




Mapping research collaborations in different countries and regions: 1980–2019

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Abstract

Most previous studies on research collaboration focus on only one particular indicator or several specific countries. The intention of this work is to examine and compare research collaborations performances in the 41 most productive countries or regions. To this end, we use indicators stemming from authorship datasets from Web of Science and InCites from 1980 to 2019. Five collaboration indicators, with respect to both the size and heterogeneity of research collaboration, were systematically examined. Results showed diversified views of collaboration patterns in different countries or regions by using different collaboration indicators. In the end, we analyzed the correlations between different collaboration indicators and synthesized them by descending dimension method.

Keywords Research collaboration · Collaboration indicators · Authorship size · Heterogeneity of collaboration

Introduction

Research collaboration has been demonstrated to be influential on scientists' productivity (e.g., Hu et al. 2014; Lee and Bozeman 2005), publication impact (Aman 2016; Glanzel and Thijs 2004; Guan et al. 2017; Hsu and Huang 2011; Katz and Hicks 1997) or a firm's innovation (Baba et al. 2009; Bodas et al. 2013; Chen and Guan 2010). Building stronger partnerships is at the core of science strategy for both individuals and institutions to conduct world-class scientific research. Consequently, in the past decades, research collaboration has evolved over time with the development of communication technology, and team science has increased considerably and coauthored publications have become much more prevalent (Aboukhalil 2014). To take just one recent evidence, a report by Clarivate Analytics based on articles in journals indexed in Web of Science has provided compelling statistical data to support the rise in author and country counts in the past ten years (Adams et al. 2019).

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Promoting and fostering research collaboration is already the consensus for all research management and policy making of each country's government. However, due to considerable variety across countries and regions in terms of their epistemic culture, language, geography and politics (Wagner et al. 2017), collaboration in some countries might be more prevalent than others. Many previous researches have proved that there is great variance in the extent to which collaborations seem to be conducted in different countries and regions. Yoshikane and Kageura (2004) compared the characteristics of four domains, and found that both the number of collaborating partners and the relationship strength with those partners varied greatly for different domains.

Research collaboration is becoming not only more extensive, but also more diverse. Using authors' affiliations, we could figure out the "cosmopolitanism" of collaborators. According to the definition by Bozeman and Corley (2004), collaboration cosmopolitanism measured the extent to which scientists collaborate with those around them (one's research group, one's university) as opposed to other universities, researchers in industry, or even researchers in other nations. In 1996, Melin has examined the subject of university's collaboration using institutional co-authorships as an indicator, to understand research collaboration in a social as well as a cognitive context (Melin 1996). Until now, we lacked a retrospective longitudinal analysis of global view of heterogeneous collaborations, e.g., international, interdisciplinary, or industrial collaborations. For disruptive innovation, heterogeneous collaborations are even more important and valued. Katz and Martin distinguished between collaboration at three levels: inter-individual collaboration in micro level, inter-institutional collaboration in meso level and inter-national collaboration in macro level (Katz and Martin 1997). This classification of collaboration patterns, frequently adopted in the follow-up studies (Wang et al. 2013), is also used in our study.

In this study, based on time-series collaboration indicators sourced from the InCites dataset from the Clarivate Analytics, we analyzed over 20 million scientists who were active from 1980 to 2019, in order to examine the diversity of research collaboration among 41 major countries or regions in the world.

Data and methods

Due to the accessibility of bibliometric data, co-authorship is continuously used as a main proxy for research collaboration. Five collaboration indicators will be used in this study, including three indicators of collaboration size, namely *# authors per paper*, *# organizations per paper*, and *# countries per paper*, as well as two collaboration heterogeneity indicators, namely, *% international collaboration*, and *% industrial collaboration*, as shown in Table 1.

All the five indicators could be achieved from Clarivate Analytics' InCites, either directly or indirectly. InCites is a comprehensive and reliable analysis and evaluation platform of scientists, institutions and regions based on Web of Science (WOS). WOS is by far the most historic and recognized scientific publication database. It indexes publications since 1901, sourced from more than 10,000 journals in all research fields including nature science, technology, engineering, medicine (SCI) and social science (SSCI). For each country or region, InCites could provide us a variety of indicators, including those of collaboration, as well as productivity and impact.

In this study, *% international collaboration*, and *% industrial collaboration* could be exported directly from InCites, but three indicators of collaboration size have to be

Table 1 Five collaboration indicators used in this research

Aspects	Levels	Indicators	Definitions
The size of collaboration	Inter-individual collaboration	# Authors per paper	Average number of authors involved in each paper
	Inter-institutional collaboration	# Organizations per paper	Average number of organization involved in each paper
	Inter-national collaboration	# Countries per paper	Average number of country or region involved in each paper
The heterogeneity of collaboration	Industrial collaboration	% Industrial collaboration	Percentage of publications those have co-authors from industry
	International collaboration	% International collaboration	Percentage of publications those have international co-authors

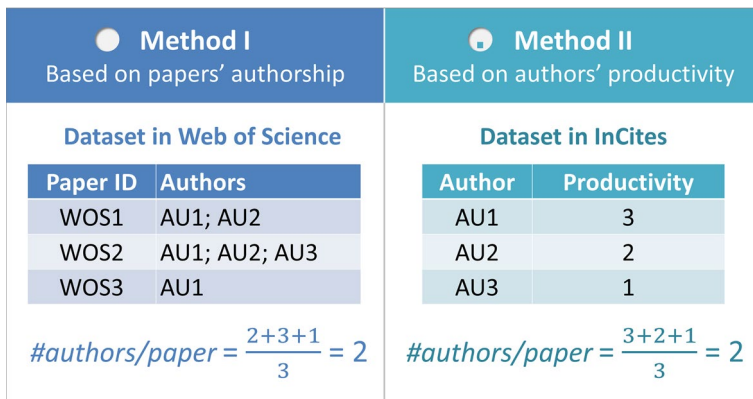


Fig. 1 Two methods for calculating the average number of authors per paper

calculated by ourselves. Taking the calculation of average number of authors per paper for example, there are two equivalent methods to conduct it, as shown in Fig. 1. Web of Science could provide us datasets for the first Method; while InCites could provide dataset for the second one. Considering the extremely large amount of records needed to download from WOS, the first method is almost impossible in practice. Thus, we chose to employ the second method, and calculate the average authorship size based on the semi-finished datasets provided by InCites.

In the InCites, by adjusting the settings of filter, indicators in two different time intervals, i.e. 1980–1984 and 2015–2019, were exported respectively, for the purpose of depicting the trends of research collaboration during the past forty years. Then, 41 most productive countries or regions, which published at least 55 thousand (or 0.5% of the total) publications between 2015 and 2019, were selected as object of observation, including 22 in Europe, 12 in Asia, 4 in America, 2 in Africa, and one in Australia, as shown in Table 2. These selected countries or regions published more than 10 million WOS papers together, account for 93% of global publication output.

Results

The size of research collaboration

In the past 40 years, the average number of authors per paper experienced a steady growth, from 2.20 in the year of 1980 to 7.00 in 2019, more than three times larger than before. The growth curve of number of authors per paper is basically liner, until the growth rate was becoming faster and faster during the past ten years. Institutional collaboration is also experiencing a liner growth during the past 40 years. This number of institutions per paper grows by 67.5%, from 1.59 in 1980 to 2.66 in 2019. In comparison, international collaboration still stay around a low level, after a much slower growth compared with individual collaboration. There is only a rise of 30% in the number of countries and regions involved in each paper, growing from 1.14 in 1980 to 1.48 in 2019. It means that, the current rising of collaboration size mainly comes from the inflation of team sizes (or intra-institutional collaboration), instead of inter-institutional or international collaborations.

The global tendencies of research collaboration have been revealed in Fig. 2. In the following sections, we will examine how it performance in 41 major countries or regions and show their difference in terms of individual collaboration, institutional collaboration and international collaboration.

Individual collaboration

The individual collaboration performance in different countries or regions during the past 40 years could be observed in Fig. 3. The right side of Fig. 3 shows the average number of authors per paper in each country or region. The left side shows their rankings in 1980–1984 and 2015–2019 respectively. To be clear, in calculating one country's average collaboration size, a publication is considered to be one of this country's publications if there is any single individual affiliated with it in that publication. And all the authors in the publications, regardless of whether or not they are affiliated with this country, will be counted. Due to the existence of international collaboration, this approach might overestimate this country's authorship, but it is the only feasible way considering the support of InCites datasets. This approach is also employed in calculating average number of institutions and countries per paper.

Among all the 41 countries or regions, scholars in France were most collaborative both in the 1980s and right now. In the past 40 years, the average collaboration size of France's publications has grown from 1.36 to 8.83 authors per paper, much higher than other countries or regions. Italy ranked sixth in the early 1980s and is second today. Its average collaboration size has growth from 1.19 to 5.87 authors per paper. Russia, the second most collaborative country between 1980 and 1984, now ranked third with an average of 5.21 authors per paper.

Among the selected countries or regions, almost all in Africa and the Middle East have experienced drops in rankings. Saudi Arabia, South Africa and Egypt have already become the least collaborative countries nowadays. In these countries, only 2.38 to 2.62 scholars are authored in each paper, much less than the average number. Obviously,

Table 2 WOS publication output of selected countries or regions (2015-2019)

Countries/regions	Papers	% of world	Countries/regions	Paper	% of world
USA	3,057,310	27.68	Belgium	150,435	1.36
China mainland	1,963,166	17.77	Denmark	127,828	1.16
England	770,367	6.97	Austria	110,092	1.00
Germany	716,519	6.49	Scotland	108,231	0.98
Japan	512,586	4.64	Portugal	99,024	0.90
France	476,359	4.31	Israel	93,646	0.85
Canada	471,188	4.27	Mexico	92,270	0.84
Italy	467,491	4.23	Norway	88,976	0.81
Australia	440,607	3.99	Singapore	87,267	0.79
India	406,542	3.68	Saudi Arabia	86,226	0.78
Spain	392,266	3.55	South Africa	84,569	0.77
South Korea	355,686	3.22	Finland	82,773	0.75
Brazil	284,784	2.58	Czech Republic	80,708	0.73
Netherlands	277,209	2.51	Greece	74,350	0.67
Switzerland	213,586	1.93	Egypt	72,908	0.66
Russia	212,471	1.92	Ireland	68,233	0.62
Iran	196,009	1.77	Malaysia	67,536	0.61
Turkey	186,457	1.69	Pakistan	65,004	0.59
Sweden	181,111	1.64	New Zealand	63,970	0.58
Poland	170,145	1.54	Argentina	57,795	0.52
Taiwan	151,983	1.38	All selected	10,263,106	92.91

compared with other countries, the processes to big science in these countries seem to be left behind.

China mainland was one of the fastest-growing regions from 1980 to 2019. Its ranking has grown from 17th to fourth in the past 40 years. At present, publications involving Chinese scholars contain approximately 5.00 authors per paper, compared with 1.43 in early 1980s. Other East Asian countries or regions, such as Japan, Taiwan and South Korea, have all experienced a rapid growth in research collaboration.

In Europe, many collaborative countries or regions in 1980s have been lagged referring to those in Asia. The ranking of Romania, Turkey, Sweden, Denmark, Ireland, England and Scotland, were all slipped down at least 5 spots. On the contrary, Greece, Portugal, Germany and the Netherland, which stayed at ranks of less collaborative countries traditionally, have ranked themselves among the highly collaborative countries recently.

USA, the most productive country of the world, ranked the 8th in terms of collaboration size, and it stay at this rank all the long time. Brazil has undergone a rapid growth, whereas Canada and Mexico have been somewhat behind others during the past 40 years.

Research fields’ distribution in a country or region may be the decisive factor of its size of individual collaboration. Particle physics, nuclear physics and astronomy & astrophysics are three typical fields where a hyper-authorship is the rule. France, Italy and Russia, the most collaborative countries at individual level, are major contributors in these fields. Experimental fields, such as materials science, chemistry, biology and medical sciences, also feature multiple authorships in publications. Over the past decades, the increasing

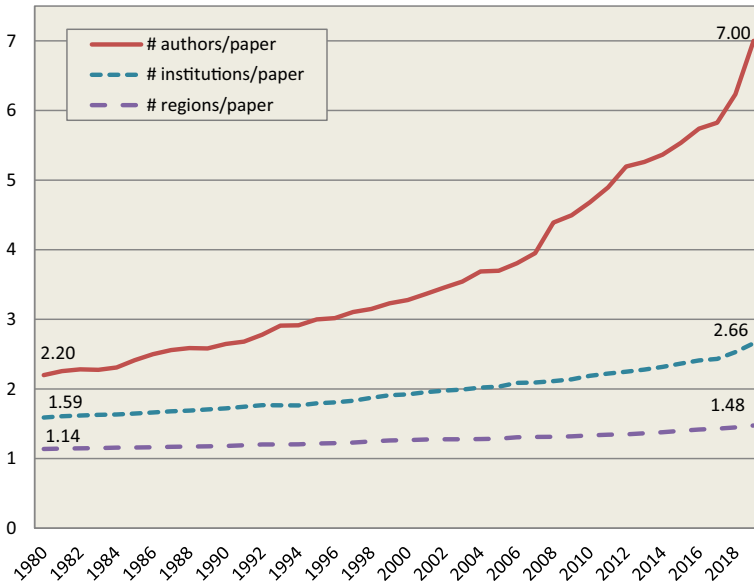


Fig. 2 Growth of the size of research collaboration from 1980 to 2019

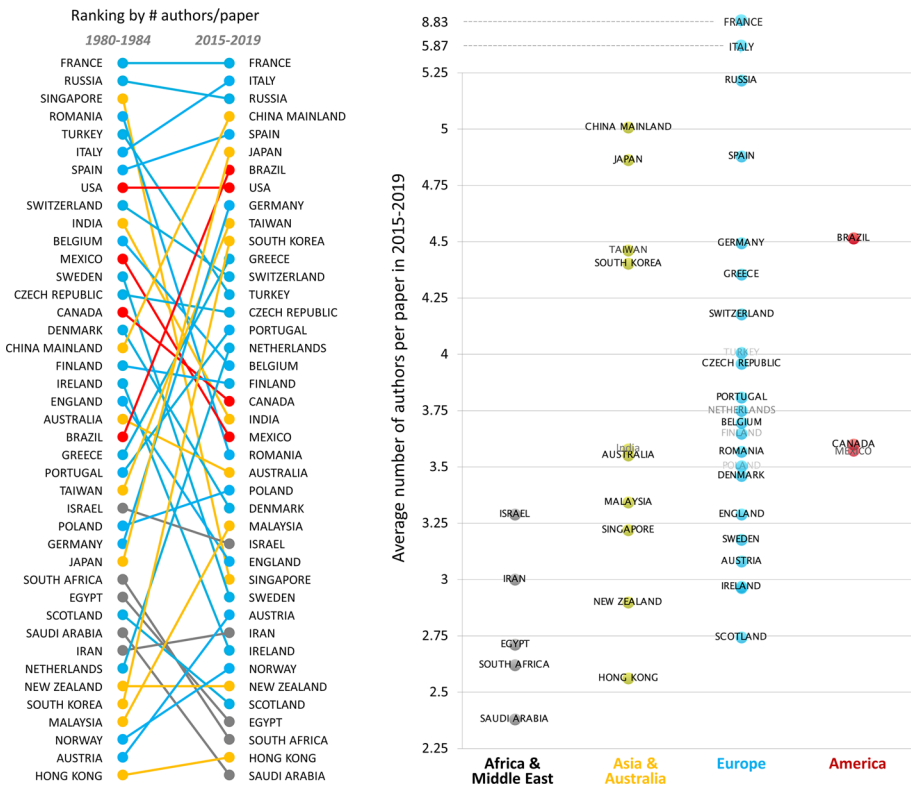


Fig. 3 Individual collaboration of 41 major countries/regions

outputs in these fields have significantly promoted the level of research collaboration of China, Brazil and other emerging countries.

Institutional collaboration

Institutional collaborations, also known as inter-organization collaborations in this study, merely represent collaborations between different organizations, i.e. universities, academies or company, other than those between different departments of same universities. Figure 4 shows the intentions of the 41 major countries or regions to conduct institutional collaborations. France, the country with the largest authorship size, ranked first also in terms of the average count of organizations (3.93) involved in one publication. USA ranks second in the average number of organizations per paper. Approximately 2.45 organizations are involved in each publication from the USA. After these, Russia, Spain and Italy have also preferred to conduct broad external collaborations. On the contrary, Hong Kong, Saudi Arabia and Scotland are the least collaborative in terms of institutional collaboration.

During the past 40 years, the top three most collaborative countries at institutional level, i.e., France, USA and Russia, remain at the top of the list. China mainland, the traditional region specialized in institutional collaboration, has tumbled to just average level. However, South Korea and Taiwan, also in East Asian, have grown to be highly institutionally collaborative country and region. Some European countries, such as Romania, Sweden, Denmark and Norway, have slipped down the rankings, while others have gone up, like Turkey, Germany and Netherlands.

The different levels of institutional collaboration are partly the result of diverse national scientific research systems in different countries or regions. The countries with high percentage of institutional collaborative papers generally have a very compete national academics of sciences, such as CNRS in France and RAS in Russia, or a comprehensive national laboratories, such as the DOE Laboratory System in the USA. The scientific system consisting of a variety of small yet specialized science institutions makes institutional collaborations necessary and inevitable.

The scales of universities are also considered as an influential factor to institutional collaborations. In China mainland, for example, universities have been extremely enlarged after a serial of university mergers around the year of 2000. France, by contrast, did the exact opposite. In the 1970s, the University of Paris was split into 13 independent universities. After this division, the universities in France have become relatively small and specific, and since then collaborations among different universities were very prevalent.

International collaboration

As it shown in Fig. 5, Europe, not surprisingly, is the world's most internationally collaborative continent. Among the 41 major countries or regions, the entire top ten are all in Europe. Greece ranks the first of the list. Each paper involved Greece scientists has authors from 3.29 countries or regions in average. Austria, Finland and Switzerland are not far behind. Close geographical distance and similar cultural context are believed to be the major reason for this scenario. However, in early 1980s prior to before the signing of Single European Act, European countries or regions didn't score particularly well in the tendency of international collaboration in early 1980s, compared with other continents. With

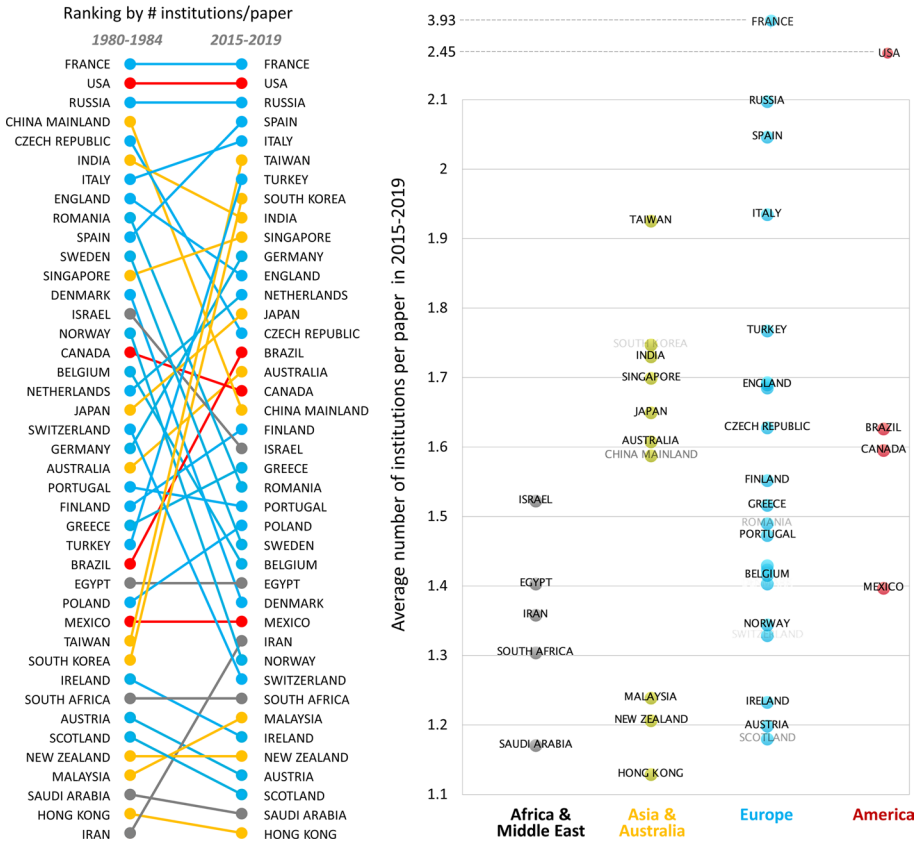


Fig. 4 Institutional collaboration of 41 major countries/regions

the accelerating process of European integration, the international collaborations among European countries have increased greatly over the past 40 years.

On the contrary, most Asian countries or regions have experienced the opposing trend in the ranking of international collaboration size, from passable to very poor. China mainland, though ranking the fourth in terms of authorship size, only contains 1.4 countries/regions per paper, come bottom of the list. India, South Korea and Japan, ranking the bottom 2nd to 6th, are also less international collaborative compared with other countries. Asian countries performed not as well in international collaboration because many researchers in East-Asian countries had poor English language skills hampering their social interactions.

The slipping in the rankings of South Korea is quite remarkable, with a fall from the top 3rd to the bottom 5th. Besides the rapid rise in ranking of European countries, the reason for the downturn South Korea of is also due to their decreasing dependence on internationalization over the past decades. One may still remember that, in the 1970s and 1980s, South Korea, together with other three Asian Tigers, namely Hong Kong, Singapore and Taiwan, had attracted world-wide attention because of their speedy industrialization. The rapid developments of South Korea extremely depended on

international trade and economic cooperation. Obviously, the export-oriented economy patterns also led to widely internationalization in science in 1980s. But now, South Korea has sufficient well-skilled domestic scientists, and thus international collaboration is not prerequisite as before. This is also the cases for Malaysia, Hong Kong, Taiwan and Singapore.

Iran has experienced the same fall in the ranking of international collaboration because of a history of United Nations Sanctions from 2003. Nevertheless, the levels of international collaboration are relatively high in other countries of Middle East and Africa, such as South Africa, Saudi Arabia and Israel, partly because they are closed to Europe and the latter is increasingly involved in the transaction of the former’s affairs. South Africa and South Africa are also acted as the leaders of their respective regions in Science.

Americas have relatively small size of international collaborations. The United States, in particular, ranks the bottom fourth in terms of international collaboration, in spite of the high ranking in average size of institutional collaboration. This unexpected fact is reasonable actually, considering that the US has such sufficient scientists and resources in domestic that the foreign collaborators are not necessary unless they are requested.

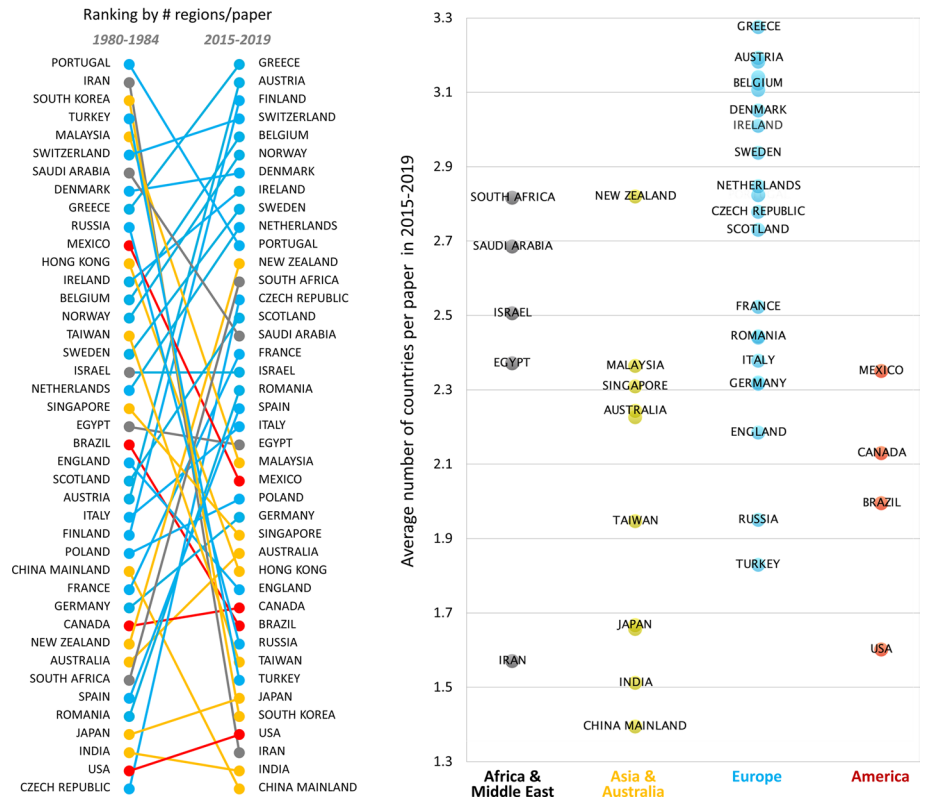


Fig. 5 International collaboration of 41 major countries/regions

The heterogeneity of research collaborations

Beyond the size of research collaborations, we also illustrate how heterogeneous the research collaborations are in the past 40 years and in different countries and regions. The heterogeneity of research collaborations is believed to be beneficial to tackle problems in key technologies and radical innovation.

International collaborations and industrial collaborations are the two most concerned heterogenetic collaborations. In this study, we used the percentages of international collaborative papers and industrial collaborative papers to measure these two aspects respectively. Figure 6 shows their growth trends since from 1980.

In the past forty years, there is a more than eightfold increase in the percentage of international collaborative papers, from 3.01 to 24.7%. This is the rapidest growing collaboration indicator among all of the measurements used in this study. Nowadays, every one out of four papers is coauthored by scientists with their foreign peers. International collaborations have already become a remarkable strategy for scientists to improve the working efficiency and level of scientific research.

Meanwhile, the growth curve of percentage of industry collaborative papers has experienced an inverted U-shaped curve. In 1980, there were only 0.58% of them belonging to industry–university collaborative papers. This percentage increased yearly and peaked at 1.92% in 2006. On the bright side, more and more businesses and private sectors participate in scientific research. On the other side, their contributions in science are still small relatively, especially considering that its proportion even began to decrease in the past ten years and dropped to only 1.59% eventually.

The proportion of internationally collaborative papers

Figure 7 shows the proportions of internationally collaborative papers of each country and region. Among 41 major countries or regions, Saudi Arabia conducts the most international collaborations in science. Today, more than 3/4 of its publications were coauthored with scientists abroad, including those from Egypt (17.6%), USA (16.3%) and China (10.2%). This performance is driven by a comprehensive national science strategy to be implemented until 2030, namely “Saudi Arabia’s Vision 2030”. To meet these objectives, the R&D Office in the Ministry of Education of Saudi Arabia provided large funding and created opportunities in support of collaborative projects with international partners over the past 3 years.

In Europe, Switzerland, Belgium and Austria topped the ranking in international collaborations. In these countries, approximately 2/3 of publications had international authorships. All these three countries are adjacent to Germany, one of the Europe’s Centers of Science. In South European, the shares of internationally collaborative publications were less than a half. While in Poland, Russia and Turkey, only 1/3 or 1/4 of publications were collaborated with other countries or regions. India, China and Japan ranked near the bottom of the world. With rare exceptions, the proportion of internationally collaborative papers reveals the same sequence with the average number of nations per paper, the indicator we discussed in “[International collaboration](#)” section.

As an exception, Greece ranks the first if measured by the international collaboration size, but merely ranks the 19th by its proportion. This shows that Greece, though having less international papers, tends to collaborate with multiple countries at the same time in its publications. Instead, Saudi Arabia has high proportion of international papers but low

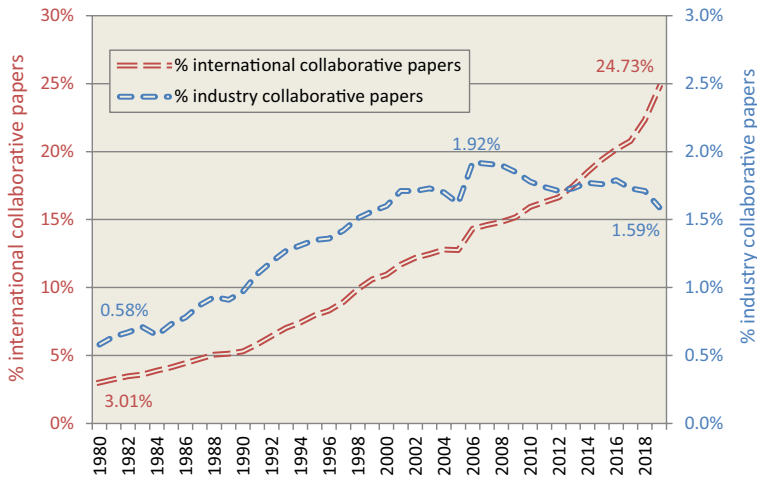


Fig. 6 Growth of the heterogeneity of research collaboration from 1980 to 2019

international collaboration size. Seemingly, they prefer to collaboration with other regions in one-to-one way. Two contradictory phenomena are the reflections of different leading research fields between Greece and Saudi Arabia. Greece’s hotspots are located in biology and medical sciences, which feature widely international collaboration; while Saudi Arabia’s preponderant fields mainly around petrochemical engineering, characterized by bi-national collaboration.

The proportion of industrially collaborative papers

The proportion of industrially collaborative papers reveals the degree of involvement by the industry and business in science. On the whole, industrial collaboration still stays at low level until now. Figure 8 shows the 41 countries or regions’ performance in industry collaboration. Among them, Switzerland, Denmark, Sweden and Belgium are the only four countries in which more than 5% of papers are industrially collaborative. In general, developed countries and regions are more willing to conduct industrial collaborations than other less developed ones. As to the temporal change trend, Japan, South Korea, USA and Taiwan, which ranked high in the 1980s, have experienced a steep drop in the ranking of industrial participation, while France, Norway, and Singapore climbed more than ten spots since the previous ranking.

Industrially collaborations also indicate the existence and activity of high-tech enterprises in different regions. Tables 3 and 4 list the 10 most productive firms and their contributions in science in 1980–1984 and 2015–2019, respectively. As shown in these tables, European and American firms have always been the dominating industrial contributors in science. Switzerland is particularly notable in industrial collaboration, although a significant amount of the research projects of Novartis and Roche is conducted in the United States with the cooperation of their American subsidiaries and US universities. In terms of the type of industry, the top four companies were all electronical in 1980–1984; while in 2015–2019, the top 7 companies almost all belongs to the biomedical areas. This reflects a change of leading industries in R&D output in the past 40 years.

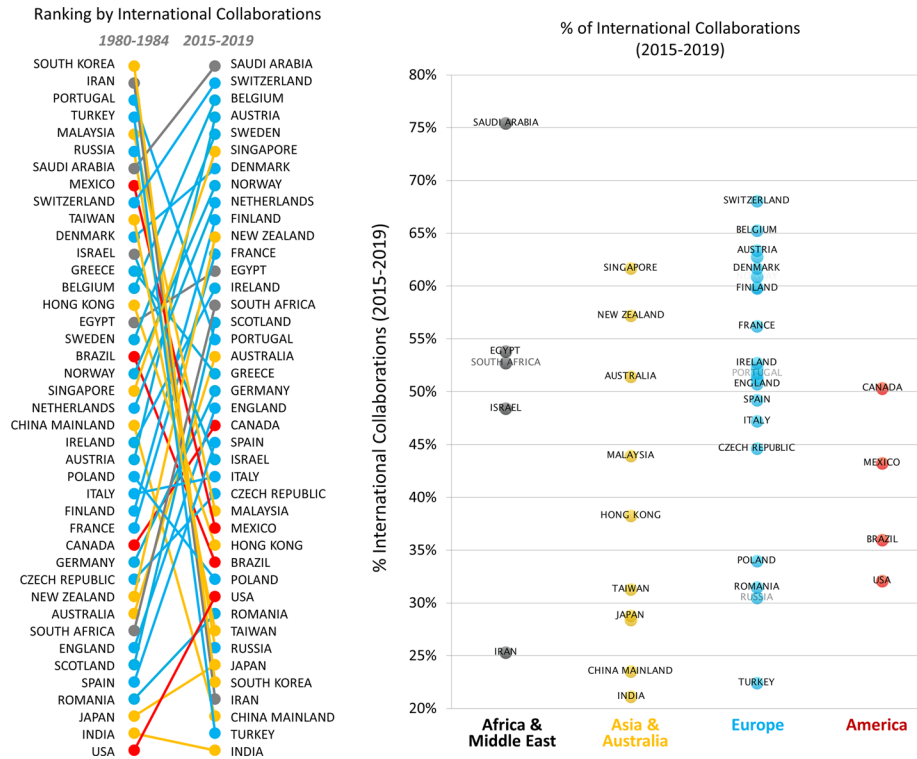


Fig. 7 The proportion of internationally collaborative papers in 41 major countries/regions

Synthesizing research collaboration indicators

The measurement of research collaborations is a very complex issue. Collaboration behavior could and should be described in different dimensional properties. In the sections above, we have already reported the collaborative performances of the 41 selected countries or regions using five different indicators. According to these results, one can observe diverse and even paradox scenarios. For example, France ranks the first if measured with the number of authors and institutions per paper, but ranks only the 17th by the number of nations involved in each paper. And for another example, papers by Asian scientist are usually more multiple authored than those by European scientists, but they are less international collaborative than the latter.

Table 5 shows the Pearson and Spearman correlation coefficients among five collaboration indicators using samples of papers from the 41 countries or regions in 2015–2019. It is found that there exists a significant positive correlation between individual and institutional collaborations, with Pearson correlation coefficient of 0.884 and Spearman correlation coefficient of 0.788. Two metrics on international collaboration are also exceptionally relevant, as shown in Pearson (0.837) and Spearman (0.817) correlation coefficients. However, international collaborations have negative (but not significant) correlations with both individual and institutional collaborations. Industrial collaborations seem to have positive correlations with all the indicators above, especially with international collaboration.

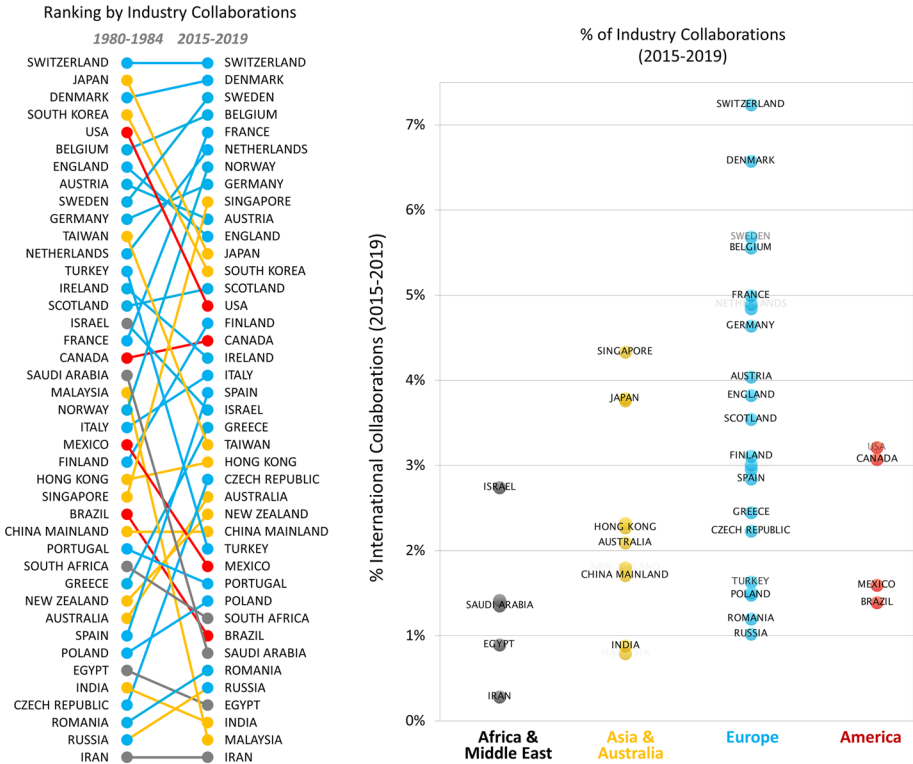


Fig. 8 Performance of industry collaboration pattern in different countries/regions

Table 3 Top 10 industrial contributors in SCI between 1980 and 1984

	Industrial organizations	Papers	% of global	Ranking	% I-U
1	Nokia Corporation (Finland)	8685	3.09	98	62.5%
2	AT&T (USA)	8058	2.87	115	65.1%
3	IBM (USA)	7396	2.63	130	27.6%
4	General Electric (USA)	3562	1.27	312	22.9%
5	Pfizer (USA)	3316	1.18	332	29.3%
6	Exxon Mobil Corporation (USA)	3188	1.13	345	23.9%
7	GlaxoSmithKline (UK)	3093	1.10	359	43.9%
8	Roche Holding (Switzerland)	2793	0.99	386	35.6%
9	Novartis (Switzerland)	2788	0.99	388	28.0%
10	Nippon T&T Corporation (Japan)	2730	0.97	400	5.13%

Table 4 Top 10 industrial contributors in SCI between 2015 and 2019

	Industrial organizations	Papers	% of global	Ranking	% I-U
1	Novartis (Switzerland)	9261	0.90	606	77.0%
2	Roche Holding (Switzerland)	8778	0.86	643	74.1%
3	Samsung (South Korea)	8197	0.80	687	87.1%
4	AstraZeneca (UK)	7756	0.76	717	75.4%
5	IBM (USA)	7052	0.69	783	76.4%
6	GlaxoSmithKline (UK)	6961	0.68	789	69.6%
7	Pfizer (USA)	6891	0.67	795	68.5%
8	Merck & Company (USA)	5765	0.56	944	67.8%
9	Siemens AG (Germany)	5351	0.52	1005	83.6%
10	Genentech (USA)	4811	0.47	1092	67.4%

With the help of descending dimension methods, we mapped all the five collaboration indicators of each country or region into a two-dimensional coordinate system, based on the multi-dimensional scaling (MDS). The distribution of them after dimension reduction is shown in Fig. 9. Basically, the dimension of y-axis mainly indicates the size of research collaboration, while dimension of x-axis indicates the heterogeneity of research collaborations primarily. It is found that, USA scientists prefer collaborated with a number of authors together yet they don't like foreign or industrial collaborators. In the Switzerland, Iran and South Korea, the opposite is the case. Research collaboration in France and Russian excels in both the size and the heterogeneity.

Besides, we could design some new metrics, by combining variety indicators together, which should be able to provide additional useful information of research collaboration. One typical metric of this kind is team size, or the average number of contributors per institution in each paper, which is defined as *# authors per paper* divided by *# institutions per paper*. According to team size, the USA surprisingly ranked at the bottom with the smallest size of team, only consisting of an average 1.84 authors per institution. Comparatively, China mainland, another science giant, ranked first with an average of 3.13 authors

Table 5 Correlation coefficients among five collaboration indicators

Spearman	# Authors per paper	# Institutions per paper	# Countries per paper	% International collaboration	% Industrial collaboration
<i>Pearson</i>					
# authors per paper	1	0.788**	-0.298	-0.409**	0.141
# institutions per paper	0.884**	1	-0.491**	-0.438**	0.109
# countries per paper	-0.242	-0.285	1	0.817**	0.415**
% international collaboration	-0.221	-0.178	0.837**	1	0.548**
% industrial collaboration	0.182	0.147	0.457**	0.562**	1

** $p < 0.01$

per institution in research, keeping the largest team size among all of the 41 countries or regions. This would imply that, scientists in the USA are the least likely to co-author with their colleagues, although they conduct the almost most institutional collaborations; while scientists in China mainland are the most willing to collaborate with their colleagues in the same organization, rather than peers in other organizations. Figure 10 provide all the 41 countries or regions’ performance of team size as well as institutional collaborations.

Discussion and conclusion

Research collaborations are needed for fruitful productivity, enlarging impact and comprehensive innovation in science. Bibliometric analysis of co-authored scientific articles revealed the structure and change of collaborative behavior is a promising approach. In this study, using a smart method based on InCites dataset, multiple dimensions collaboration indicators, with respect to their authorship size, organizational complexity, and geographic scopes, were all intensively visualized for a disciplinary and regional comparison systematically. The change of their performances in these indicators during the past 40 years has been examined.

Generally, research collaboration in science continues to grow at a remarkable rate, especially measured by the number of authors per paper or the proportion of international collaborative papers. The latter, for example, has increased from 3% in 1980 to 25% in 2019. This steep growth is believed to be stimulated by the emerging internet commutation technology over the past decades, which has created and fostered a heightened level of collaboration between different countries and regions, or even continuities.

We revealed the different collaboration tendencies among 41 major countries or regions. France is the most collaborative country both at an individual and institutional level, but Saudi Arabia was the most collaborative one at an international level. Switzerland ranked

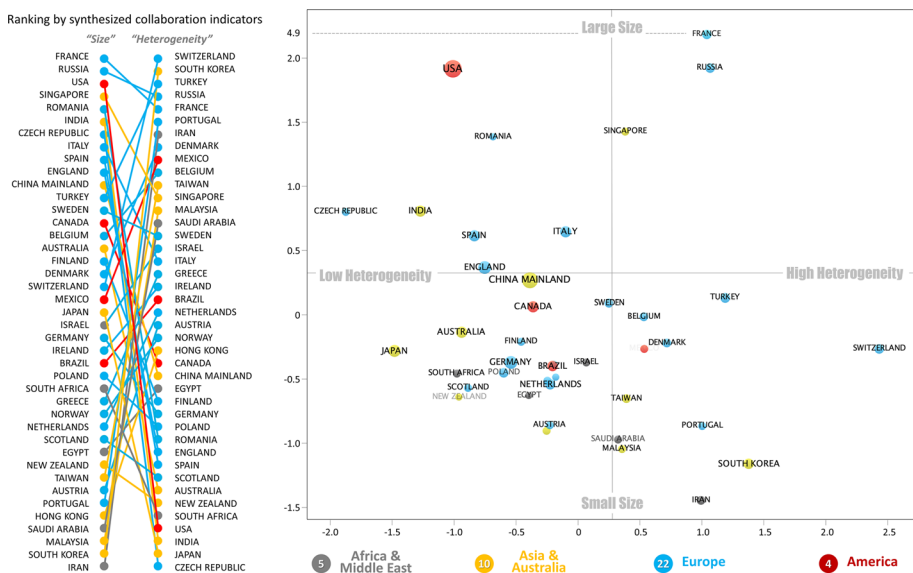


Fig. 9 Comprehensive performance in research collaboration of 41 major countries/regions

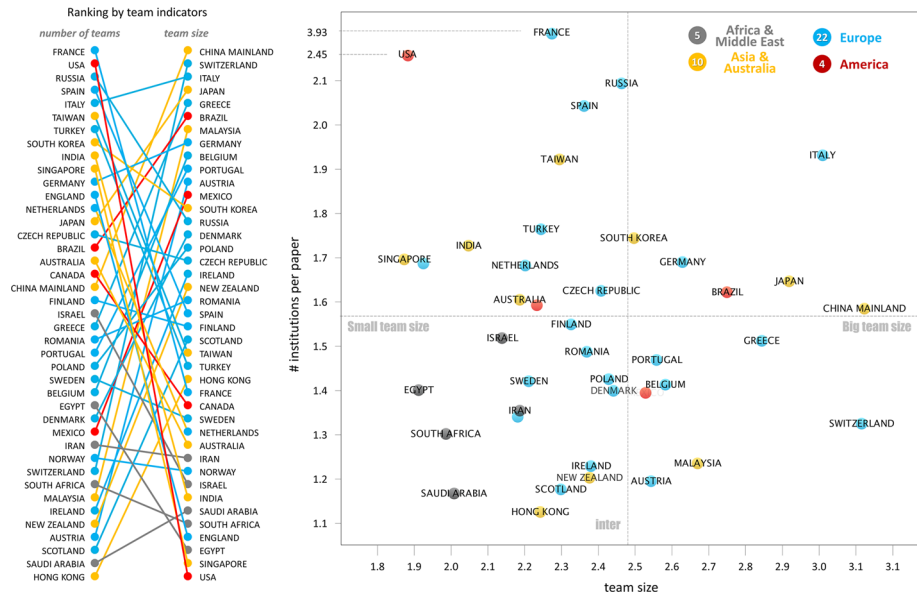


Fig. 10 Team sizes of 41 major countries or regions

first in terms of industry-university collaboration. China mainland contains the largest team size. The multiple-dimension collaboration performances of each research area were visualized in the end.

Many reasons could have led to the different patterns of research collaborations among countries and regions, including technology policies, research orientations, and multinational programmes (Adams 2013) and political affairs (Hu et al. 2018). As collaboration among organization, sector and nations becomes pervasive, this study has established large and upper views and baselines of collaboration in order for such baselines to guide scientific collaborations in each region and each organization.

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