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Measuring National-level Research Production under Fractional Counting: China versus the U.S.

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Abstract

This paper aims to examine the heterogeneity of research production between China and the United States by disaggregating the national research production into its constituent components. Different from previous studies, we introduce the share counting method to determine the number of publications attributed to each country. We analyse bibliographic metadata from over 36 million SCI/SSCI-indexed journal publications published in the period from 2000 to 2021. The research production of China and the United States is decomposed according to the document types, disciplines, and high-impact journals. In the quantitative analysis, the first finding is that China emerged as the world's largest contributor to SCI-indexed publications in 2019 under fractional counting, two years earlier than under whole counting. Surpassing the U.S. in publication count does not indicate a completely surpassing position for China in its scientific production strength, however. When it is divided by document types, China has published a smaller proportion of review-type journal publications than the U.S.; when filtered by disciplines, in the period from 2016 to 2021, China's research production leads in only 100 of 178 natural science fields and 2 of 58 social science fields. The second finding is, when only the number of papers on high-impact journals is considered, China also surpassed the U.S. in 2019; meanwhile, the proportion of high-impact journal papers of China is still lower than that of the U.S. These results reveal that there are different knowledge production patterns in China and the United States. This study contributes to a better understanding of the disparities in research productivity between the top two nations, and suggests several policy implications for China.

Keywords

research production; research evaluation; China; the United States; Science Citation Index; Social Science Citation Index; bibliometric analysis

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1. Introduction

In the evaluation of science and innovation activities, research production typically refers to the number of publications produced by a certain production unit (individual, research group, department, institution, field, and country), although it is sometimes analysed in a way that includes impact, efficiency or quality components (Abramo and D'Angelo, 2014; Thelwall and Fairclough, 2017). Assessing research performance, particularly at the national level, necessitates the availability of statistics on research production (Abramo and D'Angelo, 2011; Abramo *et al*., 2022; King, 2004). However, in the context of cross-national macro-level evaluations of research output, the research production volume is often viewed as a less significant indicator for comparison due to its dependence on the amount of resources invested in the academic system (Chen *et al*., 2020; Meo *et al*., 2013). Researchers tend to focus more on impact, quality, and efficiency indicators of output, often relegating research production as data points that has to be reported at the beginning of the analysis or used to explain the dynamic changes of the output number. As a result, the in-depth analysis of the composition and structure of research production tend to be overlooked, which may lead to incomplete analyses and potentially misleading conclusions. For instance, two countries may have a similar number of total research production, but their composition - research production in different document types, disciplines, and sources - is likely to vary, which indicates differences in their knowledge production patterns. The mixture of these categories can easily lead policy-makers to develop misconceptions that the research strength of two countries is similar and make it difficult to discern the relative strengths and weaknesses of their own country. By neglecting such nuances in the internal composition structure of research production, policy-makers may be inadequately informed when making resource allocation decisions.

Publication distribution across document types, disciplines, and sources represents three key aspects of a country's scientific publishing landscape, providing insights into its research landscape and strategic priorities (Zhang *et al*., 2011). Publications of different document types are shaped by very different processes, have different academic functions and scholarly values (Zhu and Liu, 2020), and inform policy-makers about certain research preferences of researchers in their countries (Zhang *et al*., 2011). Different scientific disciplines have different research paradigms, and contribute in markedly different manner to economic growth and social development (Abramo *et al*., 2022; Fortunato *et al*., 2018). Analyzing research production across various disciplines informs policy-makers about academic strengths and weaknesses in their countries (Harzing and Giroud, 2014). Furthermore, the distribution of national publications in journals serves as a partial reflection of the research output's quality. The academic impact of journals varies considerably, and is often measured by the journal impact factor which reflects the average citation rate of the journal and usually matches the citation rate of papers published by the journal (Schubert and Braun, 1986). Researchers generally prioritize papers published in high-impact journals, as they are generally considered to be of higher quality (Wang, 2016). Tracking top papers provides policy-makers with insights into the country's foremost academic strength.

By tracking the variation in the number of publications by different types in their country and making comparisons with other nations, policy-makers can identify their country's comparative strengths and weaknesses. This allows them to leverage strengths and address weaknesses effectively. Based on these statistics on research production, policy-makers can determine whether the research production sector is operating in line with predefined goals, decide how to adjust resource allocation, and set goals for future phases. Therefore, conducting in-depth analyses of national research production can yield valuable insights for policy makers seeking to optimize resource allocation in accordance with a country's unique knowledge production patterns.

Monitoring journal publications is a commonly employed method in the literature for measuring the research production of a nation (Huang *et al.*, 2011; Szuflita-Zurawska and Basinska, 2021). Bibliometrics provides a well-established methodology for assessing the quantity and distribution of journal publications (Joshi, 2014; Mahapatra and Sahoo, 2022). By applying this methodology to the analysis of a country's output quantity, it becomes possible to gain valuable insights into the composition and structure of the national research production.

An important issue is that due to the presence of co-authored papers, different counting methods can influence the counting results and the ranking of national publications. The whole counting method has been widely used to calculate individual country contributions in related literature (Aksnes *et al.*, 2012; Liu *et al.*, 2015a; Moreno-Delgado *et al.*, 2021; Zhu and Liu, 2020), while most researchers argue that the fractional counting method is a more reasonable approach to assessing a country's scientific research output (Gauffriau and Larsen, 2005; Rinia *et al.*, 1993; Waltman and van Eck, 2015). An obvious advantage is that fractional counting avoids the inflationary problem associated with counting in whole (Waltman and van Eck, 2015).

However, few studies have applied the fractional counting to measure research productivity at the country level due to the challenges associated with obtaining detailed data and the substantial workload involved in processing (Gauffriau, 2017). In light of this, this manuscript seeks to supplement previous research by utilizing the fractional counting method, and provides a comparison of the results across the fractional and the whole counting methods.

This paper aims to use bibliometric methods to uncover the differences in various underlying components of the national-level research production volume across countries. This theoretical significance lies in the ability to identify divergent knowledge production patterns across different countries from the perspective of research output, thereby facilitating the inference of country-related factors contributing to these disparities.

We selected China and the United States (U.S.), the top two countries in the world in terms of the number of academic publications, as a case study to illustrate the differences in the quantity distribution of research production. In recent years, the rapid increase of academic publications from China has garnered widespread scholarly attention (Liu *et al.*, 2015a; Liu *et al.*, 2015b; Tang, 2019; Tollefson, 2018; Zhou and Leydesdorff, 2006). The comparison of the volume of publication output between China and the U.S. is one of the key points to understand the nowadays global academic publishing landscape (Ahmed *et al.*, 2015; Basu *et al.*, 2018; Zhu and Liu, 2020).

The Chinese government is committed to making China an innovative country, with the main benchmark being the U.S. Previous studies have shown that the total number of SCI papers in China and the U.S. are already very close to each other using the whole counting method (Zhu and Liu, 2020). It is worth continuing this research to answer academic concerns about whether China has actually surpassed the U.S. in terms of research production. We first aim to shed light on whether such a surpassing has occurred and compare fractional results with whole results. While we emphasize that the single indicator of the total number of research production is confusing because a single figure drowns out differences in internal structure. Driven by this mission, this paper aims to offer new insights into the comparative study of research production in China and the U.S., by providing fractional measures across document types, fields, and journals. The analytical methods and results of this paper are also a reference for other countries, especially emerging science and technology countries, in optimizing their own research layout.

In our analysis, we aim to address the following questions:

[1] How does fractional counting affect the measurement of research production of China versus the U.S. compared with whole counting?

[2] What are the differences in research production between China and the U.S. in different document types, disciplines, and high-impact journals?

2. Literature Review

2.1. National-level research production assessing

Assessing national-level research production belongs to the category of Research and Development performance evaluation, also an important research topic in Scientometrics. With rapid advancements in science over the past century, there has been a heightened focus on measuring and comparing research output among countries or regions (Wong, 2019). Price (1963) and Price (1965) were the first to count the number of journals and abstracts of scientific output worldwide. Since then, the number of publications has become one of the main indicators of measuring the output of academic research. Particularly, with the establishment of large literature databases such as Web of Science (WOS), publication counting and citation analysis have become more convenient. A notable study is Larsen and von Ins (2010), which examined the growth rate of global scientific publications from 1907 to 2007 based on data from multiple literature databases.

The quantity and quality of research production vary significantly between countries (Man *et al*., 2004; May, 1997). King (2004) conducted a comparative analysis of the quantity and quality of national science output among 31 countries using Thomson ISI data. The study found that from 1997 to 2001, the European Union collectively ranked first in terms of publication quantity globally, while the U.S. had the highest number of Top 1% highly cited publications worldwide. This comparison of research production between EU countries and the U.S. has attracted the attention of researchers (Almeida *et al*., 2009; Glanzel and Schlemmer, 2007; Horta and Veloso, 2007). At the same time, with the rapid development of economy and technology, there has been a substantial growth in the number of publications from China. The quantity and quality of research production of China has garnered attention (Glanzel *et al*., 2008; Kosto, 2004; Leydesdorff and Zhou, 2005).

A considerable number of studies have measured China's research production and compared it with other countries. Almost all relevant studies report the number of publications in China or its percentage of the world's total production. But the analyses mainly focused on input-output ratios and citations (Basu *et al*., 2018; Brainard and Normile, 2022; Glanzel *et al*., 2008; Leydesdorff and Wagner, 2009a, 2009b; Leydesdorff *et al*., 2014; Moed, 2002; Moiwo and Tao, 2013; Wagner *et al*., 2022; Zhou and Leydesdorff, 2006). Based on data related to the four types of documents, namely articles, letters, notes, and reviews, from SCI database, China became the second largest producer of scientific papers in 2006 using whole counting (Zhou and Leydesdorff, 2008) yet lagged behind many countries in terms of the publications normalized by population or GDP (Moiwo and Tao, 2013) or government expenditure in academic research (Leydesdorff and Wagner, 2009b). During the same period, China's average relative citations, and the top 1% or top 10% most-frequently cited publications were still far behind the U.S (Basu *et al*., 2018; Leydesdorff *et al*., 2014). Researchers were curious on if and when China would take over the U.S. in research production, and the year 2020 is predicted as a critical divide (Zhou, 2013).

Recent researches show that in 2019, the total number of SCI papers in China did not exceed that of the U.S. by taking whole counting method, though it is already very similar (Zhu and Liu, 2020). To surprise, China had overtaken the U.S. in the relative participation in the top 1% most-frequently cited publications in 2019 (Wagner *et al*., 2022). Using different data sources and indicator calculation methods may result in different conclusions. According to statistics compiled by the U.S. National Science Foundation, China declared the largest source of research articles based on Elsevier's Scopus database with counting fractionally (Tollefson, 2018), but still lagged behind the U.S. in terms of top 1% most cited papers (Brainard and Normile, 2022). In addition, based on studies that have focused on the publication and publication efficiency of China's social science papers, it seems that China is still not yet a major player in the arena of social sciences (Chen *et al*., 2022; Liu, Hu, *et al*., 2015).

In the context of global competition in research production, it is vital for each country to establish its own research production advantages. There is a need to assess the relative comparative advantage of research production between countries. The evaluation of national research profiles involves three dimensions: document type, discipline and journal. First, differences in the number of document types can provide insights into the preferences and actions of researchers at the national level. Zhang *et al*. (2011) compared the distribution of document types in 26 countries and found that publications in China were concentrated in article types, while publications in the U.S. and the U.K. were more balanced among document types. Zhu and Liu (2020) examined the quantity of articles and reviews published in China and the U.S., and found that China has surpassed the U.S. as the leading producer of articles. However, in the case of reviews, it may take some time for China to assume the position of the largest producer. Second, in regard to the distribution of subjects, it is commonly understood that when a country publishes a greater number of articles in certain disciplines compared to others, it indicates a competitive advantage in those particular fields (Harzing and Giroud, 2014). Researches have also unveiled disparities in national production across diverse academic disciplines. Yang *et al*. (2012) highlighted, through a comparative analysis of paper quantities across various fields, that G7 countries placed a greater emphasis on life sciences, whereas the BRIC countries tended to focus more on physics, chemistry, mathematics, and engineering. Bongioanni *et al*. (2015) discovered that the U.S. had a stronger focus on medical sciences and biomedical research, while China exhibited higher scientific output in the field of physical sciences and engineering. Finally, the distribution of national scientific publications in journals is a partial reflection of the quality of research output. Wang (2016) examined the number of China's publications in high-impact journals ranked top 5% within each discipline. The findings indicate a notable and rapid improvement in the quality of Chinese research publications.

2.2. Counting methods

Almost all work on describing and comparing research systems at the national level based on specialized indicators relies on quantitative statistics of publications. A primary issue is how to allocate a co-authored paper to each co-authored country (Lindsey, 1980; Price, 1981). Different counting methods of co-author paper have been proposed by experts and scholars, and the essence of designing different counting methods is to distinguish different counting objects such as authors, countries, institutions, addresses, and design different scoring functions (Gauffriau *et al*., 2007; Waltman and van Eck, 2015). The counting method chosen significantly impacts the number of papers attributed to a country, with substantial differences in results between the whole and fractional counting methods (Egghe *et al*., 2000; Gauffriau *et al*., 2008). Gauffriau (2017) summarized the arguments in the literature for choosing different counting methods.

The current body of literature has identified several counting methods with inconsistent nomenclature.

Huang *et al*. (2011) provided a summary of counting methods, categorizing them into three types: all counting (including whole counting and complete counting), straight counting, and fractional counting (Lin *et al*., 2013). In the context of country-level research assessment, whole counting assigns one full credit to each unique collaborating country, while complete counting attributes one credit to the country of each individual author (Gauffriau *et al*., 2007). In the case of direct counting, one full credit is allocated to the most outstanding author, typically the first author or corresponding author (Huang *et al*., 2011; Lin *et al*., 2013). Fractional counting methods distribute one credit equally or proportionally among all collaborators, ensuring that each partner receives their fair share (Waltman and van Eck, 2015).

Many studies have focused on the specific differences between counting methods. Gauffriau *et al*. (2008) identified significant differences in the results when using whole counting and fractional counting to count the number of publications, and emphasized the importance of clarifying the counting methods employed in studies on all publications and citations. Similarity, Lin *et al*. (2013) conducted a comparison of three counting methods on university ranking results, and concluded that both direct counting and fractional counting are better choices compared to whole counting. Waltman and van Eck (2015) distinguished variants of fractional counting, including author-level fractional counting, address-level fractional counting, organization-level fractional counting, and country-level fractional counting, and compared the results obtained from different fractional counting methods. Research results indicate that the variations among different variants of fractional counting are relatively small, while the differences between fractional counting and whole counting are significant. In the comparison of disciplines, the issue with whole counting arose from the multiple counting of co-authored publications, which created unfair advantages in the fields with a high number of collaborations (Waltman and van Eck, 2015).

3. Data and Methods

3.1. Database construction methodology

The source journals tracked in this article are those indexed in the famous Science Citation Index Expanded (SCI) and Social Science Citation Index (SSCI). They are included in the Journal Citation Reports (JCR) released by Clarivate, and are the international mainstream academic journals widely used in research evaluation. This paper's focus is on the international perspective of assessing national-level research production, which excludes China's domestic journals.

Based on the open source bibliographic metadata database with comprehensive and high-quality meta description of publications provided by Crossref (Mryglod *et al*., 2021), we constructed a database containing author address information of SCI/SSCI-indexed publications from 2000 to 2021. It is reported that coverage of Crossref metadata approaches parity with Web of Science (WOS) and Scopus (Martín-Martín, 2021). In their latest 2022 public data file (see: https://www.crossref.org/blog/2022-public-data-file-of-more-than-134-million-metadata-records-now-available/), there are more than 134 million metadata records.

The JCR 2019 journal list was used to merge the SCI/SSCI-indexed publications (abbreviated as SCI/SSCI publications) via the journal name and ISSN. The reason for using the JCR 2019 list is to make our results as comparable as possible with previous studies, for additional citation indexes are added to the JCR list in the subsequent JCR years. In addition, journals indexed by SCI and SSCI change very little from year to year, so it doesn't cause much bias. Finally, we got 36,303,752 SCI/SSCI publications. After removing the records with missing author address information, the number of publications in the database is 34,342,010. Table 1 shows the annual volume change of SCI/SSCI publications.

Table 1
The annual volume change of SCI/SSCI-indexed publications.

Year	NO. of SCI/SSCI -indexed journal publications	NO. of SCI/SSCI-indexed journal publications with author address information	NO. of SCI-indexed publications	NO. of SSCI-indexed publications
2000	918166	842264	770381	104127
2001	927787	854683	785418	100002
2002	983690	902284	834205	101978
2003	1021311	945557	876450	102798
2004	1126837	1040180	963623	115552
2005	1189453	1081971	1006787	116367
2006	1257149	1162802	1084504	123777
2007	1337980	1237964	1152877	133064
2008	1430123	1334531	1220786	166233
2009	1510703	1412395	1298899	170197
2010	1571374	1474111	1351455	183731
2011	1648359	1551968	1423908	194586
2012	1740436	1653712	1515285	208656
2013	1854545	1759363	1621154	213910
2014	1920328	1830487	1686979	223289
2015	1979615	1893661	1744901	231669
2016	2075864	1976670	1811602	253260
2017	2137872	2037426	1880587	248133
2018	2240726	2154752	1990705	265492
2019	2466149	2377053	2182392	306586
2020	2461205	2386605	2196043	304837
2021	2504080	2431571	2224154	306282

3.2. National-level research production measurement

There are two main methods for counting national publications, the whole counting method and the fractional counting method. The whole counting method means that a count of 1 is assigned to a country if one or more authors of the publication are from that country, regardless of how many co-authors there are from outside that country. It means that the same publication can contribute to multiple countries and each country adds the same share of 1.

A notable drawback of the whole counting method is that the total share of each publication is not the same (Leydesdorff *et al*., 2014). So it is found to boost the position of more internationally tied countries with a relatively weak science base in relation to scientifically stronger but less internationally connected countries (Gauffriau *et al*., 2007). On the contrary, fractional counting eliminates this amplification effect.

The fractional counting method sets the combined share for any publication as 1. In this research, we followed the Share calculation method used by Nature Index (See: https://www.nature.com/nature-index/). The Nature Index, published by Springer Nature, is a respected and authoritative source for assessing the research output of countries and institutions. The argument of its method is that a country's research production takes into account the percentage of authors from that country per publication (Nature, 2015). For the calculation of the share counting method, all authors are considered to have contributed equally to the publication. For authors who are affiliated with more than one country, the author's Share is split equally between each country. The total Share for a country is calculated by summing the Share for individual affiliated authors. For instance, if a publication has two authors A and B, A is affiliated with China, B is affiliated with China and the U.S., then China counts 1/2+1/2*1/2=0.75, and the U.S. counts 1/2*1/2=0.25.

We did not choose a more complex fractional calculation method (such as assigning different weights to different authors), due to the fact that the different calculation formulae make little difference at the national level (Waltman and van Eck, 2015), and an additional reason is that because it is difficult to precisely set the weights for the different authors, another type of bias would be introduced, especially given the differences in the various disciplines. According to the Occam's razor principle of scientific research, we use the simplest calculation method.

This paper utilized the counting methods to calculate three indicators that measure national-level research production, as follows:

The Number of Publications – This indicator represents the absolute volume of national research production and is based on the original definition of research output.

World Share – This indicator expresses the proportion of a country's publications to all global publications, providing a measure of the relative volume of research production. World Share is particularly valuable when analyzing research production changes over time or comparing different document types and disciplines.

World Rank – This indicator indicates the world rank of a country's publications compared to all other countries. While it is closely related to World Share, World Rank more precisely informs about the relative advantage of a country's research production.

In this paper, publications of China are limited to those from the Chinese Mainland, Hong Kong, and Macao, and does not include Taiwan. This is consistent with the address identification in the WOS.

3.3. Research framework

To answer the questions posed earlier, this paper conducts four analyses to compare research production in China versus the United States. The research framework of this paper is illustrated in Figure 1. The first analysis pertains to the first question, where both the whole counting method and the share counting method are used to compare the counts of the two countries. The remaining three analyses correspond to the second question, with each analysis focusing on a different dimension. For these three analyses, only the share counting method is used.

Analysis 1: Comparison of Research Production using Whole and Fractional Counting Methods in China versus the U.S.

In this analysis, we examine JCR publications (including all SCI publications and SSCI publications), SCI publications, and SSCI publications separately. Both whole counts and fractional counts are calculated for China and the U.S. in each dataset to compare the results. This also confirm that the publication volume of the constructed database used in this paper is approximately equal to the WOS Core Collection.

Analysis 2: Comparison of Research Production by Document Types in China versus the U.S.

We focus on two document types: articles and reviews, because these two types are the most valued

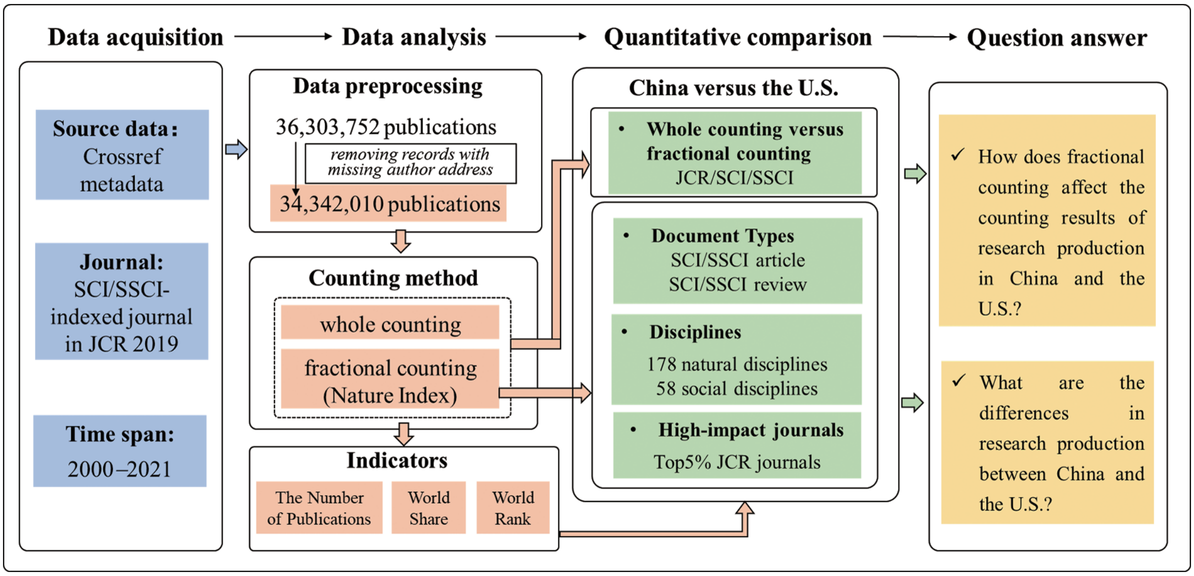

Fig. 1. The research framework of this paper.

types, accounting for a total of over 75% of all types. Note that article-type publications include conference papers that have been submitted to journals. Research production of these document types is counted separately for SCI and SSCI publications in both China and the U.S.

Analysis 3: Comparison of Research Production by Disciplines in China versus the U.S.

Based on the JCR research field categories, all publications are divided into 229 research fields, with 171 belonging to natural science, 51 to social science, and 7 to both natural and social sciences. For each of the 229 subsets, the annual production of articles and reviews from the U.S. and China during the period from 2000 to 2021 was counted by the share counting method. This analysis highlighted China's and the U.S.'s strengths and weaknesses in their respective natural and social science disciplines. World share and world rank are emphasized over absolute numbers.

Analysis 4: Analysis of National Publications from High-Impact SCI/SSCI-Indexed Journals in China versus the U.S.

In this analysis, we focused on counting the quantity of national publications from high-impact SCI/SSCI journals, to analyse the most influential and cutting-edge scientific publications in both countries. We again only considered articles and reviews. Followed with Wang (2016), we selected the top 5% of JCR journals sorted by Journal Impact Factor (JIF) in each research field as high-quality SCI/SSCI journals. The main reason for using the JIF as a proxy for paper quality compared to the number of citations is to avoid time lags in citations. Although there are still problems such as retractions and academic falsification, we currently cannot find a better method.

4. Quantitative Results

4.1. Comparison of whole and fractional counts for research production in China versus the U.S.

4.1.1. The number of JCR-indexed publications

Figure 2 shows the results of whole and fractional counts for the JCR-indexed research production in China and the U.S. A significant contrast in the number of publications between the two countries is evident in 2000, with the U.S. showing considerably higher values. However, China experienced a remarkable surge in JCR-indexed publications from 2000 to 2021. Notably, there has been a simultaneous and striking contrast in the global share of publications, with China's share rapidly increasing while the U.S. experienced a decline.

The whole counting method yields a higher numerical value than the fractional counting method, with the difference primarily attributed to papers with international co-authorship. Compared to the whole counting method, the average decline in the number of the U.S. JCR-index publications obtained using the fractional counting method is 15.40% (with the percentage decrease gradually increasing from 9.33% in 2000 to 23.59% in 2021), while China's JCR-indexed publications decreased by an average of 12.21%. In 2021, China's JCR-indexed publications using whole counting narrowly surpassed the U.S., reaching 604,934, equivalent to 24.88% of the global total, slightly higher than the U.S. at 24.60%. By employing fractional counting, China overtook the U.S. in 2020, when China's fractional counts of JCR-indexed publications reached 534,679, accounting for 22% of the world share, surpassing the U.S. by 3 percentage points.

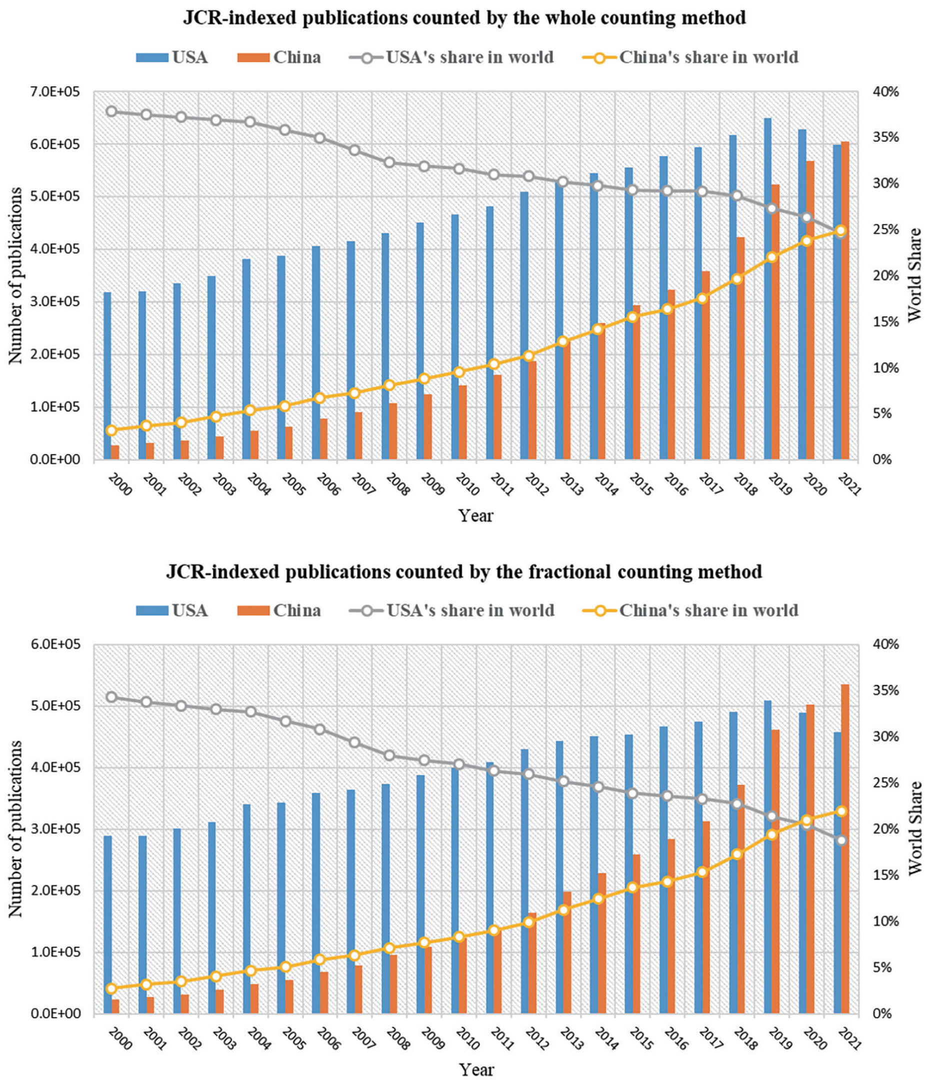

Fig. 2. The number of JCR-indexed publications counted by the whole/fractional counting method: China versus the U.S.

4.1.2. The number of SCI-indexed publications

Figure 3 demonstrates whole counts and fractional counts on the number of SCI publications in China and the U.S. Using the whole counting method, the U.S. is found to have maintained the top position during the period from 2000 to 2020, while its annual production grew from 278,070 to 572,552 as of 2019 (the average annual growth rate is 3.87%), but declined in the next two years. In comparison, the annual production volume of China continued to increase rapidly during the period from 2000 to 2021 with an average annual growth rate of 15.93%, from 26,074 to 581,468. Compared with the results from the time span from 2000 to 2019 reported by Zhu and Liu (2020), the coverage of the publications by our database is more than 90% in most years. With the fractional counting method, the U.S. SCI publications grew more slowly from 249,579 of 2000 to 400,298 of 2021 (an average annual growth rate of 2.28%), while China's SCI-indexed publications grew faster from 22,784 of 2000 to 519,840 of 2021 (an average annual growth rate of 16.06%). The share of global SCI publications for the U.S. and China exhibited contrasting trends. For instance, using the fractional counting method, the U.S. share declined from 32.40% of 2000 to 18.00% of 2021, while China's share rose from 2.96% of 2000 to 23.37% of 2021.

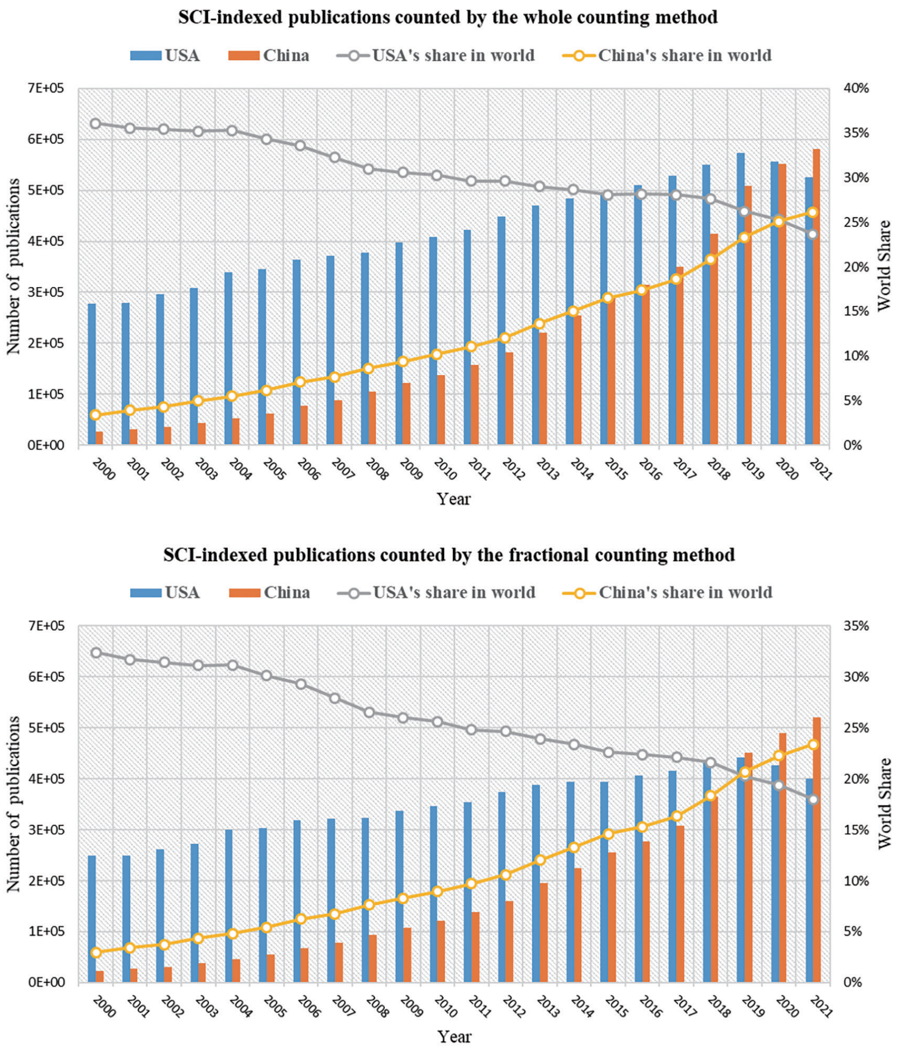

Fig. 3. The number of SCI-indexed publications counted by the whole/fractional counting method: China versus the U.S.

The disparity between fractional and whole counting methods becomes more pronounced for SCI publications. On the one hand, compared to using the whole counting method, the results obtained from the fractional counting method lead to an average annual decrease of 16.40% (with the percentage decrease gradually increasing from 10.25% of 2000 to 23.92% of 2021) in the number of SCI-indexed publications for the U.S. and 11.96% for China. On the other hand, using the whole counting method, China surpassed the U.S. in 2021 to become the world's largest producer of SCI-indexed publications, as Zhu and Liu (2020) predicted. While with the share counting method, China surpassed the U.S. in 2019.

4.1.3 The number of SSCI-indexed publications

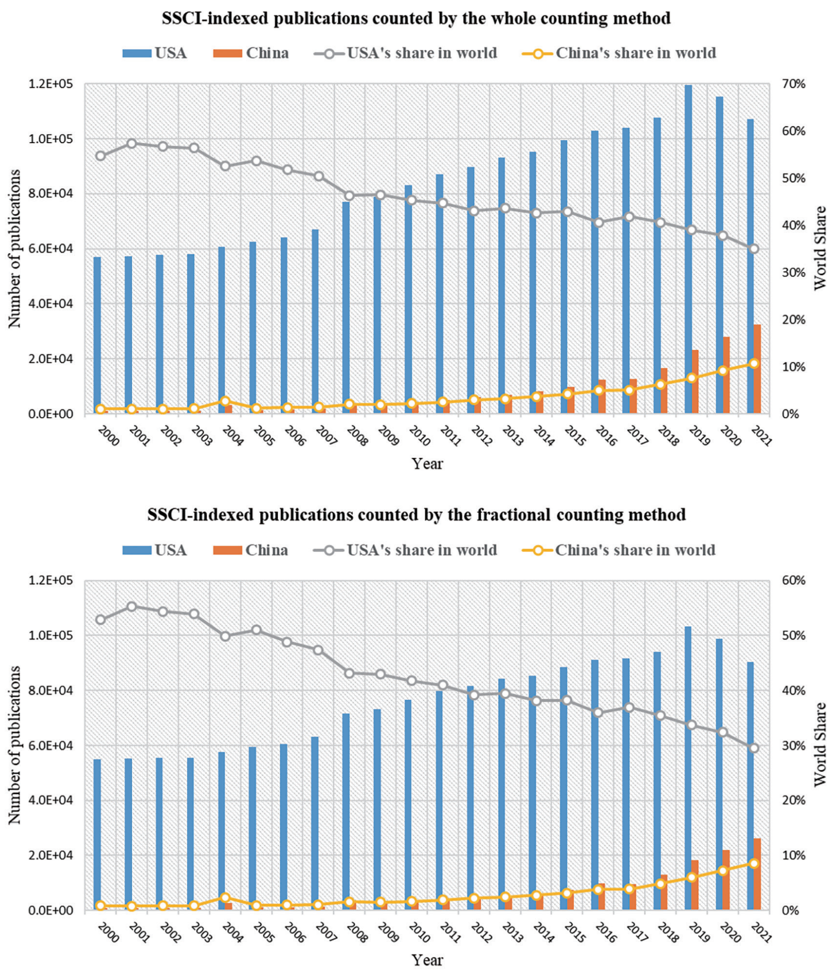

Fig. 4. The number of SSCI-indexed publications counted by the whole/fractional counting method: China versus the U.S.

Figure 4 displays the whole counts and fractional counts of SSCI publications in China and the U.S. It shows that the number of SSCI publications in the U.S. far exceeds that in China, despite the large increase in China's number. In fact, the U.S. still sits at the top of the global SSCI competitive landscape. Using the whole counting method, the number of SSCI-indexed publications in the U.S. increased from 56,961 of 2000 to 107,203 of 2021, while in China, it grew from 1,080 of 2000 to 32,566 of 2021. Employing the fractional counting method, the U.S. saw its SSCI-indexed publications rise from 55,022 of 2000 to 103,309 of 2019, with an average annual growth rate of 3.37%, but it declined to 90,405 in 2021. For China, the number of SSCI publications fluctuated from 885 of 2000 to 26,265 of 2021, with an average annual growth rate of 17.52%. It is important to note that there remains a significant gap between China and the U.S., regardless of whether the whole counting method or the fractional counting method is used. For instance, based on the fractional counting results, China's SSCI publications accounted for only 29.05% of the U.S. total in 2021.

For SSCI publications, the difference between the two counting methods is different from JCR and SCI. When using the fractional counting method instead of the whole counting method, the average annual decrease in the number of SSCI publications is smaller for the U.S. than for China. The U.S. experiences an average annual decrease of 8.49%, while China's decrease is 22.21%. These figures illustrate that China relied more heavily on international collaborations for its SSCI publishing compared to the U.S. Additionally, the U.S. is currently increasing its SSCI international collaborations. As for world rankings, by using the whole counting method, the number of SSCI publications in China has remained the third highest in the world since 2019, not only after the U.S., but also after the U.K. While by using the fractional counting method, the number of SSCI publications in China has become the second largest in the world for the first time.

4.2. Research production of different document types in China versus the U.S. under fractional counting

4.2.1. The number of SCI-indexed articles/reviews from China versus the U.S.

Figure 5 illustrates the trends in the number of article/reviews type of SCI-indexed publications in China and the U.S. China's SCI-indexed article grew from 19,908 to 434,377, with an average annual growth rate of 15.8%. China surpassed the U.S. in SCI article production in 2016, three years earlier than when considering all types of SCI publications. However, in 2020 and 2021, China's growth rate significantly dropped from double digits to approximately 4%. As for the world share of SCI articles, the U.S. and China have experienced opposite trends. The U.S. share decreased from 28.92% of 2000 to 14.68% of 2021, while China's share increased from 3.77% in 2000 to 27.50% in 2021.

For review-type publications, the annual output in the U.S. increased from 10,608 of the year 2000 to 27,090 of 2021, with an average annual growth rate of 4.57%. As of 2021, the U.S. remains the world's largest producer of SCI reviews. In China, the number of SCI reviews grew from 216 of 2000 to 26,998 of 2021, with an average annual growth rate of 25.84%. Since 2015, China has held the second position globally, and the gap with the U.S. has been steadily narrowing. By 2021, the quantity of SCI review articles in China is comparable to that of the U.S. Furthermore, the world share of the United States decreased from 41.08% of the year 2000 to 17.87% of 2021, while China's global share increased from 0.84% of 2000 to 17.81% of 2021.

Although in 2021, China and the U.S. had a comparable number of reviews, China's world share of articles has consistently been higher than its global share of reviews over time, while the opposite holds true for the U.S. This suggests that China's researchers are more inclined to publish articles than reviews compared with the U.S.

4.2.2. The number of SSCI-indexed articles/reviews from China versus the U.S.

Figure 6 shows the production of SSCI articles/reviews in the U.S. and China under the share

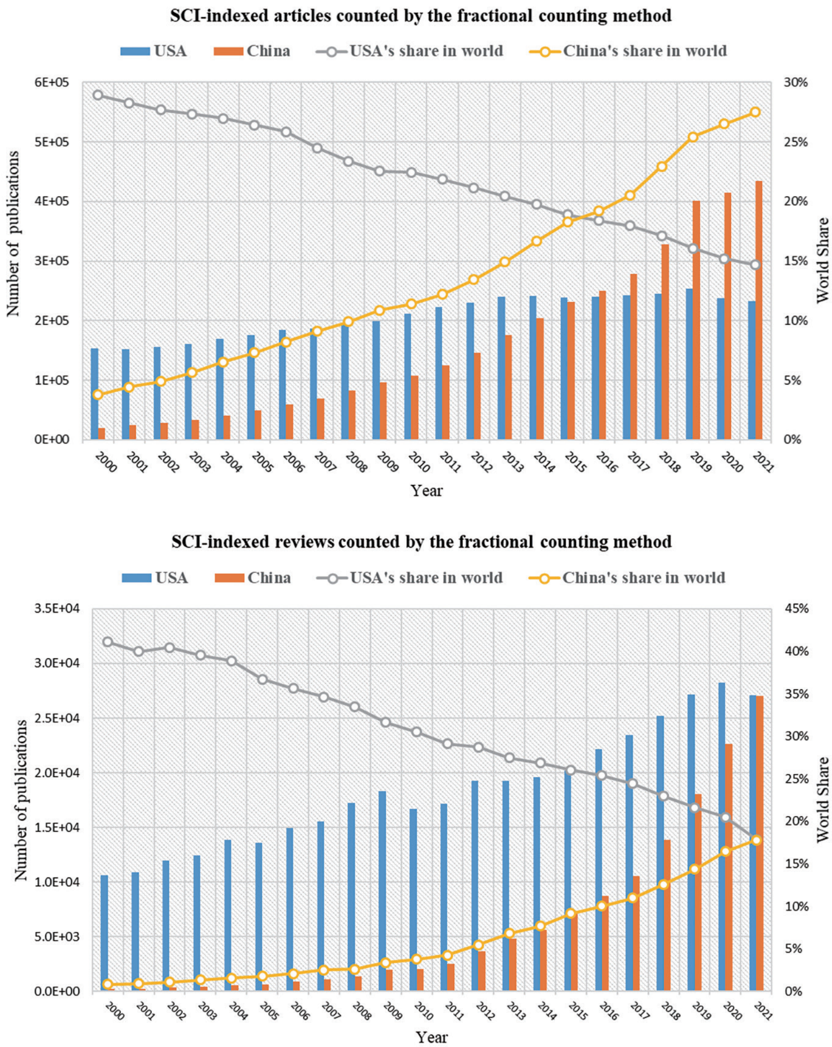

Fig. 5. The number of SCI-indexed articles/reviews under the fractional counting method: China versus the U.S.

counting method. The U.S. has held the top spot as the world's leading publisher of SSCI articles for the past 22 years. China achieved the position of the world's second-largest producer of SSCI articles in 2020, a year earlier than if considering all types of SSCI documents. Over the past 22 years, the number of SSCI articles published by China has shown a remarkable continuous growth, rising from 505 of 2000 to 17,870 of 2021, with an average annual growth rate of 18.51%. In comparison, the U.S. experienced a more modest average growth rate of only 3.03%. While the relative share of the U.S. SSCI articles has been declining, it still held a significant global share of 26.85% in 2021, in contrast to China's 9.94%.

As for the SSCI reviews, China's research production was only 841 (33.18% of that of the U.S.) in 2021, not only less than that of the U.S. but also less than that of the U.K. and Australia, ranking fourth in the world. The relative share of the U.S. SSCI reviews decreased from 62.06% of 2000 to 21.51% of 2021, and the share of China increased from 0.32% of 2000 to 7.14% of 2021.

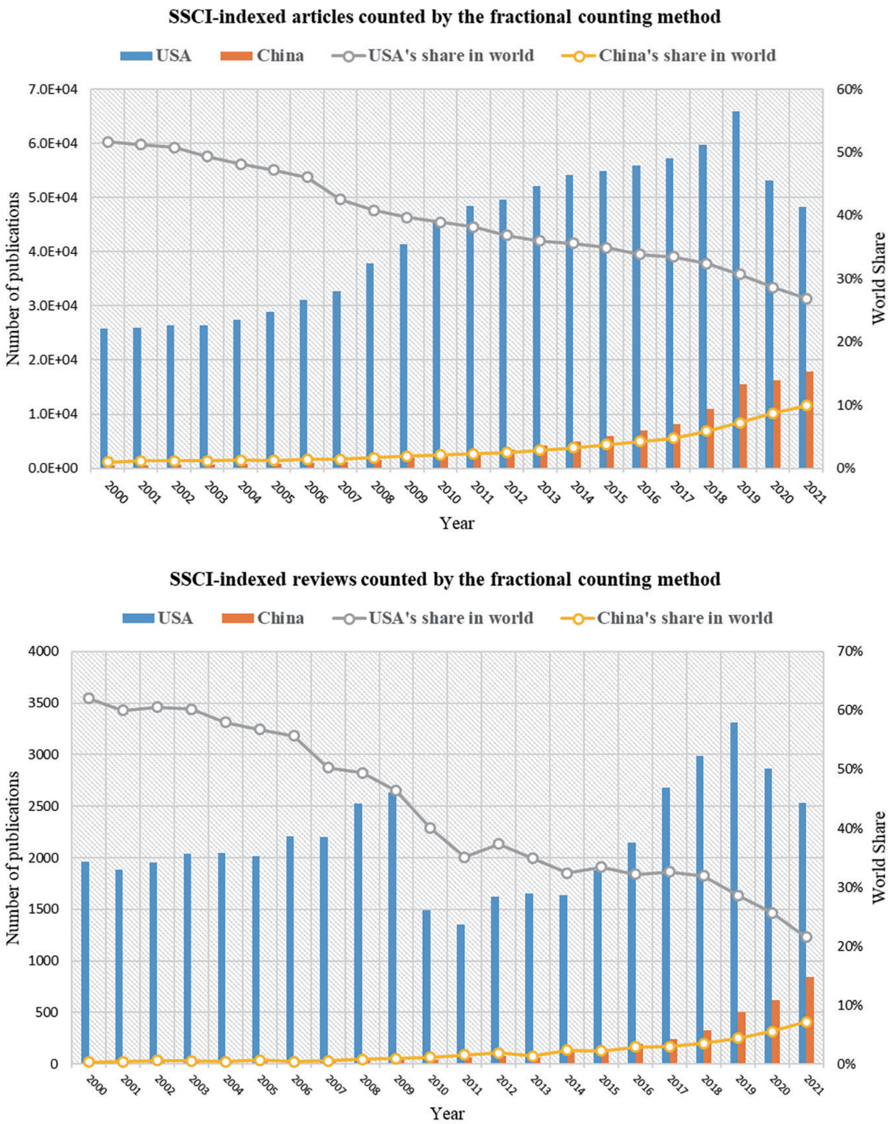

Fig. 6. The number of SSCI-indexed articles/reviews under the fractional counting method: China versus the U.S.

4.3. Research production of different disciplines in China versus the U.S. under fractional counting

4.3.1. Disciplines of natural science

Figure 7 shows the distribution of world ranks of 178 natural science disciplines in China versus the U.S. The distribution differs significantly between the two countries. China's distribution follows a long-tail pattern, while the U.S. is more concentrated. Over time, China's distribution has increasingly concentrated towards higher rankings. In the period from 2000 to 2005, China had only 5 natural disciplines ranked first globally, with nearly half not in the top 10. However, in the time span from 2016 to 2021, China achieved 100 first-place and 50 second-place rankings. In comparison, the U.S. had 170 first-place rankings in the period from 2000 to 2005 and 77 in the time from 2016 to 2021. Despite China's leading in total SCI-indexed publications, in at least 77 disciplines China does not surpass the U.S. in world rankings.

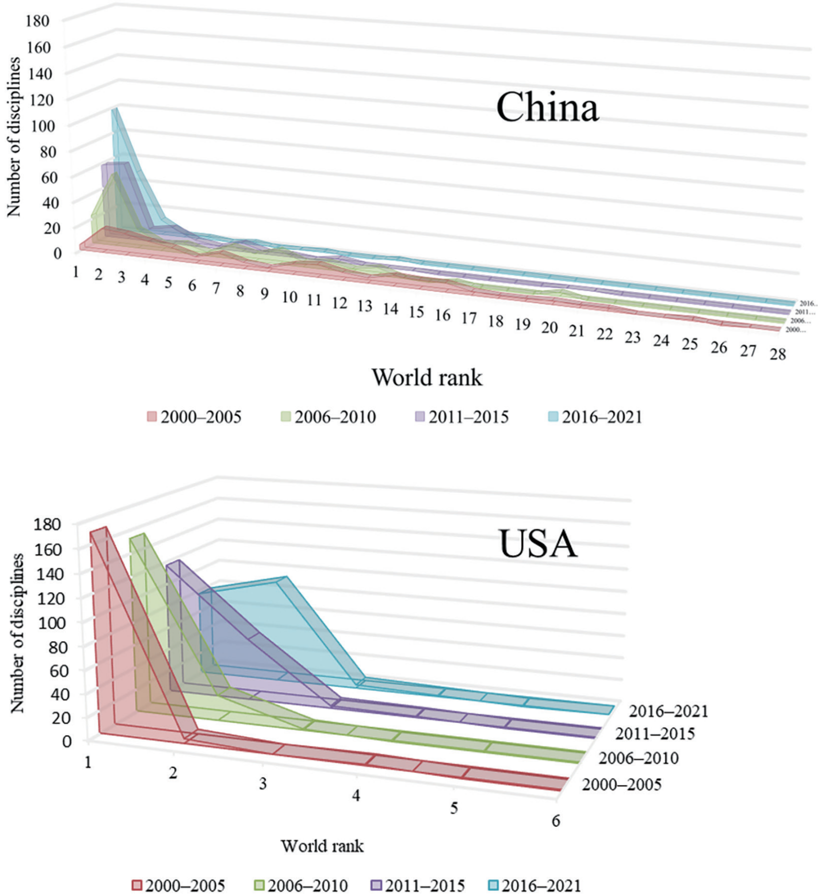

Fig. 7. Distribution of world ranks of 178 natural science disciplines in China versus the U.S.

Note: The year span from 2000 to 2021 is divided into four time-windows (2000-2005, 2006-2010, 2011-2015, 2016-2021) to illustrate trends. In each time window, the numbers of SCI publications from China and U.S. in each natural science discipline are calculated and their world ranking retrieved separately, and then the numbers of disciplines according to different ranks are summarized.

The top 5 disciplines with the largest world share and the top 5 disciplines with the smallest world share in China and the U.S. in each time window are listed in Table 2. Over the past two decades, China has exhibited the greatest comparative advantage in research production in disciplines such as “METALLURGY and METALLURGICAL ENGINEERING”; “CRYSTALLOGRAPHY”; and “MATERIALS SCIENCE, CERAMICS”. These advantages have been consistently reinforced over time. Recent emerging strengths include “ELECTROCHEMISTRY”; “AUTOMATION and CONTROL SYSTEMS”; and “IMAGING SCIENCE and PHOTOGRAPHIC TECHNOLOGY”, with notable growth, and their world shares now exceed 40%. On the other hand, disciplines such as “PRIMARY HEALTH CARE”; “HISTORY and PHILOSOPHY OF SCIENCE”; and “MEDICAL ETHICS” have experienced global disadvantage, with their world shares not exceeding 2% in the latest five years.

An interesting finding is that the dominant and weak disciplines in China and the United States are largely opposite to each other. For instance, three disciplines among the top 5 disciplines in China with the smallest world share – “SUBSTANCE ABUSE”; “HEALTH CARE SCIENCES and SERVICES”; and “EDUCATION, SCIENTIFIC DISCIPLINES” – appear in the U.S. top 5 disciplines with the largest world share. While four disciplines among the U.S. top 5 disciplines with the smallest world share – “ANDROLOGY”; “MATERIALS SCIENCE, CERAMICS”; “METALLURGY and METALLURGICAL ENGINEERING”; and “CRYSTALLOGRAPHY” – appear in China’s top 5 disciplines with the largest world share. This implies that China and the U.S. may have chosen diametrically opposed paths for the development of the disciplines.

To further explore the differences in the distribution of disciplines between the U.S. and China, we grouped 178 natural disciplines into 12 categories. The world shares of the two countries for each category are shown in figure 8. The disciplinary distribution of research production in both countries has not changed fundamentally over the past two decades. China’s relative strengths are concentrated in the fields of materials science, engineering, and chemistry, while weaknesses in the multidisciplinary sciences, medicine, and biology. It is worth noting that in the last five years, the world shares of China in computer science, geography and geophysics, and environmental science fields have grown at a significant rate. In contrast to China, the U.S. has extremely high world shares in medicine and multidisciplinary sciences fields.

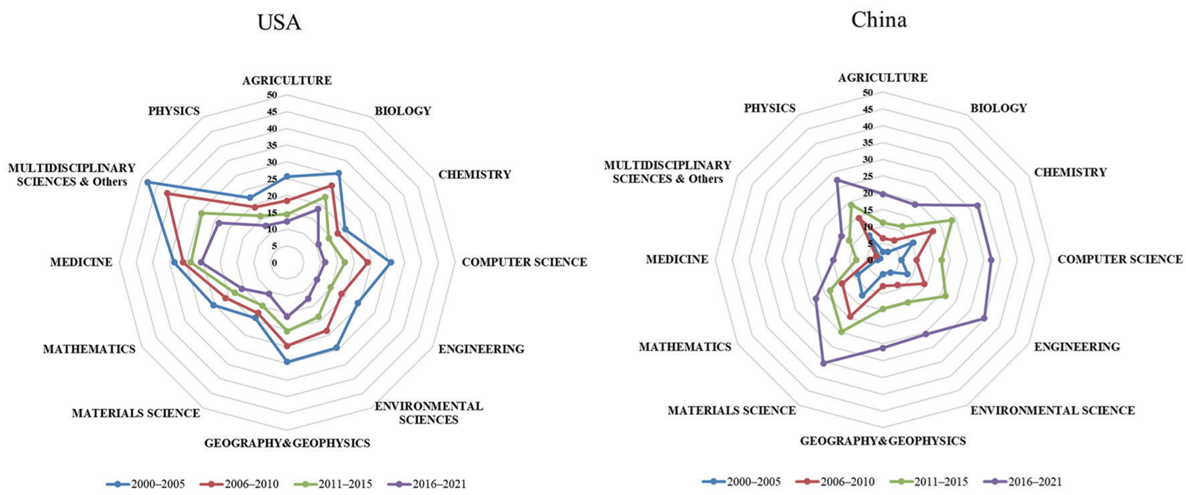

Fig. 8. The world shares of China and the U.S. in different natural science categories.

Note: For all 178 disciplines in SCI: 7 belonging to “AGRICULTURE”, 23 to “BIOLOGY”,9 to “CHEMISTRY”, 7 to “COMPUTER SCIENCE”, 23 to “ENGINEERING”, 7 to “ENVIRONMENTAL SCIENCES”, 8 to “GEOGRAPHY and GEOPHYSICS”, 10 to ”MATERIALS SCIENC”, 6 to “MATHEMATICS”, 56 to “MEDICINE”, 17 to “PHYSICS”, 5 to “MULTIDISCIPLINARY SCIENCES and Others”.

Table 2

The top 5 natural science disciplines with the largest world share and the smallest world share in China versus the U.S.

Year Span	China				USA			
	Top5 disciplines with the largest world share	**Number**	**Share(%)**	**Rank**	**Top5 disciplines with the largest world share**	**Number**	**Share(%)**	**Rank**
2000 -2005	■ METALLURGY and METALLURGICAL ENGINEERING;	9793.11	23.80	1	■ SUBSTANCE ABUSE;	3652.92	57.54	1
	■ ANDROLOGY;	99.82	19.38	1	※NURSING;	6439.26	56.00	1
	◎ PHYSICS, MULTIDISCIPLINARY;	12564.10	18.80	1	■ EDUCATION, SCIENTIFIC DISCIPLINES;	5454.76	53.88	1
	■ CRYSTALLOGRAPHY;	3715.63	18.30	1	MULTIDISCIPLINARY SCIENCES;	19825.29	51.42	1
	■ MATERIALS SCIENCE, CERAMICS;	2167.98	16.54	1	■ HEALTH CARE SCIENCES and SERVICES;	9337.26	50.82	1

(Table 2 continued)

Year Span	China				USA			
	Top5 disciplines with the largest world share	**Number**	**Share(%)**	**Rank**	**Top5 disciplines with the largest world share**	**Number**	**Share(%)**	**Rank**
2006 -2010	◘ METALLURGY and METALLURGICAL ENGINEERING; ◘ CRYSTALLOGRAPHY; ◎ PHYSICS, MULTIDISCIPLINARY; ◘ MATERIALS SCIENCE, CERAMICS; SPECTROSCOPY;	18410.43 6078.86 22903.74 3647.03 5814.08	32.61 26.10 26.00 22.90 22.33	1 1 1 1 1	◘ SUBSTANCE ABUSE; ◘ EDUCATION, SCIENTIFIC DISCIPLINES; ※NURSING; □AUDIOLOGY and SPEECH-LANGUAGE PATHOLOGY; ◘ HEALTH CARE SCIENCES and SERVICES;	5014.22 5817.38 10618.09 3931.08 11351.63	60.27 49.03 46.57 46.47 44.09	1 1 1 1 1
2011 -2015	◘ METALLURGY and METALLURGICAL ENGINEERING; INTEGRATIVE and COMPLEMENTARY MEDICINE; ⊙ ELECTROCHEMISTRY; ENGINEERING, PETROLEUM; ◘ CRYSTALLOGRAPHY;	27040.32 5448.33 17245.72 2038.89 8453.01	36.97 31.42 30.13 30.09 29.05	1 1 1 1 1	◘ SUBSTANCE ABUSE; ◘ EDUCATION, SCIENTIFIC DISCIPLINES; ※NURSING; □AUDIOLOGY and SPEECH-LANGUAGE PATHOLOGY; ◘ HEALTH CARE SCIENCES and SERVICES;	6667.73 7363.50 15022.77 5168.05 16663.94	57.98 45.19 43.80 43.24 39.83	1 1 1 1 1
2016 -2021	◘ METALLURGY and METALLURGICAL ENGINEERING; ◘ MATERIALS SCIENCE, CERAMICS; ⊙ ELECTROCHEMISTRY; AUTOMATION and CONTROL SYSTEMS; IMAGING SCIENCE and PHOTOGRAPHIC TECHNOLOGY;	49549.33 17361.45 36215.35 29704.07 11352.31	43.10 42.28 41.52 41.02 40.41	1 1 1 1 1	◘ SUBSTANCE ABUSE; ◘ EDUCATION, SCIENTIFIC DISCIPLINES; □AUDIOLOGY and SPEECH-LANGUAGE PATHOLOGY; ※NURSING; PEDIATRICS;	9749.67 10731.64 6704.20 21535.75 38165.31	59.76 42.96 42.07 39.99 37.31	1 1 1 1 1
	Top5 disciplines with the smallest world share	**Number**	**Share(%)**	**Rank**	**Top5 disciplines with the smallest world share**	**Number**	**Share(%)**	**Rank**
2000 -2005	◊PRIMARY HEALTH CARE; ◆ HISTORY and PHILOSOPHY OF SCIENCE; ◘ SUBSTANCE ABUSE; BEHAVIORAL SCIENCES AGRICULTURAL; ECONOMICS and POLICY;	6.42 10.00 25.86 94.83 8.92	0.14 0.27 0.41 0.50 0.56	19 27 22 24 20	◘ ANDROLOGY; GREEN and SUSTAINABLE SCIENCE and TECHNOLOGY; ◘ MATERIALS SCIENCE, CERAMICS; TROPICAL MEDICINE; ◘ CRYSTALLOGRAPHY;	31.55 210.68 1370.78 735.59 2441.89	6.13 9.37 10.46 11.70 12.02	4 1 4 2 2
2006 -2010	◊PRIMARY HEALTH CARE; ◆HISTORY and PHILOSOPHY OF SCIENCE; ◇MEDICAL ETHICS; ◘ HEALTH CARE SCIENCES and SERVICES; ◘ EDUCATION, SCIENTIFIC DISCIPLINES;	10.49 21.03 11.92 256.69 146.01	0.21 0.44 0.53 1.00 1.23	20 20 20 16 11	◘ MATERIALS SCIENCE, CERAMICS; ◘ METALLURGY and METALLURGICAL ENGINEERING; ☆CHEMISTRY, APPLIED; ◘ CRYSTALLOGRAPHY ; ◯MATERIALS SCIENCE, TEXTILES;	1242.44 4994.85 4960.01 2392.61 650.80	7.80 8.85 10.26 10.27 10.43	3 3 2 2 2

(Table 2 continued)

Year Span	China: Top5 disciplines with the smallest world share	Number	Share(%)	Rank	USA: Top5 disciplines with the smallest world share	Number	Share(%)	Rank
2011 -2015	◇ MEDICAL ETHICS;	22.01	0.66	21	○MATERIALS SCIENCE, TEXTILES;	614.24	6.06	4
	◊PRIMARY HEALTH CARE;	52.03	0.75	14	◘ MATERIALS SCIENCE, CERAMICS;	1514.18	6.43	4
	◆ HISTORY and PHILOSOPHY OF SCIENCE;	61.01	0.77	20	◘ METALLURGY and METALLURGICAL ENGINEERING;	5023.45	6.87	2
	◘ EDUCATION, SCIENTIFIC DISCIPLINES;	273.60	1.68	9	☆ CHEMISTRY, APPLIED	5097.60	7.99	2
	◣ SPORT SCIENCES;	784.86	1.89	13	AGRICULTURE, MULTIDISCIPLINARY;	2569.69	8.04	3
2016 -2021	◇ MEDICAL ETHICS;	60.82	1.36	13	○MATERIALS SCIENCE, TEXTILES;	736.85	4.09	6
	◆ HISTORY and PHILOSOPHY OF SCIENCE;	161.42	1.43	13	◘ MATERIALS SCIENCE, CERAMICS;	1909.98	4.65	4
	◊PRIMARY HEALTH CARE;	162.55	1.90	10	ENGINEERING, MARINE;	518.14	5.19	4
	◘ SUBSTANCE ABUSE;	419.09	2.57	5	☆ CHEMISTRY, APPLIED;	5331.76	5.20	3
	◣ SPORT SCIENCES;	1664.66	2.81	9	◘ METALLURGY and METALLURGICAL ENGINEERING;	6992.51	6.08	2

Note: Disciplines in the same color indicate that these disciplines appear in both the top 5 disciplines with the largest shares in China (or the U.S.) and the top 5 disciplines with the smallest shares in the U.S. (or China), and disciplines with the same symbol indicate that these disciplines appear consecutively in the top 5 disciplines with the largest (or smallest) shares in China (or the U.S.).

4.3.2. Disciplines of social science

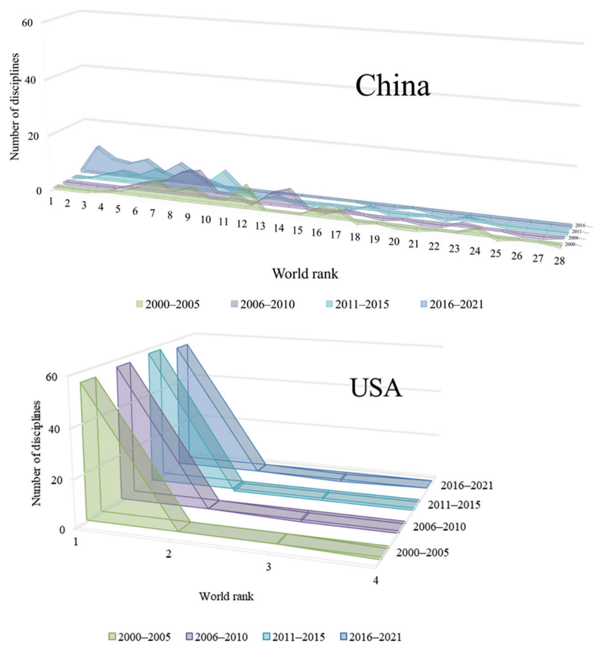

Fig. 9. Distribution of world ranks of 58 social science disciplines in China versus the U.S.

Note: The year span from 2000 to 2021 is divided into four time-windows (2000-2005, 2006-2010, 2011-2015, 2016-2021) to illustrate trends. In each time window, the numbers of SSCI publications from China and U.S. in each natural science discipline are calculated and their world ranking retrieved separately, and then the numbers of disciplines according to different ranks are summarized.

Figure 9 shows the distribution of world ranks of 58 social science disciplines in China and the U.S. Similar to natural sciences, China exhibits a long-tail distribution, but with a smaller proportion of disciplines ranked at the top compared to in natural sciences. The U.S. maintains its leading position across nearly all social sciences. During the time period from 2016 to 2021, China achieved a significant milestone by having 2 disciplines, namely "GREEN and SUSTAINABLE SCIENCE and TECHNOLOGY" and "ENVIRONMENTAL STUDIES", ranked first in the world for the first time. However, performance in six other disciplines did not make it to the global top 10.

Table 3 reveals China's consistent comparative advantage in "GREEN and SUSTAINABLE SCIENCE and TECHNOLOGY" and "TRANSPORTATION" disciplines over the past two decades, with a steady upward trajectory in rankings. Among them, "GREEN and SUSTAINABLE SCIENCE and TECHNOLOGY" has consistently held the highest global share in China. Additionally, in the time window of between 2016 and 2020, China's "ENVIRONMENTAL STUDIES" ranked first globally, while the U.S. position in this discipline was relatively weaker compared to others. On the other hand, "PSYCHOLOGY, PSYCHOANALYSIS", and "ETHNIC STUDIES" consistently rank among the top 3 disciplines with the smallest world share in China, experiencing a very gradual increase in share. "PSYCHOLOGY, PSYCHOANALYSIS" was the social science discipline in which China fell behind the U.S. with the biggest gap.

We grouped 58 disciplines in social science into 6 categories, to demonstrate the different distributions of social science research production in the two countries, which are shown in Figure 10. It appears that China's management and economics disciplines have emerged as breakthrough areas on the global stage, while history and philosophy remains the weakest areas. In contrast, while the U.S. world share in various fields has been shrinking over time, its distribution resembles a hexagonal all-rounder, except for the latest five years, during which its lead advantage in the management area has significantly weakened.

Table 3

The top 3 social science disciplines with the largest world share and the smallest world share in China versus the U.S.

Year Span	China				USA			
	Top3 disciplines with the largest world share	**Number**	**Share(%)**	**Rank**	**Top3 disciplines with the largest world share**	**Number**	**Share(%)**	**Rank**
2000 -2005	▣ GREEN and SUSTAINABLE SCIENCE and TECHNOLOGY; ◎ TRANSPORTATION; ※AREA STUDIES;	6.83 105.58 136.25	6.21 4.21 3.25	4 6 5	⊙ LAW; ◇ FAMILY STUDIES; ◆ EDUCATION, SPECIAL;	8626.36 3688.94 2298.23	79.81 71.92 70.93	1 1 1
2006 -2010	HOSPITALITY, LEISURE, SPORT and TOURISM; ※AREA STUDIES; ◎ TRANSPORTATION;	212.02 241.13 187.21	4.12 4.00 3.99	5 5 6	◇ FAMILY STUDIES; ⊙ LAW; ▣ PSYCHOLOGY, PSYCHOANALYSIS;	4781.73 8522.95 616.49	66.31 64.87 58.05	1 1 1
2011 -2015	▣ GREEN and SUSTAINABLE SCIENCE and TECHNOLOGY; URBAN STUDIES; ◎ TRANSPORTATION;	367.86 626.84 660.42	13.11 6.79 6.74	2 3 4	◇ FAMILY STUDIES; ▣ PSYCHOLOGY, PSYCHOANALYSIS; ⊙ LAW;	6654.08 865.59 10449.01	59.12 57.78 55.30	1 1 1
2016 -2021	▣ GREEN and SUSTAINABLE SCIENCE and TECHNOLOGY; ◎ TRANSPORTATION; ▣ ENVIRONMENTAL STUDIES;	9085.06 2975.25 14182.99	21.56 15.44 15.01	1 2 1	◇ FAMILY STUDIES; SUBSTANCE ABUSE; ◆ EDUCATION, SPECIAL;	10227.69 11120.38 4048.22	53.67 52.75 51.58	1 1 1

(Table 3 continued)

Year Span	China Top3 disciplines with the smallest world share	China Number	China Share(%)	China Rank	USA Top3 disciplines with the smallest world share	USA Number	USA Share(%)	USA Rank
2000 -2005	■ PSYCHOLOGY, PSYCHOANALYSIS; ○ETHNIC STUDIES; □ HISTORY and PHILOSOPHY OF SCIENCE;	1.00 1.50 5.50	0.09 0.16 0.18	24 30 29	■ GREEN and SUSTAINABLE SCIENCE and TECHNOLOGY; ◊GEOGRAPHY; ☆ REGIONAL and URBAN PLANNING;	7.00 1967.49 1437.68	6.36 27.92 32.26	3 2 1
2006 -2010	■ PSYCHOLOGY, PSYCHOANALYSIS; ○ETHNIC STUDIES; □ HISTORY and PHILOSOPHY OF SCIENCE;	0.20 5.00 15.28	0.02 0.28 0.40	32 23 20	■ GREEN and SUSTAINABLE SCIENCE and TECHNOLOGY; ◊GEOGRAPHY; ☆ REGIONAL and URBAN PLANNING;	71.09 2422.22 1475.46	15.69 21.98 25.93	1 2 1
2011 -2015	■ PSYCHOLOGY, PSYCHOANALYSIS; ○ETHNIC STUDIES; HISTORY OF SOCIAL SCIENCES;	3.00 13.47 24.02	0.20 0.42 0.52	23 23 24	■ GREEN and SUSTAINABLE SCIENCE and TECHNOLOGY; ☆ REGIONAL and URBAN PLANNING; ◊GEOGRAPHY;	473.94 1862.48 3686.69	16.89 19.86 20.29	1 1 1
2016 -2021	■ PSYCHOLOGY, PSYCHOANALYSIS; ○ETHNIC STUDIES; HISTORY;	9.48 51.41 150.58	0.41 0.96 1.08	20 17 15	■ GREEN and SUSTAINABLE SCIENCE and TECHNOLOGY; ■ ENVIRONMENTAL STUDIES ; ☆ REGIONAL and URBAN PLANNING;	2620.30 12737.04 2657.58	6.22 13.48 16.96	4 2 1

Note: Disciplines with the same color indicate that these disciplines appear in both the top 3 disciplines with the largest shares in China (or the U.S.) and the top 3 disciplines with the smallest shares in the U.S. (or China), and disciplines with the same symbol indicate that these disciplines appear consecutively in the top 3 disciplines with the largest (or smallest) shares in China (or the U.S.).

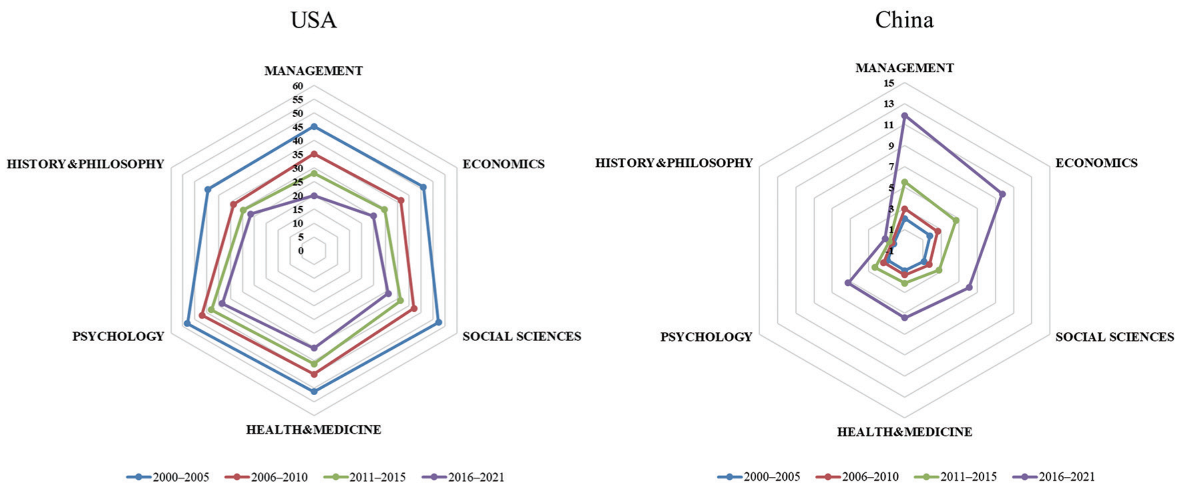

Fig. 10. The world shares of China and the U.S. in different social science categories.

Note: For all 58 disciplines in SSCI, 4 belonging to "ECONOMICS", 7 to "HEALTH and MEDICINE", 3 to "HISTORY and PHILOSOPHY", 8 to "MANAGEMENT", 11 to "PSYCHOLOGY", and 25 to "SOCIAL SCIENCES".

4.4. Research production of high-impact SCI/SSCI-indexed publications in China versus the U.S. under fractional counting

4.4.1 The number of top 5% SCI/SSCI-indexed articles and reviews

As shown in Figure 11, the number of China's articles and reviews published in the top 5% JCR journals has increased rapidly from 972 to 43,638, with an average annual growth rate of 19.86%. By comparison, that of the U.S. increased slowly from 19,603 to 27,714, with an average annual growth rate of 1.66%. Surprisingly, as the result of China's production increase has accelerated in recent years, it is in 2019 the publication volume of top papers from China surpassed that from the U.S.

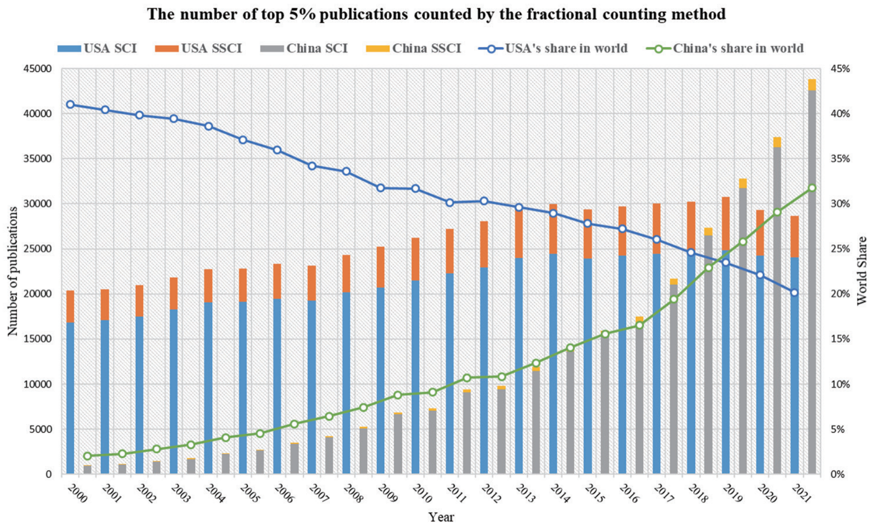

Fig. 11. The Number of the top 5% SCI/SSCI-indexed publications under the fractional counting method: China versus the U.S

Note: Only two document types - article and review - are considered.

As for the world shares of the contribution of the U.S. and China to world total articles and reviews in top 5% SCI/SSCI journals, the share of the U.S. decreased from 41.01% of 2000 to 20.16% of 2021, while China's share increased from 2.03% of 2000 to 31.74% of 2021. Therefore, the dominance of China and the U.S. in publishing top papers should not be underestimated.

When distinguishing the papers included in SCI and SSCI index again, the strength of China in publishing top SCI-indexed papers is highlighted. In 2021, China's contribution to the top SCI-indexed papers is 177% of that of the U.S. While the number of top SSCI papers published in China is far fewer than that in the U.S. In 2021, China's total articles and reviews published in the top 5% SSCI journals amounted to only 27.24% of the U.S.

4.4.2 The proportion of top 5% SCI/SSCI-indexed articles and reviews

Although the number of top 5% papers of China exceeds that of the U.S., it may be more due to the quantity of papers China has published than to the general improvement of its research quality. We noticed that the proportion of top 5% papers in all papers of China is lower than that of the U.S., as shown in Figure 12. The different finding was that, the proportion of U.S. top 5% SCI papers in its all SCI papers has shown a downward trend in the past 20 years, while the proportion of China's top 5% SCI papers in

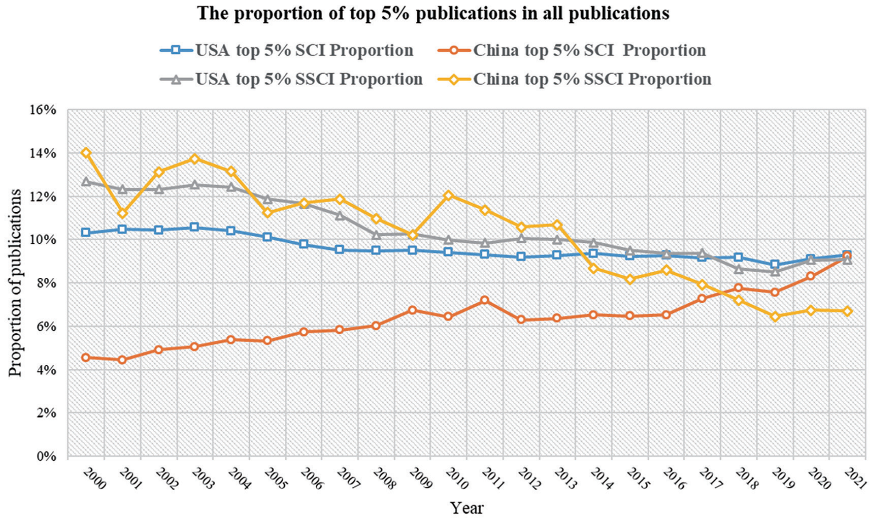

Fig. 12. The proportion of the top 5% SCI/SSCI-indexed publications in all SCI/SSCI-indexed publications: China versus the U.S.

Note: Only two document types – article and review – are considered.

its all SCI papers has shown an upward trend, and the proportion of the two was almost close at 9% by 2021. However, the proportion of China's top 5% SSCI papers in its all SSCI papers declined from nearly 14% of 2000 to 6.7% of 2021.

5. Conclusions

This paper employs bibliometric methods to examine the heterogeneity of research production between China and the U.S. by disaggregating the national research production into its constituent components. Unlike previous studies, we introduced the share counting method to determine the number of publications attributed to each country. In the bibliometric analysis, the research production of China and the U.S. is decomposed according to the document types, disciplines, and high-impact journals, and the results reveal that there are different knowledge production patterns in China and the U.S. These findings contribute to a better understanding of the disparities in research productivity between the two nations.

This paper supplements relevant research from two aspects. On the one hand, the competition in the number of publications between China and the U.S. has attracted long-term and widespread attention, and now it has come to a critical point in time. This paper provides a comprehensive and systematic review using both whole and fractional measures to annually count SCI and SSCI papers in China and the U.S., updating previous research findings. On the other hand, previous studies mainly focused on the analysis of input-output efficiency and citation indicators when comparing national research outputs, partially ignoring the implicit effective information in the research output structure. This paper provides a more comprehensive understanding of a country's research production by employing a joint analysis of document types, disciplines, and journals.

5.1. The impact of counting methods on the measurement of national research production

How does fractional counting affect the measurement of research production of China versus the U.S.

compared with whole counting?

This paper answered this question in two ways. Firstly, how much have the fractional counts been reduced compared to the whole counts? The U.S. experienced an average reduction of 16.40% in SCI publications and 8.49% in SSCI publications annually, while China saw average reductions of 11.96% in SCI publications and 22.21% in SSCI publications annually. The percentage reduction in fractional counts compared to whole counts reflects the degree of external dependence in a country's research production. The interpretation is that the U.S. is more involved in international collaborations than China for publishing SCI publications, whereas China is more involved in international collaborations for publishing SSCI publications.

Secondly, how does the fractional counting method instead of the whole counting method affect the rankings of China and the United States? By employing the fractional counting method, the finding of this paper was that China emerged as the world's largest contributor to SCI publications in 2019, two years earlier than with the whole counting method. Consequently, the whole counting method tend to overestimate the contribution of the U.S. and underestimate that of China. This disparity is attributed to the former's higher levels of international scientific research cooperation compared to China. Similarly, for SSCI publications, China ranked third in 2021 under whole counting while ranked second under fractional counting. The rapid growth of China's SCI/SSCI publications benefits from its national policies and academic evaluation system (Lin, 2013; Xu, 2020), changing the global knowledge production landscape (Liu *et al*., 2015b; Wong, 2019).

5.2. Structural differences in the research production between China and the U.S.

What are the differences in research production between China and the U.S. in different document types, disciplines, and high-impact journals?

The analysis of document types reveals that China's researchers are more inclined to publish articles than reviews compared with the U.S. China's contribution to reviews lags behind the U.S. Although China has been the world's largest contributor to SCI-indexed articles since 2016 under share counting, it still trails the U.S. in publishing SCI reviews as of 2021. As for SSCI-indexed reviews, the gap between China and the U.S. is even greater, with the U.S. publishing three times as many as China. The research and publication process of review-type papers differs greatly from article-type papers. Review-type papers usually have higher requirements for English writing. And a large number of review articles are published in specific journals and are invited by editors to be completed by highly prestigious authors (Blumel and Schniedermann, 2020). These reasons may have left China's review publication in a disadvantage.

The analysis of disciplines indicates that China and the U.S. have opposite strengths and weaknesses. China's quantitative advantage is limited to specific fields of science, as it only ranked first in 100 out of 178 natural science fields in the period between 2016 and 2021. The exceptionally good academic training of Chinese scholars in the fields of materials science, engineering, and chemistry and China's possession of state-of-the-art instruments and facilities in these fields result in China's comparative advantage in these fields (Lu, 2015). However, particularly in multidisciplinary sciences and most medical and biological fields, China's contribution still falls behind that of the U.S., consistent with the findings of Wang (2016) using articles with Chinese addresses from 2000 to 2013 in the Scopus database. This suggests that disciplines in which China lacks a comparative advantage have not significantly improved over the past decade. Besides multidisciplinary sciences, medicine and biology also particularly require multidisciplinary collaboration (Vale *et al*., 2012). However, in Chinese universities and research institutions, the boundaries of disciplines are clearly divided, which is not conducive to the development of multidisciplinary cooperation and the cultivation of multidisciplinary talents. This current situation is one of the reasons why China's scientific research in these disciplines is relatively weak. On the contrary, the U.S. has a deep research foundation in these disciplines and has established an effective multidisciplinary cooperation system.

China's research production advantages in social science on the international stage are far less than its natural science. It became the second-largest producer of SSCI publications globally in 2021, 15 years after achieving the same feat with SCI publications. In the period from 2016 to 2021, China ranked first in only 2 of 58 social science fields worldwide. Especially in the fields of history and philosophy, China has always been in a weak position in the past two decades. In addition to the fact that the amount of financial support received by social science in China is far less than that of natural science, we believe that this is related to the late start of social science research in China. For a long time, China has been a follower of the West in terms of social science research paradigms.

On the other hand, the continued dominance of U.S. in various natural and social research areas suggests that it maintains a strong and diverse research ecosystem. The U.S. remains at the forefront of scientific innovation and has a long-established tradition of excellence in various academic disciplines.

The analysis of high-impact journals reveals that although China has surpassed the U.S. in the number of top papers since 2019, its share of all papers is lower than that of the U.S. The number of papers contributed by Chinese authors in high-impact journals has also become the first in the world since 2019, which may be a departure from people's traditional impression. This accomplishment is largely due to the growth in articles published in high-impact journals in China during the decade following 2010. The increase in publications in top-tier journals indicates that Chinese researchers are producing impactful and noteworthy research that is recognized and accepted by the global scientific community. Recent research on the top 1% of most highly cited articles has also shown that China surpassed the U.S. in relative participation in 2019 (Wagner *et al*., 2022). As this analysis uses journal impact factor as a proxy for paper quality, it can serve as a complement to studies on the quality and impact of Chinese publications.

6. Implications and Future Work

6.1. Policy implications

We recommend that monitoring authorities use fractional measures rather than whole measures to quantify research production of a country. The quantitative strength of China's SCI research production should no longer be underestimated. However, it is essential to emphasize that while China's total number of publications appears to be approaching or even surpassing that of the U.S. in recent years, it does not imply a complete overtaking in academic publication production. Significant structural differences exist in the research production of the two countries. These findings provide valuable reference information for policy-makers to optimize the allocation of scientific research resources in their respective countries. Therefore, we suggest that policy-makers separate different document types, disciplines, and sources when measuring national research production and making funding and resource allocation decisions.

First, we recommend that China's research administrations encourage their senior researchers to write and publish reviews. Review-type documents are usually reviews, commentaries, and recommendations on research topics in the field, tend to receive more citations, and have greater impact (Blumel and Schniedermann, 2020). As China leads in many fields concerning both paper quantity and the number of top papers globally, it has the opportunity to actively contribute to shaping the direction of global science development. By proactively writing reviews, Chinese scholars can exert their influence in guiding research advancements within their respective fields.

Second, China should work to change the situation of its weak disciplines. Given that China's scientific research allocation is heavily influenced by national strategy and government planning, Chinese science and technology authorities should pay more attention to promoting the development of diverse research fields (Ma and Xiong, 2020). Considering China's relatively smaller world share in the social sciences compared to natural sciences, we recommend encouraging social science researchers to publish in international journals and actively participate in the international dialogue by providing more financial support. Also, we recommend that promoting interdisciplinary science should be included in the government planning, as interdisciplinary science has emerged as a vital pathway to major scientific breakthroughs gaining global consensus (Bromham *et al*., 2016). China's National Natural Science Foundation established a Department of Interdisciplinary Science and a special fund in November 2020 to support interdisciplinary research projects. Building on this initiative, we propose optimizing the academic evaluation system to fully recognize the value of interdisciplinary research, as well as promoting the establishment of interdisciplinary exchange platforms to facilitate knowledge sharing and collaboration among scholars from different disciplines (Brown *et al*., 2015; Pautasso and Pautasso, 2010).

Third, the contrasting strengths and weaknesses of China and the U.S. in the academic landscape present opportunities for potential collaboration and knowledge exchange between the two nations. While competition for academic prominence is inherent, it should not hinder international cooperation. We advocate for Chinese authorities to actively promote and foster international collaboration in scientific research.

Moreover, it is very important that China should strive to enhance the quality of its scientific research (Tang, 2019; Wang *et al*., 2021), starting by shifting away from an over-emphasis on quantitative indicators in research evaluation.

6.2. Research limitations and future work

Our research has some limitations. First, the share counting method used in this paper assumes that all authors of a paper contribute equally, which may overlook the role of Chinese researchers versus their international collaborators in leading the studies. Further investigation is needed to avoid overestimating the contribution of Chinese authors to internationally co-authored papers (Brainard and Normile, 2022). Second, the classification of publications into different research fields was based on the subject categories of journals, which may introduce a fallacy because journal contents cannot be treated as homogeneous (Wagner *et al*., 2022), although this is a common practice. Third, it's worth noting that JCR journals have a language bias, and a significant proportion of social science research in non-English-speaking countries like China is published in domestic journals in the native language (Moreno-Delgado *et al*., 2021; Shu *et al*., 2019). Therefore, it would be premature to conclude that the number of social science studies in China is less than in the U.S. Further investigation of the publishing status of domestic journals in China is warranted. Despite this limitation, our analysis enables a deeper understanding of social science research activities in China.

This study provides insights into the extent to which China's versus the U.S. research systems prioritize document types, different areas of research, and high-impact journals from the perspective of SCI/SSCI journal publications. In the future, the author will take into account the input elements of research activities to further answer what factors contribute to the structure differences in the research publication among different countries.

It is important to acknowledge that the choice of indicators can significantly impact the results when measuring a country's publication output and impact. Designing a perfect indicator is almost impossible, so the findings presented in this paper should be interpreted with caution. Moreover, the number of academic publications alone cannot fully represent a country's scientific strength. Nonetheless, our research offers valuable insights for policy-makers.

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