



Analyzing China's research collaboration with the United States in high-impact and high-technology research

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Keywords: China–United States relations, coauthorship, high-impact research, high-technology research, research collaboration

ABSTRACT

This study investigates China's international research collaboration with the United States through a bibliometric analysis of coauthorship over time using historical research publication data. We investigate from three perspectives: overall, high-impact, and high-technology research collaborations using data from Web of Science (WoS), *Nature Index*, and *Technology Alert List* maintained by the U.S. Department of State. The results show that the United States is China's largest research collaborator and that in all three aspects, China and the United States are each other's primary collaborators much of the time. From China's perspective, we have found weakening collaboration with the United States over the past 2 years. In terms of high-impact research collaboration, China has historically shared a higher percentage of its research with the United States than vice versa. In terms of high-technology research, the situation is reversed, with the United States sharing more. The percentage of the United States' high-technology research shared with China has been continuously increasing over the past 10 years, while in China the percentage has been relatively stable.

1. INTRODUCTION

China has experienced rapid economic development in recent decades. During this development, China has collaborated with the United States, building a number of partnerships in many areas. Among them, the Fulbright project is perhaps the most representative in the area of science and education. In 1945, Senator J. William Fulbright proposed the "Fulbright project," with the goal of promoting mutual understanding through educational exchange; China was one of the first participating countries. Although the Fulbright Scholar Program has experienced multiple suspensions and restarts in China owing to political issues with the United States (Infeld & Li, 2009), it has been an essential part of educational exchange between the two countries. Another well-known program is the Scientific Cooperation Exchange Program (SCEP), initiated by the Foreign Agricultural Service of the United States Department of Agriculture. This program offers opportunities for US companies to initiate long-term cooperation with Chinese companies to promote agricultural development and economic growth. Since 1979, the program has facilitated exchanges for more than 3,000 participants on topics including food safety and security, animal and plant health, and agricultural biotechnology

and emerging technologies (Foreign Agricultural Service, 2020). These programs enable educators, researchers, professionals, and students from the two countries to study, teach, and research in each other's countries. In turn, this has created many opportunities for the two countries to exchange knowledge and collaborate on research.

The partnership between the two countries experienced ups and downs in the second half of the 20th century, and in the 21st century, economic, diplomatic, and political issues have arisen that could affect the two countries' normal relationship. In 2008, China established the "Thousand Talents Plan" to recruit international lead experts in research, innovation, and entrepreneurship (Zweig & Wang, 2013). The plan has brought more than 7,000 scientists and researchers of diverse fields to China over the past 10 years (Jia, 2018), mostly from the United States. Consequently, the US National Intelligence Council has raised concerns about technology transfer (Postiglione & Simon, 2018). In 2017, the United States Trade Representative initiated an investigation of China under Section 301 of the Trade Act of 1974 to determine "any unreasonable acts, policies, and practices of China related to technology transfer, intellectual property, and innovation" (United States Trade Representative, 2017). Beginning with this investigation, several issues have arisen between the two countries. In 2018, the Trump administration announced a series of plans to impose tariffs on Chinese imports in response to the results of an investigation concluding that China had stolen US intellectual property (Diamond, 2018). In May 2018, the Trump administration announced a limit on the validity of visas issued to Chinese graduate students: Chinese students in STEM-related fields would only be able to obtain 1-year visas (Postiglione & Simon, 2018).

The ongoing trade war between China and the United States and a series of related issues pose potential threats to collaboration between the two countries. Specifically, the enduring scientific collaboration between the two countries is likely to be affected. Against this background, we aim in this study to explore research collaboration between the two countries through bibliometric analysis of coauthored publications. We analyze historical research publication data and investigate collaboration over time. The goal is to understand any changes and trends in research collaboration from three perspectives: overall, high-impact, and high-technology research collaborations. We intend to test the following three hypotheses.

1. Collaboration patterns change along with countries' changing economic powers. With the growth of China's economic power, its collaborators and its importance to other countries as a collaborator also change.
2. Collaborations in high-impact research, defined as research that is featured in renowned publication venues, exhibit different patterns from overall collaborations. High-impact research has a different set of expertise and resource requirements and may warrant different collaborative norms.
3. Collaborations in high-technology areas, characterized as highly protected, sensitive research areas that are of national interest, are the most susceptible to international relation disputes. Three high-technology areas are selected in this paper: nuclear science and technology; remote sensing; and robotics. Even given the promotion of country-level collaboration, collaborations in high-technology areas are often seen as delicate and cautious.

2. LITERATURE REVIEW

Research collaboration is a common endeavor that plays many positive roles in the scientific community. Studies have reported that research collaboration results in higher scientific

quality (Melin, 2000), improved research productivity (Lee & Bozeman, 2005), and increased financial support (Beaudry & Allaoui, 2012; Heffner, 1981). Katz and Martin (1997) summarized different levels of research collaboration, ranging from the individual to the international level. Although research collaboration does not necessarily lead to coauthored papers, bibliometric analysis of coauthorship has been widely used as an approach to understanding research collaboration (Subramanyam, 1983). Different levels of research collaboration can be analyzed by aggregating coauthorship data at different levels (Melin & Persson, 1996). For literature on research collaboration at the individual level, readers can refer to Bozeman and colleagues' work (Bozeman, Fay, & Slade, 2013), in which they systematically organize relevant studies and discuss them extensively.

International collaboration is a widely studied topic within the scientific community (Frame & Carpenter, 1979). Scientific articles by authors from two or more countries have been used to measure international collaboration (Luukkonen, Tijssen et al., 1993). Researchers have studied international collaboration from diverse perspectives, including factors affecting collaboration (Jeong, Choi, & Kim, 2013; Stead & Harrington, 2000); patterns of collaboration (Coccia & Wang, 2016; Kim, 2006); strategies of promoting collaboration (Bagshaw, Lepp, & Zorn, 2007); spatial characteristics of collaboration (Hoekman, Frenken, & Tijssen, 2010; Ponds, Van Oort, & Frenken, 2007); impacts of international mobility on collaboration (Jonkers & Tijssen, 2008); and gender differences in collaboration (Abramo, D'Angelo, & Murgia, 2013).

Plenty of studies have focused on the international collaboration of individual countries or regions such as the United States (Luo, Flynn et al., 2011), Europe (Thijs & Glänzel, 2010), Korea (Kim, 2005), Vietnam (Nguyen, Ho-Le, & Le, 2017), Malaysia (Yu, Wah et al., 2013), Iran (Hayati & Didegah, 2010), and Africa (Adams, Gurney et al., 2014; Mègnigbèto, 2013). Among them, China (Zheng, Zhao et al., 2012) is one of the most studied countries. China's international research collaboration has been studied with respect to its collaborative relationships with the Group of Seven (G7) nations (He, 2009), the United States (Tang, 2013; Tang & Shapira, 2011), Germany (Zhou & Bornmann, 2015), Australia (Niu, 2014), and overseas institutions (Wang, Xu et al., 2013). These studies identified China's major collaborators and explored collaboration patterns. Tang and Shapira (2011), analyzing patterns and dynamics of China–US collaboration in nanotechnology, found that the United States is China's largest research collaborator in this field, which has helped China to grow in traditional fields as well as expand research territory to the emerging field of nanotechnology research. In a later study, Tang (2013) found that only elite Chinese scientists in the nanotechnology field tend to collaborate with researchers from the United States, yielding a positive effect on China's research quality.

Many research fields have been studied, including nanotechnology (Wang, Xu et al., 2012), physics (Zhou & Lv, 2015), and energy (Wan & Craig, 2013). The focus of this study differs from previous studies in the following respects: The study aims to analyze patterns in China–US collaboration in a reciprocal manner—from the points of view of China and the United States, respectively; in addition to overall collaboration, the study also aims to explore collaboration specifically in high-impact and high-technology research; 3) all the above patterns are explored over time to understand any changing patterns.

3. DATA AND METHODS

Research publication data were retrieved from the WoS Core Collection. Only journal articles (i.e., articles and reviews) were retrieved and conference proceedings were not

included in the analyses. We combined field tags available in the *Advanced Search* to identify a research article's information, including publication year, publication name (journal name), country, and WoS Category. For example, we retrieved all research articles written by researchers affiliated with Chinese organizations by using the query "PY=2018 AND CU=(PEOPLES R CHINA)". We retrieved all the research publications published between 1999 and 2018 by Chinese and US organizations and used the "Analyze Results" function to get intermediate data, which were then downloaded to local computers for analysis and visualization. Collaboration was measured on the basis of research articles, specifically, the addresses field of author information. If a research article's addresses field includes addresses of two or more countries, the collaboration counts of all the country pairs increase by one. This includes the case in which an author has addresses of two or more countries.

We investigated China's international research collaboration based on the following three aspects.

- International research collaboration for China. We analyzed all Chinese research articles included in the WoS Core Collection to identify major collaborators with China and changes over time in collaborative relationships. We aimed to obtain an overview of China's overall international research collaboration.
- International collaboration for China in high-impact research, defined as research articles published in 82 high-impact science journals compiled by *Nature Research* (specifically, the latest version of *Nature Index* available as of March 2019). We analyzed China's research publications in 82 journals to determine the country's performance in high-impact research and its collaboration with other countries. By fixing the number of journals, the total number of published articles remained relatively stable, which was beneficial for identifying true high-impact research, avoiding artifacts such as apparently increased performance in high-impact research caused by the increasing total number of journals.
- International collaboration for China in high-technology research, defined as research in fields identified in the *Technology Alert List* maintained by the U.S. Department of State (Goklany & Trewavas, 2003; Li & Stodolska, 2006). Considering exact matches between fields in the list and WoS categories, we selected three fields, namely Nuclear Science and Technology; Remote Sensing; and Robotics. We analyzed collaboration in high-technology research because we hypothesized that collaborations in high-technology areas are the most susceptible to policy disputes. Considering recent issues of technology transfer between the two countries, we believe the two countries' collaboration in high-technology research could be affected.

4. RESULTS

4.1. International Research Collaboration for China

Figure 1 shows international research collaboration involving China over the latest 20 years. Yearly percentages of collaborative work between China and other countries in China's overall research work are shown. Six countries appeared as China's top five research collaborators over the latest 20 years: the United States, Australia, England, Canada, Germany, and Japan. In 2018, China collaborated with the United States in more than 12% of its research work. We fitted a linear regression line for collaboration with the United States based on the data from 1999 to 2016. The linear regression line has an R^2 value of 0.87, representing small differences

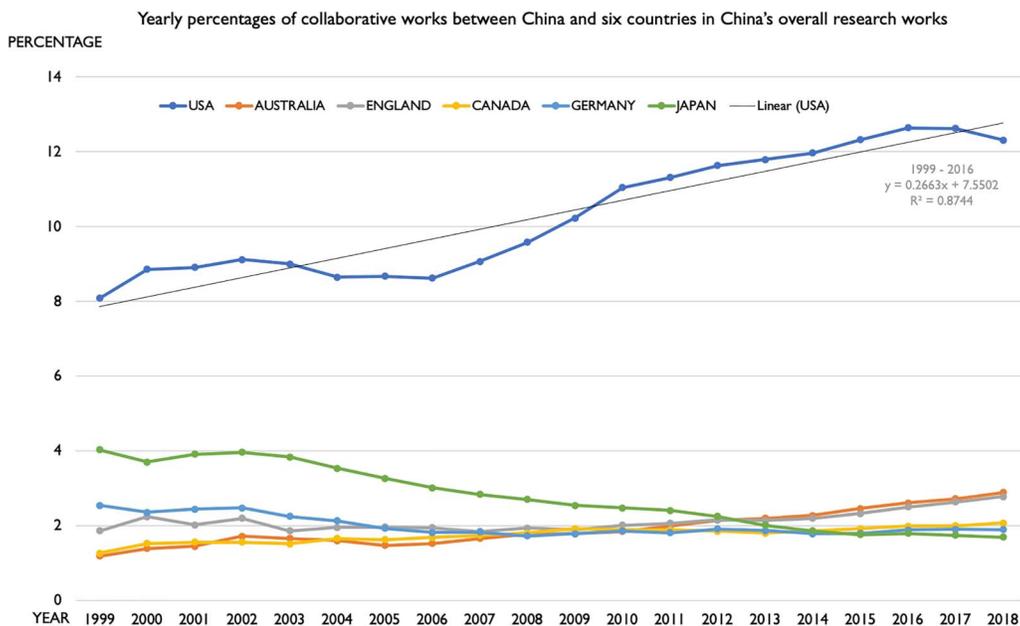


Figure 1. International research collaboration for China (1999–2018).

between actual and predicted values. The actual values between 2004 and 2009 are smaller than the predicted values, while for the other years before 2016, the predicted values are slightly higher. The predicted values for 2017 and 2018 are 12.6099 and 12.8762, respectively. Compared with the actual values of 12.618 and 12.308, respectively, we find that in 2017, the predicted value was on par with the actual value, and in 2018, the actual value was smaller than the predicted value. In fact, the 2018 value was also smaller than that of 2017. The results suggest that collaboration in the past 2 years has been slipping.

Figure 2 shows temporal changes in collaborative ranks for each specific country, measured by the volume of coauthored research articles between the country and each of the collaborators. For example, in 2018, China's top five collaborators, sorted by the volume of their co-authored research articles with China, were the United States, Australia, England, Canada, and Germany. However, in 2009, the list was occupied by the United States, Japan, Canada, England, and Germany. China's top five collaborator list has been relatively stable in recent years.

There are a few notable points worth discussing.

The United States has always been China's largest collaborator, and China has been the United States' largest collaborator since 2011. The United States also appears to be the largest collaborator for the other examined countries (Japan, Germany, Canada, England, and Australia). This pattern shows a steady and close collaborative relationship between China and the United States, which also shares other major collaborators, such as England, Germany, and Canada. While France has been collaborating steadily with the United States, that country does not have a strong collaborative relationship with China.

Japan used to be a strong collaborator for China, second only to the United States for many years. However, Japan began to lose its status as one of China's strongest collaborators in 2013 and was no longer one of China's top five collaborators in 2015. Nevertheless, from the



Figure 2. International research collaboration for China, United States, Australia, England, Canada, Germany, and Japan (2009–2018).

perspective of Japan, China has always been the country's second-largest collaborator over the past 10 years.

Australia appeared on China's top five collaborator list in 2011, and after 2 years became China's second-largest collaborator. China has been a strong collaborator for Australia over the past 10 years, with a change in rank from three to two in 2017.

China has maintained close collaborative relationships with England and Germany. England has been China's third-largest collaborator for the past 9 years, while Germany has been China's fifth-largest collaborator for many years. These two countries have collaborated extensively over the years, with each being the other's second-largest collaborator at various times. However, China has not been a major collaborator for either for a long time. In 2017 and 2018, however, China was one of England's top five collaborators. Whether a similar trend will appear between China and Germany is worth keeping an eye on. England and Germany have also closely collaborated with other European countries such as France, Italy, Switzerland, the Netherlands, and Scotland, which are not China's strong collaborators.

Although there have been changes in rank, Canada has been on China's top five collaborator list for many years and has been its fourth-largest collaborator since 2015. China has steadily improved its status as one of Canada's top five collaborators, from fifth in 2009 to fourth in 2013, to third in 2014, and finally to second in 2018.

4.2. International Collaboration for China in High-Impact Research

Figure 3 shows international collaboration in high-impact research for China over the past 20 years. Research articles published in 82 high-impact science journals compiled by *Nature Research* (specifically, the latest version of *Nature Index* available as of March 2019) between 1999 and 2018 were considered. In 1999, China published 949 articles in *Nature Index* journals, and the size has grown exponentially to 17,044 in 2018. Seven major collaborators in China's high-impact research are shown in Figure 3 with the volume of journal articles on

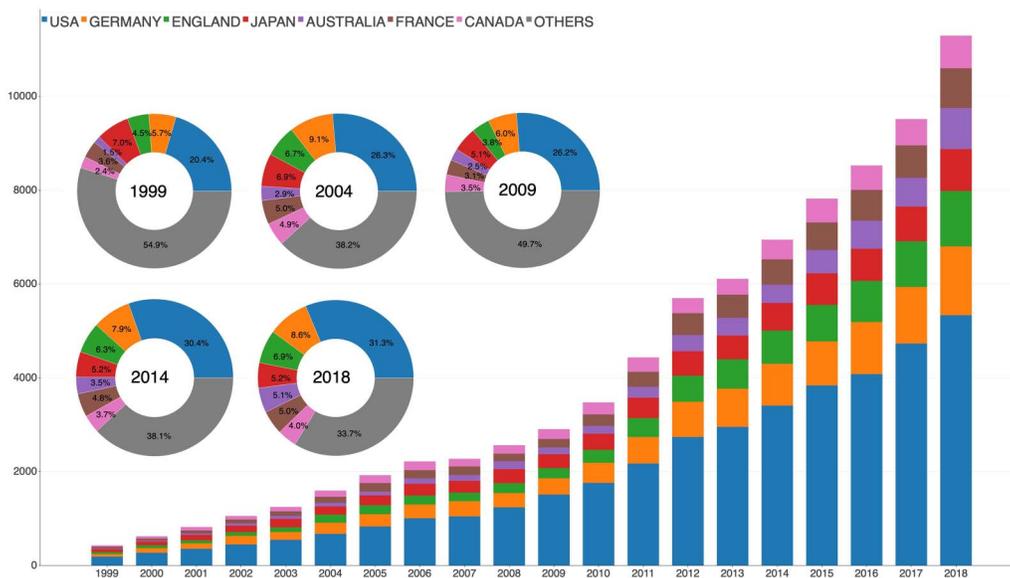


Figure 3. International collaboration for China in high-impact research (1999–2018).

which they have collaborated. Countries that have appeared on China's top five collaborator list in high-impact research more than once were selected as China's major collaborators.

In high-impact research, the United States is again China's largest collaborator, as manifested by its volume of collaborative work and share of China's overall collaboration (Table 1). In 1999, 20.4% of China's high-impact research publications were with the United States, and the percentage went up to 31.3% in 2018. Since 2009, China has been one of the United States' top five collaborators in high-impact research and became its largest collaborator in 2014 (Table 2). In 2018, China collaborated with the United States on approximately one-third of its high-impact work, while approximately 16% of the United States' high-impact

Table 1. International collaboration for China in high-impact research (2009–2018)

Year	Total publications	Publications with US	Percentage	Rank of US
2018	17,044	5,339	31.325	1
2017	14,455	4,736	32.764	1
2016	12,696	4,082	32.152	1
2015	11,925	3,841	32.21	1
2014	11,226	3,413	30.403	1
2013	9,654	2,959	30.651	1
2012	8,658	2,743	31.682	1
2011	7,639	2,178	28.512	1
2010	6,609	1,764	26.691	1
2009	5,779	1,516	26.233	1

Table 2. International collaboration for United States in high-impact research (2009–2018)

Year	Total publications	Publications with China	Percentage	Rank of China
2018	34,043	5,339	15.683	1
2017	33,671	4,736	14.066	1
2016	33,642	4,082	12.134	1
2015	37,836	3,841	10.152	1
2014	37,042	3,413	9.214	1
2013	36,077	2,959	8.202	2
2012	37,753	2,743	7.266	2
2011	36,429	2,178	5.979	3
2010	32,823	1,764	5.374	4
2009	36,182	1,516	4.19	4

work was with China. This confirms again the two countries' strong collaborative relationship, not only in overall research but also in high-impact research.

Following the United States, Germany has been China's second-largest collaborator. China has collaborated with Germany more closely in high-impact research than in overall research, where Germany was China's fifth-largest collaborator. In 2018, England was China's third-largest collaborator, constituting 6.9% of China's high-impact work, following Germany's 8.6%.

Japan, Australia, and Canada were also major collaborators for China. Australia and Canada have both steadily increased their percentages from 1.5% and 2.4% in 1999 to 5.1% and 4.0% in 2018, respectively. Japan's percentage, on the other hand, shrank from 67.0% in 1999 to 5.2% in 2018. France, while not on China's top five collaborator list in terms of overall research collaboration, has been included in the counterpart list in high-impact research for many years.

4.3. International Collaboration for China in High-Technology Research

Nuclear Science and Technology, Remote Sensing, and Robotics were selected from the WoS categories, and research articles published under these three categories were analyzed. Table 3 shows levels of international collaboration in high-technology research for China. There has been rapid growth in high-technology research in China, from 979 articles in 2009 to 5,546 articles in 2018. In high-technology research, the United States is again China's largest collaborator. Each year, more than 10% of China's high-technology research articles are copublished with the United States. Despite increased overall collaboration between China and the United States, from China's perspective, collaboration in high-technology research has remained at a stable level for the past 10 years, generally at a level of 12–13%. Of note is that the two countries' collaboration in percentage terms recorded its highest point in 2015 (14%) and has slipped over the past 3 years. Countries such as Canada, Germany, England, Japan, Australia, and France were also major collaborators, although percentages were generally under 4%. In the early years of this survey, China collaborated with Japan on approximately 5% of its high-technology research articles; however, the percentage has dropped to 2% in recent years.

Table 3. International collaboration for China in high-technology research (2009–2018)

Year	Total publications	Top 1	Top 2	Top 3	Top 4	Top 5
2018	5,546	US (13.2%)	GERMANY (3.2%)	CANADA (2.6%)	ENGLAND (2.5%)	AUSTRALIA (2.1%)
2017	4,740	US (13.0%)	CANADA (2.9%)	GERMANY (2.6%)	JAPAN (2.2%)	AUSTRALIA (2.1%)
2016	3,927	US (13.5%)	CANADA (2.7%)	ENGLAND (2.5%)	AUSTRALIA (2.5%)	GERMANY (2.4%)
2015	3,583	US (14.0%)	JAPAN (3.0%)	FRANCE (2.7%)	CANADA (2.3%)	AUSTRALIA (2.2%)
2014	3,038	US (13.2%)	FRANCE (3.0%)	CANADA (2.8%)	JAPAN (2.8%)	GERMANY (2.7%)
2013	2,328	US (13.0%)	GERMANY (3.2%)	FRANCE (3.1%)	JAPAN (3.1%)	CANADA (2.5%)
2012	1,639	US (12.9%)	JAPAN (3.3%)	CANADA (3.0%)	GERMANY (2.5%)	ENGLAND (1.8%)
2011	1,402	US (13.3%)	JAPAN (5.3%)	CANADA (3.5%)	GERMANY (3.3%)	FRANCE (2.9%)
2010	1,210	US (12.4%)	JAPAN (4.5%)	CANADA (3.1%)	FRANCE (2.8%)	GERMANY (2.7%)
2009	979	US (11.0%)	JAPAN (4.6%)	GERMANY (3.4%)	CANADA (3.1%)	FRANCE (3.0%)

The United States has been another key contributor to high-technology research, typically publishing more than 3,000 articles per year (Table 4). Prior to 2016, the United States published more high-technology research articles than China each year. Since 2016, the situation has reversed, and in 2018, China produced approximately 1,000 more research articles than the United States in high-technology research. China has been the United States' largest collaborator since 2010. The percentage of the United States' high-technology work with China has increased steadily each year from 3.5% in 2009 to 16.9% in 2018. Compared with the percentages from China's perspective, which have been stable over the past 10 years, from the US perspective they have been increasing every year. This may partly explain the background of the *Technology Alert List*.

Table 4. International collaboration for the United States in high-technology research (2009–2018)

Year	Total publications	Top 1	Top 2	Top 3	Top 4	Top 5
2018	4,310	CHINA (16.9%)	GERMANY (4.5%)	FRANCE (4.0%)	CANADA (3.7%)	ITALY (3.6%)
2017	4,048	CHINA (15.2%)	GERMANY (4.9%)	ENGLAND (4.1%)	FRANCE (4.1%)	ITALY (3.9%)
2016	3,852	CHINA (13.8%)	GERMANY (5.0%)	FRANCE (4.2%)	ITALY (3.8%)	CANADA (3.6%)
2015	3,673	CHINA (13.7%)	GERMANY (4.7%)	ENGLAND (3.6%)	FRANCE (3.3%)	CANADA (3.3%)
2014	3,398	CHINA (11.8%)	GERMANY (5.1%)	FRANCE (4.5%)	ITALY (3.7%)	JAPAN (3.6%)
2013	3,560	CHINA (8.5%)	GERMANY (5.4%)	FRANCE (4.9%)	ITALY (4.2%)	JAPAN (3.2%)
2012	2,828	CHINA (7.5%)	GERMANY (4.6%)	FRANCE (4.0%)	ITALY (3.5%)	JAPAN (3.0%)
2011	3,313	CHINA (5.6%)	GERMANY (5.1%)	FRANCE (4.4%)	JAPAN (4.3%)	ITALY (4.0%)
2010	2,549	CHINA (5.9%)	GERMANY (4.4%)	FRANCE (4.1%)	ITALY (3.7%)	JAPAN (3.5%)
2009	3,087	GERMANY (4.6%)	FRANCE (4.4%)	ITALY (4.4%)	JAPAN (3.8%)	CHINA (3.5%)

5. DISCUSSION AND CONCLUSIONS

In this study, we investigated China's international research collaboration from three perspectives: overall, high-impact, and high-technology research. Overall, the United States, Australia, England, Germany, Canada, Japan, and France were major collaborators with China. In terms of overall research collaboration, China has maintained reciprocally close relationships with North America and Australia, while with European countries (England and Germany), collaborative relationships seem to be one-way based on the collected data. This is explained by the fact that China has not featured on England and Germany's top five collaborator lists for a long time. However, we witnessed a change over time, with China becoming one of England's top five collaborators in 2007. This trend is worth investigating when subsequent data becomes available. In high-impact research, a strong collaborative relationship between China and the United States was shown again. In 2018, China shared 31% of its high-impact research work with the United States, and the United States collaborated on 16% of its high-impact work with China. The relationship has become increasingly close, and we expect this trend to continue. Japan has been China's close collaborator for many years, although in recent years, China has collaborated more with Germany and England than with Japan. In high-technology research, more than 13% of China's research articles in 2018 were published with the United States, and the United States collaborated on 17% of its high-technology work with China.

This paper produced the following findings. From the Chinese perspective, in terms of overall research collaboration between China and the United States, the actual value (percentage) is smaller than the predicted value in 2018; in high-impact research, the percentage in 2018 is smaller than in 2015, 2016, or 2017; and in high-technology research, the percentage has been decreasing since 2016. However, from the perspective of the United States, we did not find such phenomena. China has been playing a continuously increasing role in the United States' high-impact and high-technology research. This demonstrates the difference between analyzing collaboration from China's perspective and that of the United States.

In terms of high-impact research collaboration, China shared a larger percentage of its research with the United States than vice versa (31% vs. 16%). However, in high-technology research, the situation is reversed, with the United States sharing more (13% for China vs. 17% for the United States). This may be partially attributed to the *Technology Alert List*.

The percentage of the United States' high-technology research with China has been continuously increasing, from 4.6% in 2009 to 16.9% in 2018. However, in China, the percentage has been relatively stable over the past 10 years, remaining at the 12–13% level. It seems that there is an invisible barrier for Chinese researchers to collaborate with US researchers in the selected high-technology areas. This is a significant finding, considering that collaborations between the two countries in all other areas are rapidly increasing.

The three hypotheses are all supported.

With the growth of China's economic power, some of its major collaborators' statuses have changed, manifested by the rise of Australia and the fall of Japan as collaborators. China's collaborative status with other countries has also changed. Its importance as a collaborator with the United States, Australia, England, and Canada has strengthened over the past 10 years.

Collaborations in high-impact research exhibit different patterns from overall collaborations. China collaborates with the United States more intensively in high-impact than in overall research (31.3% vs. 12.3% in 2018). In addition, China collaborates with certain countries such as Germany and France more intensively in high-impact than in overall research.

Collaborations in high-technology research are the most susceptible to international tensions. While we identified a slightly decreasing trend of collaboration between the two countries in terms of overall and high-impact research in 2018, a similar trend was seen as early as 2016 in high-technology research.

The study used research publications as a proxy for measuring research collaboration, yet research collaboration does not necessarily link to research publications, and therefore we should interpret the results with caution. For example, research collaboration could be measured using patent data as well. In addition, only journal articles have been explored in the study, and we expect that analysis of other forms of research publications, such as conference papers, will broaden our understanding. In terms of counting the number of collaborative works among countries, we used the raw count without considering the number of authors that belong to specific countries in a publication. For example, if a journal article is written by researchers of two countries (no matter how many researchers belong to each country), the two countries' collaborative work increases by 1. However, some weighting mechanisms may be applied to measure the intensity of collaboration more accurately. We used the country classification mechanism used in WoS, in which the United Kingdom is represented by its constituent countries. Our analysis was based on this mechanism without further data integration. In terms of defining high-impact and high-technology research, we used *Nature Index* and the *Technology Alert List* respectively, and the two sources may not fully represent these categories. In addition, to perform exact matches between the fields in the *Technology Alert List* and WoS categories and eliminate uncertainties, some disciplines in the *Technology Alert List* were not considered.

International issues between China and the United States motivated us to investigate research collaboration between the two countries. We have identified several changes and trends in China's international research collaboration with the United States and other countries. From the results, we did not find any specific signal showing any impacts of the ongoing international tensions between the two countries on their research collaboration. However, we do not conclude that the two countries' research collaboration has been unaffected, given that academic publishing is a long process and may not reflect the impacts in a timely way. Chinese students and researchers in the United States who have steadily been contributing to the two countries' collaboration may be one of the factors in us not seeing a trend of diminishing collaboration. Regardless of recent issues between the two countries, in the long term, China and the United States have steadily been improving their relationship in scientific research, which may be a sign of the two countries' intentions to continue collaborating in their research.

AUTHOR CONTRIBUTIONS

Yongjun Zhu: Conceptualization, Methodology, Writing—original draft, Writing—review & editing. Donghun Kim: Investigation, Visualization, Writing—original draft. Erjia Yan: Conceptualization, Writing—original draft. Meen Chul Kim: Visualization, Writing—original draft. Guanqiu Qi: Project administration, Writing—original draft, Writing—review & editing.

COMPETING INTERESTS

The authors have no competing interests.

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DATA AVAILABILITY

Access to the data used in this paper requires a subscription to the WoS Core Collection.

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