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On the development of China's leadership in international collaborations

Wei Quan[1,2,3] · **Philippe Mongeon**[3,4,5] · **Maxime Sainte-Marie**[3] · **Rongying Zhao**[1,2] · **Vincent Larivière**[3,4]

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Abstract
This paper studies the relationship between leadership, team size, and citation impact in China's international research output from 1980 to 2016, measured in terms of number of authors, institutions, countries, and citations. Distinction is here made between leading and non-leading Chinese international collaborations, which respectively refer to papers whose first or corresponding author is affiliated to a Chinese institution and papers co-authored by researchers from a Chinese institution but whose first and corresponding authors are not. Analysis at the individual, institutional, and country level show that while average team size by paper increases over the period, the main collaboration mode remains bilateral at the country level. We also observe a positive relationship between team size and research impact up to a certain point, but Chinese-led international collaborations tend to imply smaller teams and have lower impact than non-leading collaborations.

Keywords Collaboration · Team size · China · Research evaluation · Citation analysis

Introduction

Collaboration is at the heart of contemporary scientific research. As shown by Price (1963) more than 50 years ago, scientific research is increasingly collaborative, as the relative importance of single-authored papers has steadily decreased in both Natural & Medical Sciences and Social Sciences & Humanities fields (Larivière et al. 2015) since 1900. One of the main reasons for this trend lies in the enhancing effect of collaborative work, which positively affects both scientific productivity (Lee and Bozeman 2005; Tohidi and Tarokh

✉ Wei Quan
wei.quan@umontreal.ca

1 Research Center for Chinese Science Evaluation, Wuhan University, Wuhan, China

2 School of Information Management, Wuhan University, Wuhan, China

3 École de bibliothéconomie et des sciences de l'information, Université de Montréal, Montreal, Canada

4 Centre for Science and Technology Studies, Leiden University, Leiden, The Netherlands

5 Danish Centre for Studies in Research and Research Policy, Aarhus University, Aarhus, Denmark

2006; Liang and Zhu 2002) and research impact (Van Raan 1998; Sampson and Clark 2009). With the development of communication technologies and the consequent reduction of geographical constraints, international collaborations have become more frequent, both within and across institutions, fields, and countries (Chang et al. 1998); the internationalization of big science is evocative in that respect, as the ten biggest experiments in the world currently are all multinational projects ("Big Science: The 10 Most Ambitious Experiments in the Universe Today" n.d., Esparza and Yamada 2007).

For developing countries, international collaborations represent an ideal opportunity to improve both scientific visibility and research impact by allowing their researchers to work with colleagues from more advanced scientific countries. This is particularly true of China, whose ambition to address long-standing and crippling "brain drain" issues (Favell et al. 2007) has led economists, bibliometricians, and policymakers to focus on assessing and improving China's international collaboration record. As research collaborations are strongly dependent on scholar mobility (Barjak and Robinson 2008; Guimerà et al. 2005; Kakihara and Sørensen 2004; Crespi et al. 2007), China has put much effort and resources in promoting international collaborations through mobility funding initiatives. The China Scholarship Council (CSC), a non-profit agency led by the Chinese Ministry of Education, provides such funding for Chinese or foreign students and researchers interested in studying or doing research abroad and in China respectively. China hired 14,945 foreign researchers in 2013 and dispatched 15,645 CSC-funded scholars to 87 countries in 2012, mainly for short-term (3–6 months) visiting stints (Wu Xian 2017). In addition to the CSC funding programs, the National Natural Science Foundation of China (NSFC), the country's main scientific foundation, offers funding for foreign researchers with the aim of stimulating China's international scientific production (Yuan et al. 2018). According to the annual report of the NSFC (Yang and He et al. 2016), the organization funded 1056 out of 4772 international applications in 2016, for a total of 897 million RMB (14.1 million USD).[1]

According to various studies (Arunachalam et al. 1994; Zheng et al. 2012; He 2009; Wang et al. 2013), China's effort in stimulating research and scholar mobility really paid off. In terms of both production and impact, the country raised the quality of its publications and increased its share in the total world research output. This trend was not limited in fundamental research but also involved technological development, as shown by the increase of patent activities (Ma et al. 2009) in some fields of material science (Cyranoski 2009) and nanoscience (Tang and Shapira 2012; Guan and Ma 2007). On the international collaboration front, China became with the United States and the United Kingdom the country most deeply involved in scholar mobility (Robinson-Garcia et al. 2018). The country steadily raised its share of international publications and increased its leadership role both in scientific collaborations (Xie et al. 2014) and in the formulation of scientific regulations, for example in the bioethical domain (Sleeboom-Faulkner 2013). In addition, an analysis of the collaboration network of China (Zhang et al. 2006) has shown that the country established new collaboration links with other countries, and strengthened its ties with the more scientifically advanced ones (i.e., USA, UK, Canada, Japan), although the strength of these links varies depending on the discipline (Wang et al. 2017).

The aim of the present paper is to analyze this state-driven, evidence-based scientific, and technological revitalization initiative by disentangling the relationship between team

[1] 1RMB = 0.16USD, checked on 09/05/2018.

size and leadership in Chinese international collaborations. Previous studies on collaborative work have indeed shown that team size and leadership both have an effect on performance (Srivastava et al. 2006; Zaccaro et al. 2001). Within the scholarly community in particular, it has also been shown that team size positively correlates with both productivity (i.e., number of publications) (de Beaver and Rosen 1979) and impact (i.e., number of citations) (Bu et al. 2018). Moreover and contrary to what was previously thought (Wallmark et al. 1973), empirical studies now suggest that there might be an optimum team size in terms of both scientific productivity and impact (Rodríguez et al. 2012; Tsukuda 1990; Tohidi and Tarokh 2006; Kameda et al. 1992; Guimerà et al. 2005). Regarding leadership, research has shown that the latter can affect both collaboration output (Slater 2005; Manganote et al. 2014) and impact (Burpitt and Bigoness 1997; Mccoll-Kennedy and Anderson 2002; Slater 2005; Hallinger and Heck 2010; Manganote et al. 2014). Not much has been said however on the relationship between leadership and team size, despite their obvious relatedness: after all, collaborative research is always initiated, overseen, and coordinated by a specific team member, and given that developing and maintaining research collaboration networks is a difficult and often decade-long task, all the more so at the international level, team leadership constitutes a crucial dimension of collaborative research.

In light of these considerations, the present study aims to assess the relationship between leadership and team size in China's international collaboration output. More precisely, this research aims to address the following questions:

1. How has leadership and team size evolved by discipline at the individual, institutional, and national level between 1980 and 2016?
2. How are team size and citation impact related?
3. How are team size and citation impact related to leadership?

Methods

Data for this study has been extracted from the Web of Science Core Collection (SCI, SSCI, A&HCI). All co-authored articles, notes and reviews published between 1980 and 2016 and having at least one author affiliated to a Chinese institution were retrieved from the database. Amongst the extracted articles, 351 were international collaborations whose authors were affiliated to one common multinational institution and were thus removed from the dataset. The remaining 581,919 articles were partitioned in two subsets: the first one, henceforth named China-as-leader, contains all 356,391 articles in which the first or corresponding author is affiliated to a Chinese institution; the other subset, called China-as-participant, includes the 225,528 remaining articles (i.e. those co-authored by Chinese scholars in non-primary and non-corresponding roles). Citation data was also extracted for both China-as-leader and China-as-participant subsets, amounting to a total of 3,384,644 and 3,308,869 citations respectively. Finally, number of authors and institutions were extracted for each China-led and China-participating article. In the following, 2-authors articles will refer to articles with one China-affiliated author and one non-China-affiliated author; the same denominative logic also applies to the number of institutions involved in articles. Data are grouped in three broad disciplines: Medical fields (MED), natural sciences and engineering (NSE), and social sciences and humanities (SSH).

We present the evolution of China's research leadership, which are at discipline level(NSE and SSH). We also represent papers' average team size, as well as the relationship between scientific impact and three types of collaboration, which are at the (a) individual level (number of authors), (b) the institutional level (number of institutions), and (c) the national level (number of countries). Publications are presented from 1980 onward and a citation window of 5 years is considered for each article, which means that all references from articles published after 2012 are ignored. To show the impact level of Chinese international collaborations in each discipline, we use a normalized citation average, the baseline score of 1 corresponding the annual citation average for the corresponding discipline in the whole database. We also present the evolution of large-scale collaborations involving China; large-scale collaboration here refers to papers co-written by more than 100 authors and involving at least 30 institutions. Based on these criteria for large-scale collaborations, 4248 papers involving Chinese scholars either as leaders or participants were considered for analysis.

Results

In what research areas are Chinese scholars leading international collaborations?

Tables 1 and 2 display the frequency, collaboration ratio, and leadership ratio of the main specialties involved in China's international collaboration effort, respectively ordered by collaboration frequency and rate. The 20 specialties in which China published the most articles as a result of international collaborations are displayed in Table 1. Results show that while the bulk of Chinese international collaborations involve natural sciences and engineering specialties, international collaborations constitute only a small minority of the total Chinese output in these fields. Chinese-affiliated scholar also play a leading role in most cases, with notable exceptions inGeneral Physics and Cancer.

The 20 specialities for which international collaborations have the highest share of publication are shown in Table 2. For the most part, these are specialties in which China publishes only a small number of papers, generally led by scholars from other countries. Economics, Management, and Astronomy stand out however in terms of international collaboration frequency, while the latter also distinguishes itself by the relatively low proportion of China-led papers. Overall, results presented in Tables 1 and 2 suggest that China has become a leader in certain fields (mainly Natural Sciences) and is able to produce a lot of publications without having to collaborate. Inversely, the specialties where the collaboration rates are the highest are for the most part fields in which China is not very active and mostly plays a participant role in the collaborations.

Who leads China's international collaborations?

Figure1 shows the evolution by discipline of the proportion of international collaborations led by China-affiliated scholars. The left subfigure shows that China's leadership in Natural Sciences disciplines slightly declined in the early 1990s, but has continuously increased since the beginning of the 2000s; the only notable exception to that trend is in Physics, perhaps due to China's increasing participation in international big science projects. The right subfigure shows that a similar trend has developed in Social Sciences from 2000 onward. Social Sciences data for the pre-2000 period as well as Arts & Humanities data for the

Table 1 China's top 20 collaborative specialties ranked by collaboration number from 1980 to 2016

Specialty	International collaborations	Collaboration rate (%)	China as leader (%)
Materials Science	34,859	21.35	63.78
Electrical Engineering & Electronics	27,198	28.37	62.91
General Biomedical Research	25,041	28.57	54.85
Physical Chemistry	22,050	15.69	57.95
General Physics	21,222	16.42	35.36
Computers	19,940	31.39	68.13
Applied Physics	17,951	25.39	52.29
General Chemistry	17,130	13.84	63.92
Environmental Science	16,431	29.31	64.23
Biochemistry & Molecular Biology	16,147	27.83	48.25
Botany	13,567	31.73	55.63
Neurology & Neurosurgery	12,132	31.10	47.21
Agriculture & Food Science	12,088	31.26	62.86
Cancer	11,650	24.73	39.17
Optics	11,647	18.18	60.34
Earth & planetary Science	11,593	38.57	56.29
Applied Mathematics	11,379	23.50	62.51
General Mathematics	11,229	20.94	58.83
Mechanical Engineering	10,487	20.91	66.10
Pharmacology	10,391	21.00	52.90

whole period were excluded due to the low number of international collaborations involving China-affiliated scholars.

Figure 1 shows China's increasing leadership in international collaborations for the period observed. For both Nature Sciences and Social Sciences, China usually played a leading role, though in some disciplines the percentage of China as leader still less than 50%, in almost of the disciplines China plays a leading role in recent years especially after 2010, like Engineering and Technology, Mathematics and Social Science. However, we also find that China played a long-term participating role when collaborated with other countries, especially at some disciplines like Clinical medicine, Physics, Psychology and Health.

Average team size of China's international collaborations

Figure 2 shows the average number of authors, institutions and countries by discipline paper, for the 1980–2016 period (1990–2016 for SSH). For the whole period, papers in NSE, MED and SSH fields involve larger teams (i.e., more authors, institutions and countries), which confirms results obtained by previous studies (Gazni et al. 2012; Larivière et al. 2015). For example, in 2016, the average number of authors by paper for NSE, MED and SSH are respectively 18, 9, and 4. However, articles in NSE fields have more authors since the 1990s, which can be explained by China's growing involvment in the massively collaborative field of High Energy Physics. Indeed, if we exclude papers from that field from the data, the resulting NSE scores decrease substantially (as shown by

Table 2 China's top 20 collaborative specialties ranked by collaboration rate from 1980 to 2016

Specialty	International collaborations	Collaboration rate (%)	China as leader (%)
Demography	194	70.04	33.20
Psychoanalysis	2	66.67	0.00
Experimental Psychology	754	66.43	42.91
Social Sciences, Biomedical	220	66.07	41.11
Developmental & Child Psychology	593	63.90	29.55
Addictive Diseases	346	58.45	38.35
Anthropology and Archaeology	385	54.92	38.98
Economics	5039	54.24	50.79
Management	8287	53.51	50.73
Allergy	232	53.33	15.95
Miscellaneous Psychology	774	53.01	49.49
Miscellaneous Professional Field	1209	52.91	63.10
Public Health	1651	52.55	41.95
Physiology	1794	52.30	30.80
Geography	892	51.18	48.04
Environmental & Occupational Health	2427	50.87	37.20
Psychiatry	1835	50.68	34.75
Human Factors	524	50.53	61.32
Health Policy & Services	670	50.49	42.18
Astronomy & Astrophysics	6773	49.36	28.84

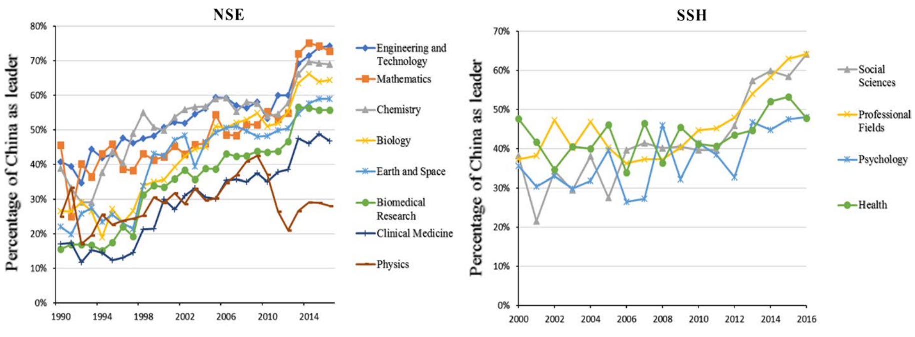

Fig. 1 China's leadership of international collaborations by discipline 1990–2016

the dotted lines). Moreover, while averages in all three disciplinary groups increase over the whole period, growth is slower but steader in SSH; as will be shown later, this difference could also be explained by China's participatory role in large scale collaborations.

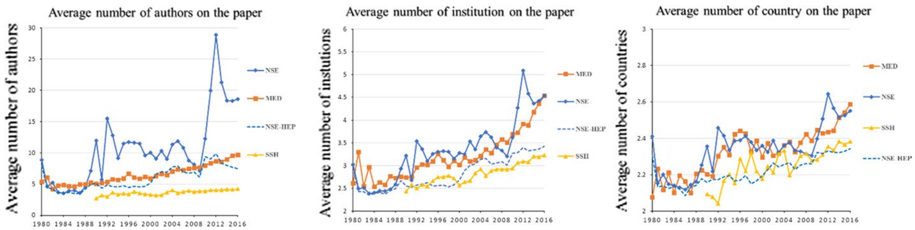

Fig. 2 Average number of authors, institutions, and countries by paper and discipline between 1980 and 2016

Evotuion of team size in China's international collaborations

Figure 3 presents the evolution of international team size over the 1980–2016 period for both contribution types (China-led and China-participating) and all three collaboration levels (author, institution, country). Globally, results show that 2-author, 2-institution, and 2-country papers decreased in both leading and participating context over the period: in the case of China-led articles, the proportions drop respectively from 33 to 5%, 61 to 37%, and 89 to 86%; as for China-participating articles, the same ratios drop from 20 to 5%, 40 to 26%, and 73 to 60%. In light of this and despite the fact that 2-countries articles remained the most frequent type of country-level collaboration throughout the observed period, there has thus been a gradual shift from bilateral to multilateral (3 or more) settings in Chinese international contributions, and that the number of authors, institutions, and countries involved in both China-led and China-participating contributions is in constant growths.

As regards to author frequency, the number of collaborators by paper grows during the observed period—irrespective of contribution type. With the sole exception of China-participating articles published in 1980, the relative majority of annual article counts for both contribution types switched from 2 to 4–5 authors by paper between 1987 and 1991, and then to 6–10 authors around 2008. In the case of articles with 2–3 authors, the decline in proportion starts around 1984, while the slow but steady decline of 4–5 authors articles starts after 2000. In fact, following the first year, only China-led and China-participating articles with 4+ authors have grown in proportion over the whole period. As for large-scale collaborations (articles with 21 or more authors), while their proportion has increased in the last few years, the share of annual Chinese-led and Chinese-participating international collaborations has mostly remained under 5%.

Turning to institutions, results show that Chinese-led and Chinese-participating international collaborations switch from a 2-institution to a 3–4 institution international collaboration regime in 2012 and 2006 respectively. In fact, and for both cases, all multi-institutional regimes increase at the expense of the bi-institutional one, although in a different manner: for the Chinese-led regime, the fastest-growing regime is the 3–4-institution one, while the most impressive increases for the China-as-participant group are those involving articles with 5+ affiliated institutions. Finally, at the country level, while Chinese international collaborations remain essentially bilateral, the relative importance of multilateral collaborations has grown over time. While this multilateralization as remained modest for Chinese-led collaborations, the same cannot be said of Chinese-participating collaborations, which have reached 40% of all collaborations in 2016.

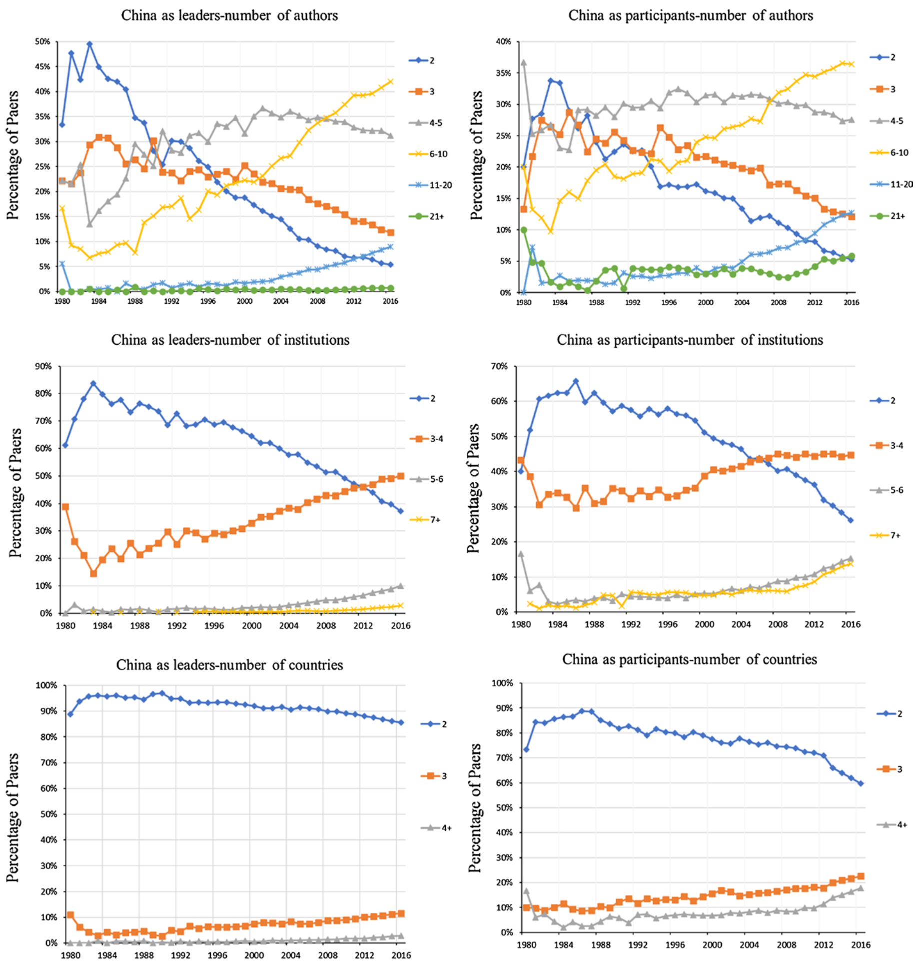

Fig. 3 Percentage of papers by author, institution, and country frequency for China-led and China-participating international collaborations, 1980–2016

Relationship between scientific impact and team size

Figure 4 presents, for both leadership settings, the field-normalized impact of papers as a function of author, institution, and country frequency Average Relative Citation (ARC) counts were calculated for distinct author, institution, and country count values based on at least of 100 articles (hence the missing values in the plots). Overall, team size positively correlates with citation impact up to a certain range: when the number of collaborating authors, institutions, and countries is respectively below 20, 14, and 9, an increase in team size is directly and steadily correlated to an increase in ARC counts. In light of these results, it seems reasonable to conclude that team size has a positive statistical relationship with research impact, regardless of the collaboration level. However, leadership plays a role in the effect in terms of numbers of authors: while ARC scores are lower for China-leader

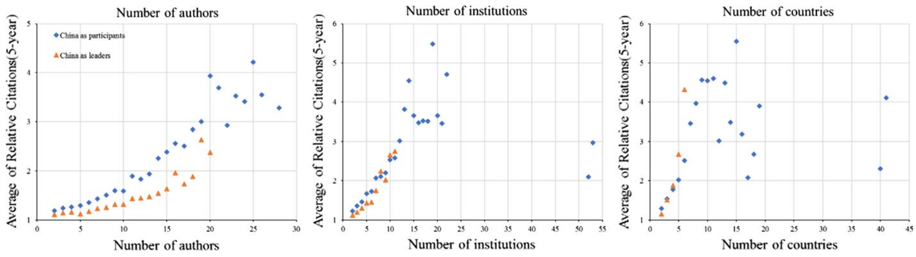

Fig. 4 Average relative citations (ARC) as a function of author, institution, and country frequency for China-led and -participating international collaborations, from 1980 to 2016. Results are based on 5-year moving window averages; only ARC scores based on 100 and more papers are shown

irrespective of the number of authors, no such difference between China-leader and China-participant can be observed in the case of institutions and countries.

Evolution of the impact of Chinese international collaborations

Figure 5 presents the ARC scores of all Chinese scholarly contributions between 1980 and 2012, grouped by various author, institution, and country frequency ranges. For both contribution types and regardless of the growing oscillations observed for the upper frequency ranges, we find that articles that are more collaborative tend to have a higher citation impact; in virtually every year observed, Chinese collaborations written by more than 10 authors outscore less collaborative Chinese contributions by a margin. It is also noteworthy to mention that while all Chinese collaboration types show above-average scores since the early 2000s, Chinese-led contributions usually have a lesser impact than those in which China has only a participatory role.

For Chinese-led collaborations, papers involving 4 institutions or less have a below-average impact until the early 2000s, period after which it slightly but steadily increases above the world average. A similar increase can also be observed in participating context for the whole period. At the country level, research impact grows in proportion with country frequency; notwithstanding the wavy patterns observed for larger teams, this relationship is constant over time, in both leading and participatory roles. For example, the ARC score for China-led binational papers increases from 0.48 in 1980 to 1.32 in 2012. Overall, China-participating papers had a larger impact than Chinese-led papers, be it at the author, institution or country level; this trend is even more pronounced in the post-2000 period. Based on these results as well as those shown in Fig. 1, it is also possible to assert that the collaboration regimes that have the highest research impact in both participating and leading contexts are not those that are the most frequent.

Large-scale collaborations

Given the positive relationship between research impact and the number of authors, institutions or countries involved in Chinese international collaborations, a detailed portrait of large team size collaborations seemed in order. While the first large international collaboration involving Chinese researchers or institutions was published as late

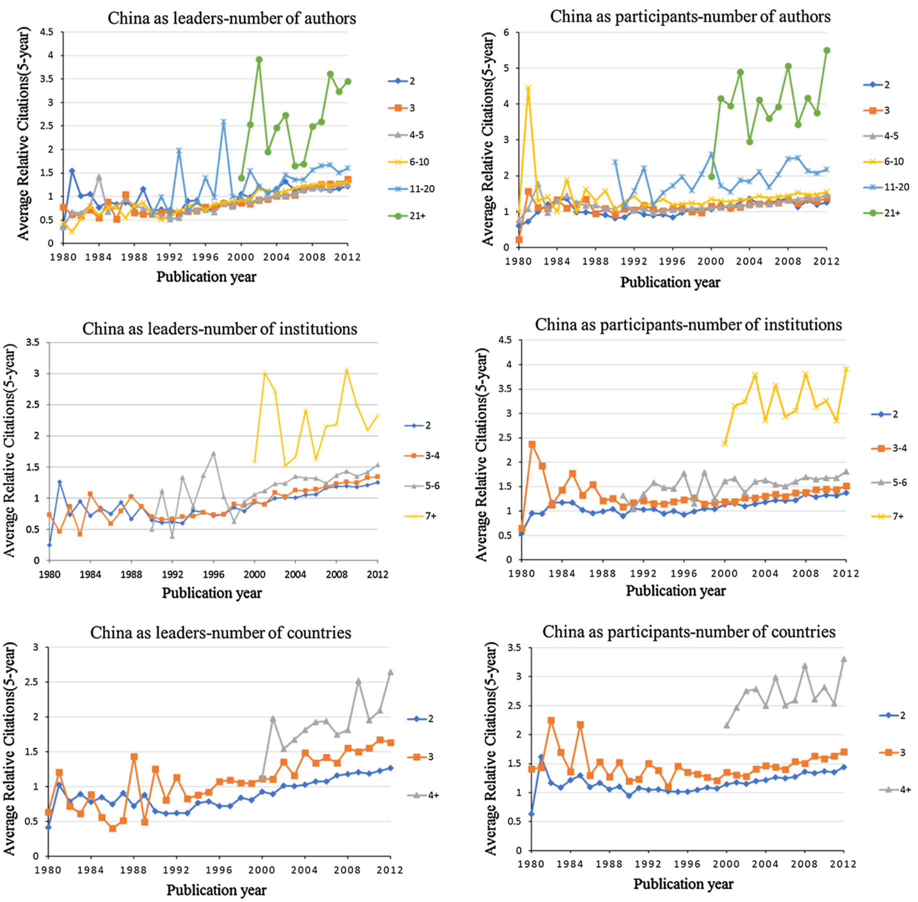

Fig. 5 Average relative citations (ARC) of papers in China-led and -participating international collaborations as a function of author, institution and country frequency, from 1980 to 2016. Results are based on 5-year moving window averages

as 1989, Fig. 6 shows that massively collaborative research quickly grew over the years, going from 3 papers in 1989 to 507 in 2016. Amongst the 4248 large-scale collaborations observed during that period, the number of authors, institutions, and countries involved respectively grows from 100 to 5154, from 30 to 1040, and from 3 to 91. As regards to specialty, Table 3 shows that most of these papers were published in Physics journals; this shouldn't come as a surprise, given the increasingly collaborative nature of Physics research. However, the most significant statistic relating to China's large-scale international collaborations relates to leadership: of all papers considered, only 190 were Chinese-led. The country's leadership in big science collaboration is thus seriously lacking; in our opinion, this deficiency is technological in origin, as most of the large-scale, state-of-the-art instruments needed for the development of that discipline, such as particle accelerators and telescopes, are located in the United States and Europe.

Figure 7 presents the result of the field-normalized impact of China's large team size international collaborations. While most papers with large numbers of collobarting

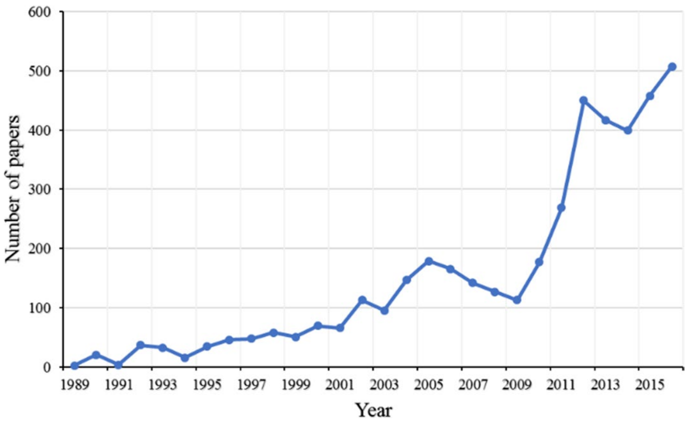

Fig. 6 Evolution of paper frequency for China's large-scale international collaboration, from 1989 to 2016

Table 3 Paper frequency by speciality for China's large-scale international collaborations

Speciality	Papers
Nuclear & Particle Physics	2851
General Physics	948
Astronomy & Astrophysics	86
General Biomedical Research	74
Electrical Engineering & Electronics	73
Genetics & Heredity	69
Applied Physics	36
General & Internal Medicine	26
Cancer	22
Other	63

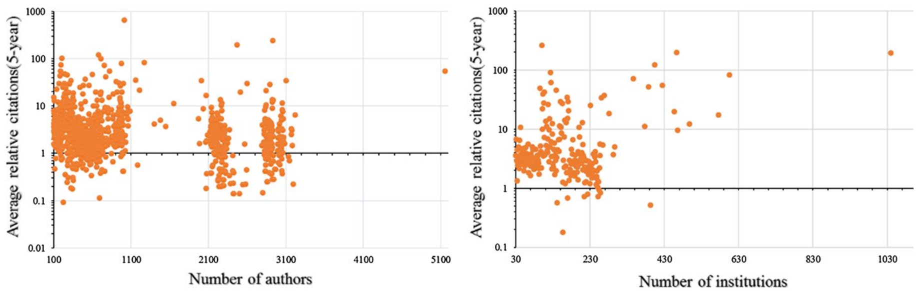

Fig. 7 Average relative citations (ARC) of China's large-scale international collaborations by author and institution frequency, 1980–2016

authors or institutions have above-average ARC scores, no strong correlation with research impact can be observed. This suggests that regardless of the higher citation impact of large-scale international collaborations, larger is not necessarily better.

Discussion and conclusion

This study shows that China's leadership in both Natural Sciences and Social Sciences has increased since 1990s, with a majority of China-affliated scholars assuming leading roles in most disciplines. Whether at the author, institution or country level, China's international collaborations has been increasing in both leading and participating contexts from 1980 onward. During that period, the average number of authors by paper steadily increased since 1980, going from 4 to 7 in 2016 in leading context and from 10 to 38 in in participating context. During the same period, the proportion of 2-author China-led papers went from 33% to 5% and from 20 to 5% for China-participating ones. The decrease in 2-author China-led papers is mainly due to the increase in papers with 6–10 authors and papers with 11–21 authors; the proportion of the latter has also decreased since the early 1980s, mainly in favor of papers with more than 6 authors. At the institutional level, 2-institution papers also decreased over time, accounting in 2016 for 37% and 26% of all papers in leading and participating contexts respectively. Hence, a majority of papers in both contribution contexts are the result of collaborations involving 3 or more institutions. At the country level, the proportion of bilateral collaborations remains high over the whole period, despite a slight but steady decrease, especially in participating context. Meanwhile, trilateral collaborations went from 11% of all Chinese-led collaborations in 1980 to 12% in 2016, and from 10 to 23% in participating context for the same period. In sum, while China's international collaborations has become increasingly diverse at the individual and institutional level, most collaborations remain bilateral at the country level; this particular situation can be explained as the result of the country's national funding policy, notably as regards to the promotion of scholar mobility towards specific countries.

Regarding the relationship between team size and research impact, average relative citation scores positively correlate with the number of authors, institutions, and countries up to a certain point, above which the relationship becomes wavier—for instance beyond 20 authors and 14 institutions in participating context. Our results also provide evidence that team size influences citation impact over time. Papers with 11 authors or more gain larger impact in both leading and participating contexts, but even more so in the latter case. For papers with multiple (more than 2) institutions and countries, larger team size positively correlates with research impact: for instance, the ACR scores of Chinese-led papers published in 2012 and involving 3 and 4 institutions are respectively 1.6 and 2.6; a similar phenomenon is also observed in papers with 4 and 3 countries in the same publication year. These results regarding the relationship between team size and citation impact could however have been affected by the fact that China collaborates mostly with USA-affiliate scholars; indeed, research has shown that USA's citation advantage affects other countries citation impact (Gingras and Khelfaoui 2018). The results indicate that within an appropriate range, team size positively correlates with the citation impact of China's international collaborations. For international collaborations, when team size becomes out of appropriate range that will spend more time and higher expense to communicate with collaborators from different countries, which may affect the quality of collaborative papers.

Regarding 2 country collaborations, our study shows that China's international collaborations decrease in both leading and participating contexts between 1980 and 2016, which contrasts with the increase reported for the 1973–2012 by Larivière et al. (2015) for all fields. Both studies however agree on the fact that papers involving 2+ countries are more cited. Finally, as regards to large team size collaborations involving China, our study shows that most papers obtain higher-than-average impact during the observed period: some papers obtain 10 to 100 times more citations than the world average; one paper with 1011 authors is even 600 times above the average citation impact. Not all large-scale collaborations are sucess stories, however; for example, a paper with 2422 authors has 10 times less citations than impact of the average level.

Overall, these results show that China's international collaborations maintain a relatively high citation impact over time. Our study also suggests that international collaborations help promote China's scientific impact, that team size also positively correlates with research impact up to a certain point, whether at the author, institution or country level. As for the existence of an optimal team size for China's international collaborations, the evidence presented in this research would seem to support the opposite claim, as different optima are obtained depending on the factors considered. Thus, contrary to what Liu's (2012) study might imply, finding this number is far from simple or obvious.

Overall, this paper examined Chinese leadership in international collaborations and its relationship with team size and impact. One of the main findings to report is that China plays a mostly and increasingly leading role in international collaborations. Furthermore, most Chinese international collaborations are bilateral, probably due to the specific funding infrastructure regulating research interactions between China and other countries. Assessing the impact of funding on China's international collaborations, along with other potential factors such as disciplinary culture and interdisciplinary practices, will be addressed in future research.

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Author Contributions Conceived and designed the experiments: WQ RYZ VL. Performed the experiments: WQ PM MSM. Analyzed the data: WQ. Contributed reagents/materials/analysis tools: WQ PM MSM RYZ VL. Wrote the paper: WQ PM MSM.

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