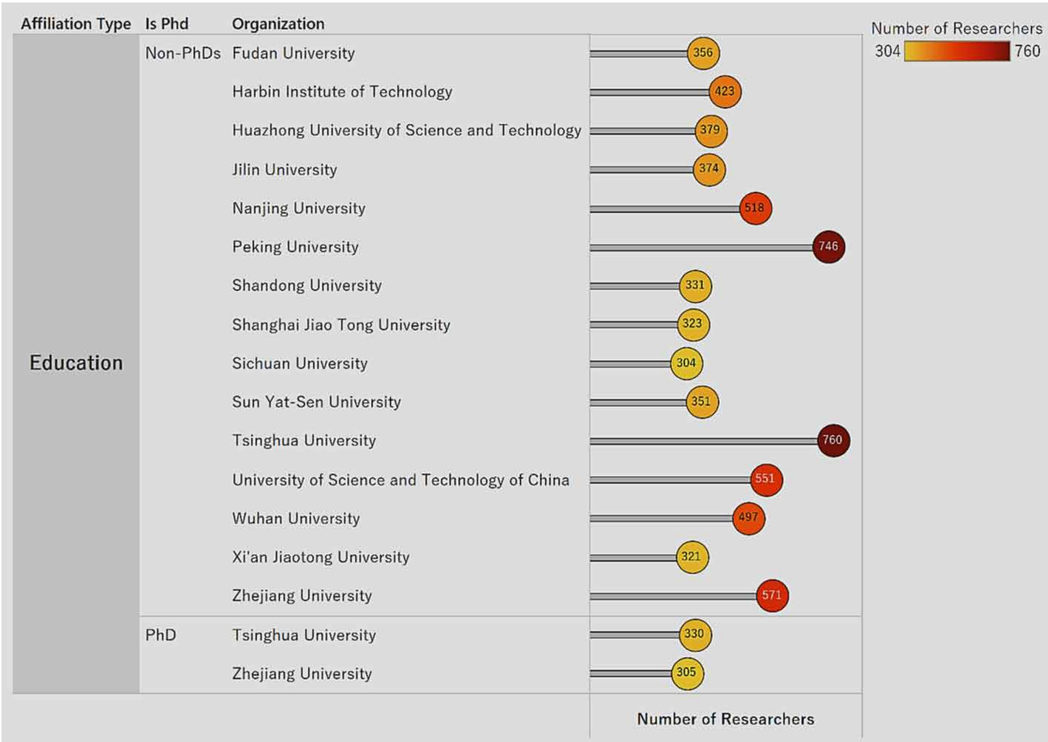


Figure 18. Distribution of researchers in China by affiliation type



of researchers, which is approximately 150. The figure indicates that most researchers in India are non-PhD educational researchers. Anna University Chennai has the most researchers, including non-PhD researchers (316) and PhD researchers (240). Indian Institute of Technology Kanpur and Indian Institute of Technology Madras also have relatively large numbers of both PhD and non-PhD researchers. Most researchers registered in ORCID in India are affiliated with academia (education). In terms of industry (employment), there is only a small number of non-PhD researchers.

4.20 The Distribution of Researchers in the United States

Figure 20 depicts the distribution of researchers in the United States by affiliation type. Data is shown for the top 10 organizations with the highest number of researchers. The figure indicates that most PhD researchers in the United States are affiliated with an educational institution. UC Berkley has the highest number of PhD researchers (more than 800), followed by the University of Michigan, Texas A&M University, and MIT. On the other hand, MIT leads the number of non-PhD researchers in academia, followed by the University of Michigan, and UW-Madison. Compared to other countries, however, in terms of industry (employment), the US has a relatively high number of researchers, especially at CU Boulder (more than 1,200 researchers), although all of these are non-PhDs.

4.21 PhD and Non-PhD Migrations and Non-Migrations in Different Countries

Figure 21 is a stacked bar chart that shows PhD (red) and non-PhD (grey) migrations and non-migrations in the countries Australia, Brazil, China, Great Britain, India, and the United States. As seen, in general, the number of PhD (red) migrants are higher in each of these six countries. This shows that if a researcher has a PhD, the potential migration is higher than that of a non-PhD.

Figure 19. Distribution of researchers in India by affiliation type

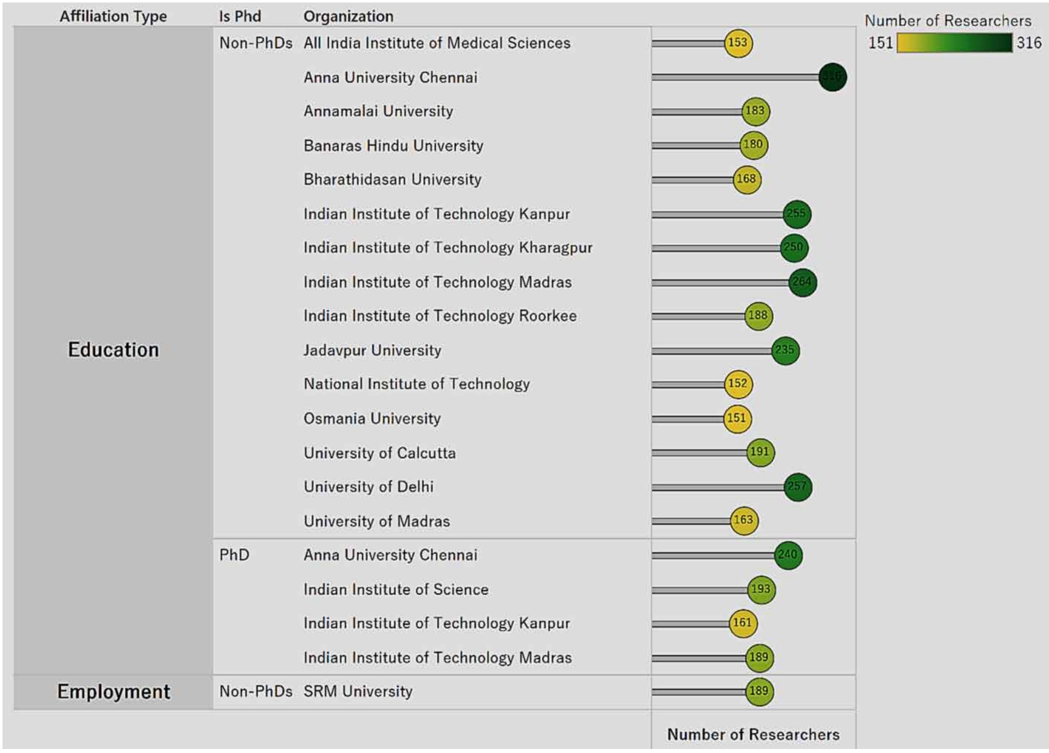
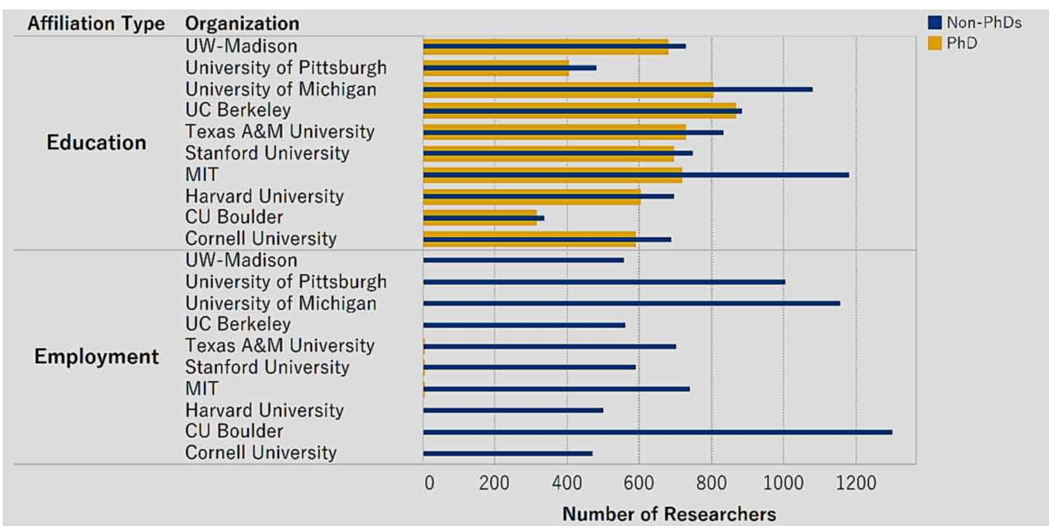


Figure 20. Distribution of researchers in the US



4.22 Number of PhD Researchers Who Migrated to the United States and Other Countries

Figure 22 depicts a trend of the number of PhD researchers who migrated to the US and other countries. The cumulative number of PhD researchers from 1971 to 2016 is displayed for each country. Over

Figure 21. PhD and non-PhD migration in six countries

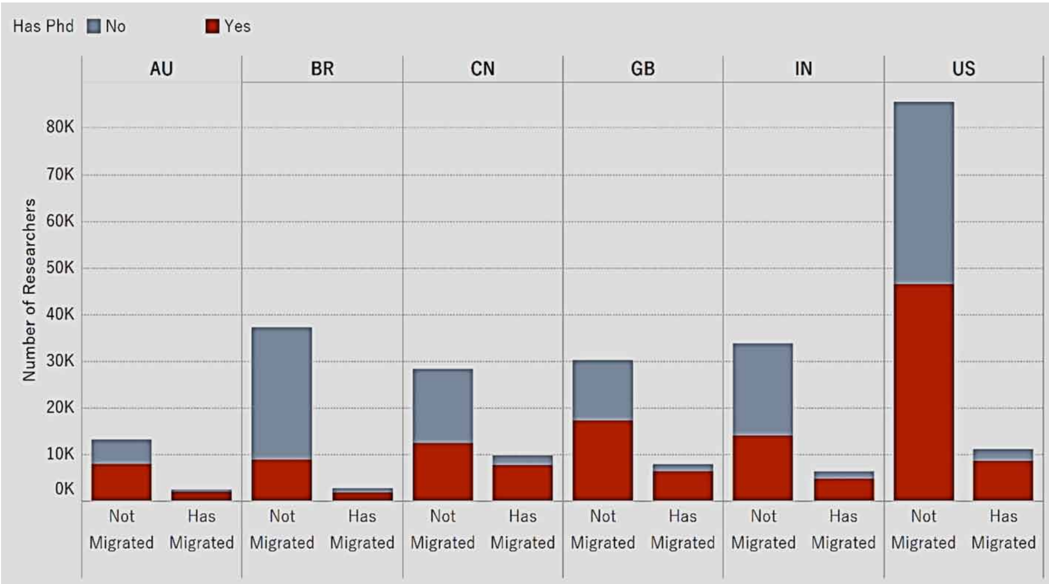
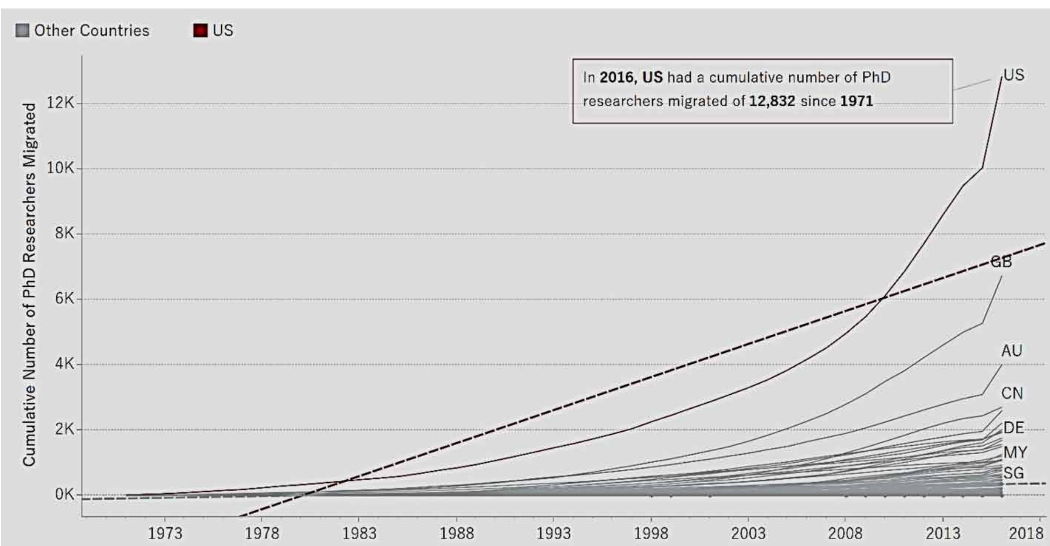


Figure 22. Trend of the number of PhD researchers who migrated to the United States vs. other countries (1971 to 2016)

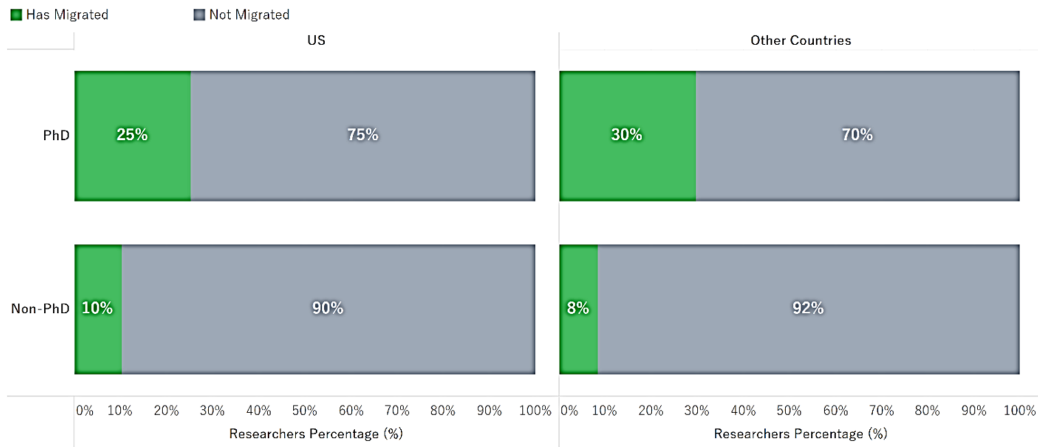


the years, the number of PhD researchers who migrated to other countries has increased significantly. In 2016, there were 12,832 PhD researchers who migrated to the United States. Following this are Great Britain, Australia, and China.

4.23 The Migration Percentages of PhD and Non-PhD Researchers for the United States Compared to All Other Countries

Figure 23 shows the migration percentages of PhD and non-PhD researchers for the United States compared to all other countries. Of the total number of PhD researchers in the United States, about

Figure 23. Comparison of PhD and Non-PhD migration for the United States and other countries



25% migrated. Among the non-PhD researchers, about 10% migrated. In the other countries, about 30% migrated while among the non-PhDs about 8% migrated. This again confirms that more PhD researchers are prone to migration while non-PhD researchers prefer to stay in their home countries.

5. DISCUSSION

Our analysis offers insight into different arenas. First, it provides a lens into the distribution of S&Es in different countries. At the outset, we found that the United States had the highest number of PhD researchers followed by Brazil, Great Britain, China, India, Spain, and Australia. This may reflect the popularity of ORCID in these countries over others. Second, in addition to the distribution of educated professionals, our analysis reflects the trends in scientific migration. Our findings show that while the overall number of PhDs has been increasing annually, in terms of migration, the trend has slowed in recent years. Additionally, the United States and Great Britain have the highest number of researchers (both PhD and Non-PhD) and research organizations in the world. As magnets for highly skilled and qualified scientists, particularly scientists from developing countries, it is natural that these developed countries will have the highest migration rates. In terms of geographical mobility, the majority of researchers migrating to the United States appear to be from China, Canada, Great Britain, and India. Most PhDs are also earned in home countries.

Third, our findings allow reflection on the level of national incentives and barriers that countries offer for scientific education. For example, compared to other countries, Brazil and Russia have a higher number of non-PhD researchers. The reason could be the prevalence of national level barriers to doctoral completion such as lack of funding, lack of readiness of the PhD institutional infrastructure for large-scale expansion of doctoral education, and difficulty transitioning to a structured model of doctoral education (Maloshonok, 2016; Maloshonok & Terentev, 2019).

It is also interesting to note the recruitment pattern of educated professionals in academia versus industry. Overall, our analysis shows that the number of PhDs employed in academia is higher than that in industry. This points to a general trend that more PhDs are seeking academic jobs. In addition, there is differentiation in the migration rate for PhDs and non-PhDs. The PhD migration rate is high, although the total number of PhD migrations is lower in the countries that have a higher number of researchers. In general, while the number of PhDs has increased over time, the number of migrating PhDs has dropped since 2012. The number of PhDs migrating out of the United States climbed in 2003 but decreased in 2012, while 2016 saw the lowest number of PhD migrations out of the United States. There may be a few possible reasons for the low migration out of the United States. The migration of PhD researchers depends on the state of the economy in the home and foreign country, the rules and regulations enforced on educational exchange, and the general state of the world market. One possibility is that the United States economy has improved or is perceived as offering better opportunities. However, Canada, China, Great Britain, and India continued to have the highest number of PhDs migrating to the United States. Relatively speaking, the number of PhDs migrating to the United States is higher than the number migrating out. This may be a cause for concern for developing countries from which the migration arises, particularly since this migration can result in brain drain.

Regarding migration to various organizations (e.g., universities, research centers, etc.), our results show that the University of California, Michigan, and MIT in the United States were the top institutions receiving migrant scientists, while Texas A&M University had the highest number of enrolled PhDs. Of all the countries, the United States, Spain, and Great Britain have the highest number of organizations with PhDs. It is noteworthy that China and Russia, while having a relatively high number of PhDs, are not among the top 25 countries in terms of organizations housing researchers.

Australia, Great Britain, and the United States had a higher number of employed PhDs in organizations. Looking at non-PhD researchers, the United States had the highest number, followed by Brazil, China, Spain, Great Britain, and India. Furthermore, in terms of migration, the number of non-PhD researchers who migrated was lower than that of PhD researchers. They were more likely to stay in their home countries. Exploring further, the United States and Great Britain had the greatest number of organizations employing non-PhD researchers, with the University of Oxford heading this list of organizations. At the same time, the number of non-PhD researchers in education (academia) was higher than in employment (other organizations). While Brazil, China, India, Italy, and Russia have more non-PhD researchers, they do not have large organizations with a concentration of researchers, so it is conceivable non-PhDs were dispersed within organizations in their native countries. Overall, while the number of non-PhD migrations in each of the major countries is more than that of PhD migrations, a PhD researcher is more likely to migrate compared to a non-PhD researcher. In general, more PhD researchers choose to migrate to the United States or other countries, while non-PhD researchers choose to stay in their home countries. The United States and other developed countries continue to be magnets for migration of highly qualified scientists.

6. SCOPE AND LIMITATIONS

This study has some limitations. We extracted the data during a specific time period, that is, in summer 2019. Due to missing values and a lag in the updating of data in the ORCID system, 2017 is the earliest time period with complete data available that can provide a snapshot of scientific patterns and mobility. As the database expands and as more data becomes available for new variables, future studies can explore a longitudinal timeframe and utilize a more expansive set of variables. In addition, although we used the visualization method, there are alternative techniques—such as predictive statistical models and data mining (e.g., association, clustering, etc.)—that could potentially be deployed. Although visualization as a methodology offers descriptive analysis, further empirical investigation is needed to draw quantitative conclusions. Also, while this research focuses on PhD and non-PhD researchers and their mobility patterns across key countries, information on the effects of mobility (e.g., brain drain), researchers' productivity patterns, and additional demographic data are not included.

Additionally, the use of ORCID data, however relevant, comes with its own set of limitations in terms of coverage, representativeness, and lack of standardization (Gomez et al., 2020). In terms of representativeness, it is possible that the data in ORCID may be more representative of highly international and mobile young researchers. Access to individual demographic data would help ascertain whether certain researcher (scientist) demographics lead to different patterns of migration and mobility. Also, given that the source is secondary, one can only assume that the data were accurately recorded in the database. There may be additional variables, such as geopolitical risks, human rights and refugee aspects, coups and wars, health issues (e.g., epidemics), terrorism, religion, and other events that can in the future be studied in the context of impacting migration and mobility.

International scientific and technological talent mobility is both a well-established phenomenon and a new issue that is receiving increased attention. In the past, scholars have done qualitative analyses of the factors influencing the flow of international scientific and technological talent and have done so from different angles; others have proposed relevant models of the flow. But many of the studies are conducted at micro or regional levels. Therefore, future studies may examine large-scale global migratory patterns. Additionally, as the ORCID database collects data going forward, longitudinal time series studies could examine migration and mobility over time to study patterns and trends. Although this study is aimed at highly educated populations, these findings can serve as an essential reference for other researchers to replicate analyses, conduct their assessments, and better understand the flow of researchers in their environments. Further research may focus on systematic analysis of institutions with regard to mobility in people, disciplines, or research areas. It can also include analysis of specific institutions and countries with the most significant number of researchers as well as other incentives for domestic strategic approaches as an international partnership.

Also, the use of specific data to assess the impact of researchers' mobility (especially for internationally mobile researchers) is limited, and we should adopt more sources and types of data. In addition to descriptive analysis, other indicators can be included for broader evaluation and benchmarking, including refining the addition of researchers and activities, for example, creative efforts and international cooperation. Rewards and honors, among other indicators, can help determine the corresponding value of the researchers. Additional quantification of the benefits of migration may be identified. Research of scientific migration and mobility is at a nascent stage, but one can see how the availability of new data and analytical tools could accelerate its maturing process.

As more complete data becomes available, further studies can analyze differences in the types of researchers who migrate to target countries or migrate out of home countries as well as their long-term mobility trends. In addition, future studies can incorporate cultural and economic dimensions. This may help ascertain if culture and economic motivation impacts mobility. In the current context of scientific mobility, it will be interesting to explore whether mobility is impacted by geopolitical activities and risks.

7. CONCLUSION AND IMPLICATIONS

Our research draws the following conclusions. Overall, developed countries have more PhD researchers compared to developing countries, and these PhDs tend to be employed in large organizations, mostly in academia. The United States continues to have the largest number of non-PhD researchers. Typically, there is a net positive migratory flow of PhD researchers from home countries to the United States and Great Britain. But we see that the flow fluctuates based on factors including economic condition, immigration laws, and trends. However, overall, migration has been from developing to developed countries, warranting further investigation of the resulting brain drain.

As carriers of knowledge, highly educated people represent innovation and pre-eminence in research and advancement of science. They are also a driving force for economic growth, obviously a key goal of both developed and developing countries. By researching the phenomenon of scientific mobility and migration, our paper contributes to theory and practice in several ways. It revisits the much-studied phenomenon of highly educated scientific migration and expands the research significantly with an empirical analysis of newly available data from the ORCID database. In the context of scientific migration and mobility, studying the movement across borders is inherently a difficult task. Most research has been done indirectly by capturing publication data of scientists. While most studies have used traditional bibliometric databases to infer career progression from publication data, they lack the educational biographies of scientists. The current study utilizes ORCID, which includes self-reported educational, employment, and bibliometric data of scientists, thereby making it more comprehensive.

In terms of methodology, the paper contributes to the application of current techniques such as visualization and descriptive analytics. Using visualization, this research analyzes researchers' education level, migratory patterns, and whether they worked in academia or other organizations, across several countries. The advantage of visualization, a data-driven method, is to explore what the data directly reveal, with no preconceived notions as to the patterns and relationships. Additionally, data-driven studies have been used to understand and comprehend a phenomenon well.

With the increased global and regional connectivity of recent times, the relevance of global scientific mobility becomes an integral task. Our findings have strong practical implications for policy making. Governments can frame policies targeted towards attracting and retaining skilled talent. Further, policies can be designed to provide adequate social infrastructure for highly skilled professionals and their families.

As the ORCID database expands to include emerging PhDs and scientists from developing countries, it should be recognized that migration patterns and experiences of international scientists in developing countries may be different than in developed countries. This circumstance suggests additional research in this dimension. Future research can further explore a comparative hybrid approach involving bibliometric analysis as well as analysis of ORCID data to accurately contextualize the phenomenon of scientific mobility worldwide. Some issues associated with scientific mobility that warrant future exploration include open borders, trade agreements, and liberal immigration policies. Finally, while it may not be possible to prevent the increase of migration as a phenomenon, it may be possible for nations to carefully monitor and evaluate international scientific mobility with the objective of transforming the phenomenon of brain drain into brain circulation.

LIST OF ABBREVIATIONS

ORCID: Open Researcher and Contributor ID

DECLARATIONS

Availability of Data and Materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Competing Interests

The authors have no relevant financial or non-financial interests to declare.

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Authors' Contributions

All authors contributed equally to all parts of the manuscript preparation and submission.

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COMPLIANCE WITH ETHICAL STANDARDS

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COMPETING INTERESTS AND FUNDING STATEMENTS

The authors of this publication declare there are no competing interests.

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