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Exploring the Role of International Research Collaboration in Building China's World-Class Universities

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Abstract: This study explored the international research collaboration led by China's world-class universities and its impact during the first construction cycle of the "Double First-Class" initiative (2016–2020). We collected international collaborative publications based on the Scopus database and examined the performance of international research collaboration in terms of quantity, impact, collaborative networks, and subject areas using scientometric indicators and social network analysis. We found that international collaboration accounts for only a quarter of the total output but is far above the overall level of scientific papers in terms of quality and impact. The United States, the United Kingdom, Australia, and Hong Kong remain China's closest partners. Meanwhile, ties with Belt and Road partner countries have become stronger with the introduction of foreign policy. China's medicine and multidisciplinary research have gained prominence in the context of the global health crisis. Thus, international research collaboration effectively improves research performance, deepens academic networks, and disseminates local issues and solutions to the world, thereby enabling China's world-class universities to reconcile global engagement with Chinese characteristics.

Keywords: world-class university; international collaboration; China

Citation: Zhang, D.; Ding, W.; Wang, Y.; Liu, S. Exploring the Role of International Research Collaboration in Building China's World-Class Universities. *Sustainability* **2022**, *14*, 3487. https://doi.org/10.3390/su14063487

Academic Editors: Jinyuan Ma, Chuanyi Wang and Yuzhuo Cai

Received: 18 January 2022
Accepted: 14 March 2022
Published: 16 March 2022

1. Introduction

China is considered the fastest-rising country in terms of scientific research, and its rapid expansion in paper output is remarkable [1,2]. In the global scientific system, China is second only to the United States. Some studies partly attribute China's success to the government's long-term investment in China's world-class university construction projects [3–5], primarily the "985 Project" and the "Double First-Class" initiative.

With strong political will and financial support, the "985 Project" launched in 1999 is a model for building top universities that plan to allocate educational resources. The project responds to the goal of world-class universities by chasing mainstream ranking indicators; however, some problems, such as a solidified identity, lack of competition, and inefficiency, have been noted during its 15-year-long application [5–7]. In 2015, the State Council in China announced the Overall Plan for Coordinately Advancing the Construction of World First-Class Universities and First-Class Disciplines, which defines the principles, objectives, and general ideas of the "Double First-Class" initiative, replacing the original "985 Project". The initiative is targeted at establishing a cluster of world-class universities in China through a competitive and collaborative model and is becoming a major strategy for China to increase its international competitiveness and achieve sustainable development [6,8].

These projects have resulted in outstanding international publication performance [5] and emerging research collaboration centrality [9], indicating that China is increasingly being integrated into the global scientific system as a latecomer. Even in terms of scientific paper indicators, China has clearly built world-class universities [1]. The development of higher education in China seems to substantiate the center-periphery dynamic trend, in which developing countries desire world-class universities to catch up with those at the

center [10]. China's world-class universities are increasingly moving toward the Western academic center while implementing a dual model that exemplifies both local development and international engagement. One main task is to strengthen international research collaboration further and grasp the frontiers of international scientific research to serve the needs of major national strategies at both national and institutional levels [11].

With the advent of big science [12], international research collaboration is considered a global trend and an important issue in modern scientific innovation [13–16]. Most studies that have analyzed the impact of international research collaboration based on collaborative publications [17,18] and collaborative networks [19,20] found that international research collaboration, compared with national collaboration, generally has a better quality of research output [21,22], which contributes to the impact and prestige of the research [23–25]. Based on these benefits, collaboration with international scholars has become an attractive research activity for world-class universities [26].

Although some excellence initiatives have seemed successful, given that international research collaboration is fruitful as a strategy for increasing international impact [27–30] and expanding academic networks [26,31], the bias toward internationalization at the expense of local issues remains prominent [32]. In the context of peripheral countries, embedding cultural identity and regional development in the internationalization of higher education is a major obstacle to catching up with academic centers [33,34]. China has attempted to reconcile international engagement with Chinese characteristics through international research collaboration in building world-class universities [11], but the role it plays in the context remains unclear. To fill the research gap, this exploratory study addresses the following research questions: (1) What is the impact of international research collaboration on the research output of China's world-class universities? (2) What are the national research collaboration networks led by world-class universities? (3) What are the Chinese characteristics of international research collaboration in terms of subject areas?

This study selected 42 universities of the "World-Class" project in the "Double First-Class" initiative in China and analyzed all collaborative publications from these universities during the first construction cycle of the "Double First-Class" initiative (2016–2020). In the following sections, we present the literature review, followed by the description of the main data and methods used to address the research questions, as well as a detailed discussion of the results. The article concludes with a summary of the current status, contributions, and limitations.

2. Literature Review

A copious volume of literature has underscored that international research collaboration is a well-recognized internationalization strategy in building a world-class university [4,28,35–37]. In the age of global science, countries and institutions alike can benefit from international exchange and collaboration [26]. These findings of political and practical implications make it necessary to review this topic. Specifically, we first review the characteristics and pathways of a world-class university, then we sort out the role that international research collaboration plays and identify the research gaps.

Against a backdrop of increasingly intense global competition and the development of a knowledge-based economy, a world-class university is no longer just a description of a top research university; it is gradually developing into a global concept that influences the reshaping and restructuring of higher education systems in Asia, Europe, and many countries around the world [32,38–40]. Specifically, world-class universities are deeply embedded in national higher education development plans to gain sustainable productivity and core competencies in the world [32,41,42].

While the pursuit of excellence is very clear across countries, it is difficult to achieve a consensus on the concept of a world-class university [32,43], presenting challenges for policymakers and administrators in the process of building and evaluating top universities [44]. As Altbach points out, "Everyone wants a world-class university. No country feels it can do without one. The problem is that no one knows what a world-class university is, and no one

has figured out how to get one" [45]. To address this bottleneck, scholars have explored the definition and constituent elements of a world-class university, with some of the fundamental characteristics frequently mentioned being (1) excellence in research; (2) concentration of talents; (3) adequate resources (mainly facilities and funding); (4) favorable governance; and (5) global engagement and collaboration [36,39,40,43,45–47]. Further, the emergence of university rankings has made global competition among higher-education institutions quantifiable and visible, and even the results have become an indication of world-class status or reputation [42,48], creating an intrinsic connection between world-class universities and university rankings.

Thus, the path of building world-class universities for emerging countries is relatively clear: Increasing financial investment in research, using research achievements as performance indicators, improving international reputation, and placing emphasis on various university rankings, which are heavily influenced by the Western higher education system [1,36,44,49]. Various excellence initiatives around the world have largely followed this path, including the Japanese Top Global University Project, the Korean Brain Korea 21 Project and World Class University Project, the Taiwanese Develop First-Class Universities and Top-Level Research Centers, the Russian 5-top100 Project, and the German Excellence Initiative, resulting in the augmentation of national research publications and the enhancement of international prestige [29,30,44,49–54].

World-class universities foster national scientific innovation capacity and international competitiveness. In a global scientific context, international research collaboration provides opportunities for world-class universities to increase their research efficiency and impact, which might benefit both national and global systems [31]. Based on an analysis of international collaborative publications and citation data at the national and institutional levels, Marginson has found a rapid increase in co-authorship rates and a better academic impact. World-class universities are free to engage in knowledge generation and sharing through open, collaborative networks [26]. Mok has suggested that regional and international research collaboration can give institutions a high profile in world-class competitions, which might be an effective strategy for sustainable development [55]. Research collaboration also plays a role in the practice of different countries and regions: Top Russian universities have achieved both quantitative and qualitative growth due to changes in research collaboration patterns [28], research collaborations between Korean and international scholars are considered a key factor in the success of the Korean World-class University Project [44], and the growth in European scientific publications is largely attributable to international research collaboration [37].

International research collaboration has been deeply rooted in the development strategies of world-class universities, paving the way for the internationalization of higher education. Yet, despite the current trend, some studies have suggested that modern universities have become effective instruments for enhancing national competitiveness but have lost the role of serving the nation-state and protecting national development [56,57]. Singapore, with its many international partners, has been questioned for its reliance on external scholars for research development in the midst of globalization [34], while squeezing the space for local students [58].

Similarly, studies have shown that Chinese scholars are prone to neglect local issues in the pursuit of global science, thereby limiting their contributions to national and regional development [59]. Indeed, national publications show a downward trend [3]. Although international research collaboration is considered a strategy that can balance global and national characteristics in building China's world-class universities [11], relevant studies have focused on its role in China's global engagement and have rarely shown how Chinese characteristics are expressed in a global context.

3. Methods and Materials

3.1. Methods

The purpose of this study is to determine the role of international research collaboration in building world-class universities in China, which previous studies have not addressed. As an exploratory study, we do not make assumptions about the results but, rather, use scientometric methods and extensive literature data to provide valid evidence for exploring the issue.

In this study, we use the co-authorship approach to analyze international research collaboration. The measure is that if a publication in which the co-authors are from two countries or regions and at least one author is affiliated with a world-class university in China, then it represents the international collaborative output of China's world-class universities. While co-authorship is one of the ways to signify scientific collaboration [60], it is widely recognized as a reliable proxy because its data are objective and easy to access and process at scale [13].

This study also uses six main indicators to describe the scale, quality, and impact of published research, as shown in Table 1. Citation analysis has been an important metric in scientometrics as a measure of the impact of academic research [61,62]. This study uses citations per publication as a key indicator, but citation analysis is controversial because of citation motives, self-citation, and biased citing, among others [63]. Therefore, we introduce FWCI and percentile rank indicators to increase the reliability of measuring the quality and impact of research [64,65]. Based on these indicators, we can analyze the structure and trend in international research collaboration over time and explore the role of international research collaboration in building China's world-class universities in a comprehensive manner through comparisons between institutions and countries.

Table 1. Categories of indicators.

Research Object	Indicator	Indicator Description
Research Scale	Publication	The number of publications of a selected entity.
Research Quality	Field-weighted Citation Impact (FWCI)	The ratio of citations received relative to the expected world average for the subject field, publication type, and publication year. The world's average FWCI is 1.00.
	Top Journal Percentile	The percentage of publications of a selected entity that have been published in the world's top 1%, or top 10% journals.
Research Impact	Citations per Publication	The average number of citations received per publication.
	Outputs in Top 10% Citation Percentile	The percentage of publications of a selected entity that are highly cited, having reached a particular threshold of citations received.

Furthermore, social network analysis is used in sociology to analyze the network relationships and interaction patterns between participants, and collaborative networks can clearly show the research community of knowledge production [66]. To clarify the status of national collaboration networks led by world-class universities, this study takes the countries to which the authors of the papers belong as nodes in the network, and a collaborative publication indicates the collaborative links between the countries to which the authors are affiliated. We visualize the collaborative networks through a VOS viewer (v. 1.6.16; Leiden University's Centre for Science and Technology Studies, Leiden, Netherlands), supplemented with research quality and impact indicators to describe the trends of national research collaboration networks.

3.2. Materials

The data in this study were collected from Scopus, one of the largest abstract and citation databases, considered as a suitable tool for scientometric analysis [67]. The journal coverage of Scopus is broader than that of Web of Science, providing detailed information,

such as author profiles with affiliations, number of publications, and number of citations received per publication, which met the data needs of this study [68].

Five main subjects are covered in Scopus: Life sciences, social sciences and humanities, physical sciences, health sciences, and multidisciplinary, altogether covering 27 subject areas, as shown in Table 2. Given that data on the subject areas were directly available, this study explored international research collaborations in the 27 subject areas, using the data to extrapolate the overall performance of China's world-class universities in the five major subjects.

Table 2. Categories of subject areas.

Subject	Subject Area
Health Sciences	Dentistry Health Professions Medicine Nursing Veterinary
Life Sciences	Agricultural and Biological Sciences Biochemistry, Genetics and Molecular Biology Immunology and Microbiology Neuroscience Pharma Toxicology
Physical Sciences	Chemical Engineering Chemistry Computer Science Earth and Planetary Sciences Energy Engineering Environmental Science Materials Science Mathematics Physics and Astronomy
Social Sciences and Humanities	Arts and Humanities Business Management and Accounting Decision Sciences Economics, Econometrics, and Finance Psychology Social Sciences
Multidisciplinary	Multidisciplinary

Scival is a research management tool based on Scopus data; it is capable of supporting research performance analysis, cross-sectional comparisons between institutions, and research collaboration indicators [69]. The collaboration metrics in Scival are divided into four mutually exclusive types of collaboration based on the affiliation of the publication: International, national, institutional, or single authorship. Based on Scival's data criteria, this study retrieved 352,475 international collaborative publications published between 2016 and 2020, with at least one author affiliated with China's world-class universities. The publication types included articles, reviews, conference papers, books, and book chapters.

4. Results

4.1. International Research Collaboration Output and Impact

4.1.1. System Scale in China and World-Class Universities

Before exploring the status of international research collaboration in China's world-class university cluster, this study examined international research collaboration in China as a whole. As shown in Figure 1, China's international research collaboration output is

steadily growing, converging with the degree of growth of China's overall research output. Notably, international research collaboration output accounted for about 22% of China's overall research output during 2016–2020, a proportion that has not changed significantly in the past five years. Compared with the 14.4% proportion of international research collaboration in 2010, the current international research collaboration in China seems to be manifesting a steady rise after a period of rapid growth, underscoring that international research collaboration is an important part of China's research system. However, this is insufficient to prove that China's research growth is dependent on it.

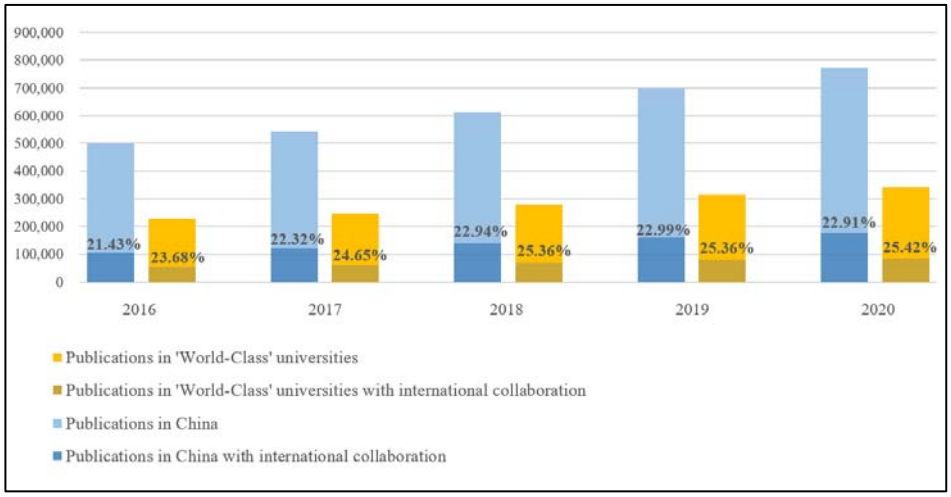

Figure 1. Trends in international research collaboration in China and its world-class university cluster.

The research output of China's 42 world-class universities is prodigious, as illustrated in Figure 1. The 42 universities accounted for almost half of the national output, and their international research collaboration output showed the same proportion. The result is consistent with Wang's study in 2013, which found that China's top universities dominated more than half of all international research collaborations [70] and had an absolute advantage in both scientific research and international collaboration. In 2016, 23.68% of the research output of China's world-class universities involved international research collaboration, and this percentage rose to 25.42% by 2020. Although the overall level of international research collaboration in China's world-class universities exceeds that of the nation, this advantage is not that apparent compared with the funding and policy benefits received by world-class universities. It can be argued that China's world-class universities conduct scientific research mainly in a national and institutional collaboration pattern.

4.1.2. Comparison of Overall Output and International Research Collaboration

Although the scale of international research collaboration in China is relatively small, as shown, international research collaboration can increase the visibility of scientific research around the world and effectively improve research performance in an index sense. This is validated by the research performance of China's world-class university cluster (Table 3). In terms of overall output, the quality and impact of the research results of China's world-class universities improved significantly, with the FWCI value rising from 1.15 to 1.39, the proportion of papers published in the top 1% journals rising from 3.2% to 3.9%, and over 35% of academic papers published in the top 10% journals, with nearly 20% of articles appearing in the top 10% of highly cited papers in each discipline. The proportion of academic papers published in the top 1% journals increased from 3.9% to over 35% in the top 10% journals, and nearly 20% of articles appeared in the top 10% of highly cited articles in each discipline.

Table 3. Trends in the research performance of China's world-class university cluster.

		Quality			Impact	
		FWCI	**Top 1% Journal Percentiles**	**Top 10% Journal Percentiles**	**Citation per Publication**	**Outputs in Top 10% Citation Percentiles**
2016	total	1.15	3.2%	30.1%	17.6	16.2%
	IRC	1.83	6.1%	48.2%	29.1	27.0%
2017	total	1.2	3.5%	32.1%	16.3	17.6%
	IRC	1.87	6.6%	50.1%	26.4	28.3%
2018	total	1.24	3.4%	32.0%	13.6	18.9%
	IRC	1.86	6.7%	48.8%	21	29.3%
2019	total	1.26	3.5%	32.7%	9.7	18.4%
	IRC	1.85	6.9%	48.2%	14.5	30.0%
2020	total	1.39	3.9%	35.2%	6.3	19.6%
	IRC	1.93	7.0%	50.2%	8.7	27.9%

The quality and impact of research output from international research collaborations are much higher than those of the overall output of China's world-class universities. The FWCI value of the overall research output of China's world-class universities in 2016 was 1.15, whereas the FWCI value of publications involving international research collaboration was 1.83, a difference of 0.68. By 2020, this gap has narrowed to 0.54. A comparison of the overall and international research collaboration outputs reveals the advantages of international research collaboration in terms of research quality, impact, and global reputation.

4.1.3. The Role and Performance of Individual Universities in the Cluster

In this study, a two-dimensional scale–quality coordinate plot was created based on the total number of publications and FWCI values of the international research collaboration of 42 world-class universities from 2016 to 2020 to examine the distribution and position of individual universities in China's world-class university cluster. Figure 2 shows that China's world-class universities are unevenly developed in terms of international research collaboration. For the scale dimension of research output, Tsinghua University, Peking University, Shanghai Jiao Tong University, and Zhejiang University stand out, with a total number of publications exceeding 25,000; for the quality dimension, Wuhan University, Fudan University, Huazhong University of Science and Technology, and Tsinghua University all have FWCI values exceeding 2.4. Tsinghua University is outstanding in both size and quality indicators and has been recognized as the top university in China in recent years, soaring high in global university rankings. In China's world-class university cluster, the total number of publications in international research collaborations averages about 8300, and the average FWCI value is 1.87, both of which exceed the world average but still lag behind the research standards of the world's top universities. Within the cluster, 12 universities are rated below the average. Xinjiang University, Yunnan University, and Minzu University of China are at the lowest level in the world-class university cluster, with an international visibility and international research level far lower than those of other universities. They are included in the world-class university cluster because of China's inclination to support nationalist projects in building world-class universities.

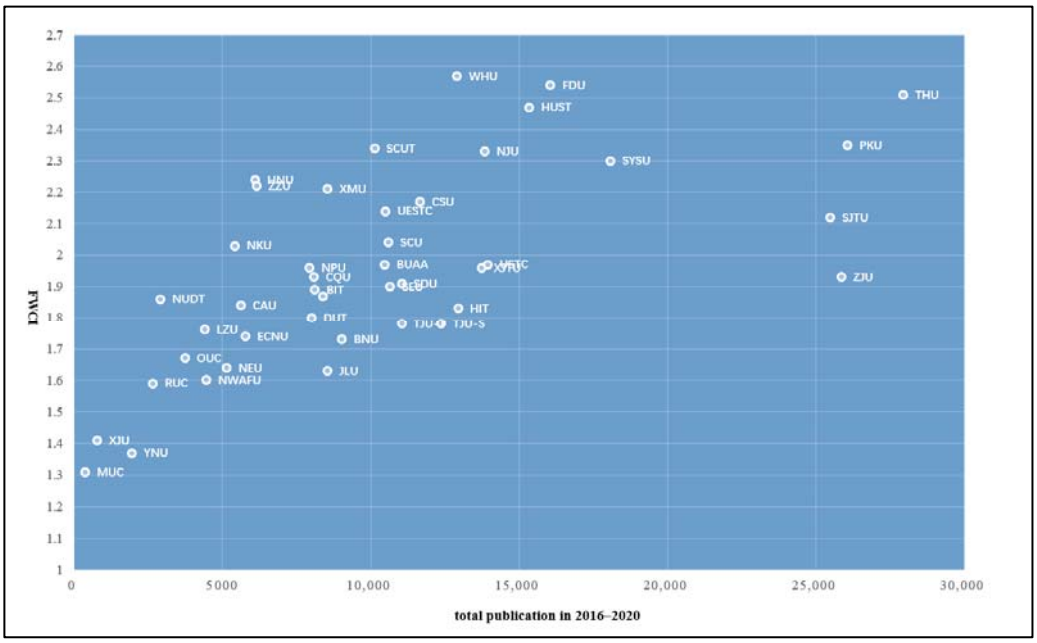

Figure 2. Distribution of China's world-class university cluster in terms of publication and FWCI.

The individual universities in China's world-class university cluster are unevenly developed by factors such as economic level, historical accumulation, and geographic location. As presented in Table 4, for Tsinghua University, Peking University, and Zhejiang University, the world's leading universities in China, high-quality international collaborative work is maintained by ensuring that 50% of their international research collaboration output is published in the top 10% of journals each year and that they have a place in highly cited papers. For those universities that are not otherwise dominant in international discourse, China's "Double First-Class" initiative gives them the opportunity to participate in international research collaboration and is continuously improving the quality of the latter. From 2016 to 2020, the percentage of international research collaboration papers in the top 10% journals and in the top 10% citations at Hunan University, Zhengzhou University, and Xinjiang University increased by more than 10%.

Table 4. Trends in the international research collaboration of individual universities.

University	Top 10% Journal Percentiles (%)					Outputs in Top 10% Citation Percentiles (%)				
	2016	2017	2018	2019	2020	2016	2017	2018	2019	2020
HNU	47.1	56.3	58.2	59.8	59.7	31.7	38.7	38.7	37.9	35.1
NKU	53.5	55.8	55.9	57	59.5	28.8	27.5	30.9	31.7	31.9
THU	57.2	57	58.6	57.4	57.6	31.6	31.5	33.8	32.6	32.4
NJU	59.1	60.9	57.4	55.9	56.4	25.7	27.7	30.5	24.8	33.8
SCUT	55.1	58.9	53.9	55.7	56.2	35.8	38.5	37.6	38.2	36.6
CAU	44.9	52.3	54.3	54.3	55.9	28	31.7	30.7	30.6	27
TJU-T	50	52.5	52.7	52.8	54.7	24.8	27.5	28.5	32.8	32.6
BUAA	45.5	55.7	55.5	55	53.8	24.8	29.1	28.7	27.8	27.2
NWAFU	43.8	45.2	47.5	50.6	53.8	25.4	26.8	25.7	26.2	31.5
ZZU	44.7	46.9	47.8	49.2	53.7	27.4	30.1	32.8	38.9	38.1
WHU	44.8	48.9	48.8	50.2	53.4	25.3	27	25.4	27.9	32.5
NPU	44.2	49.4	48.2	50	53	23.9	24.2	27.9	29.9	27
PKU	54.4	58.7	55.1	52.4	52.9	31.2	30.5	31.4	30.7	30.2
DUT	47.5	46.3	47.5	49.5	52.7	27.3	28.6	29.8	30.8	28.8
XMU	51.4	52.9	52.7	52.4	52.7	26.9	29.6	29.6	30.7	29.6
SYSU	51.7	51.8	50.7	50.2	52.6	30.7	28.8	28.8	30.1	28.1

Table 4. *Cont.*

University	Top 10% Journal Percentiles (%)					Outputs in Top 10% Citation Percentiles (%)				
	2016	2017	2018	2019	2020	2016	2017	2018	2019	2020
HUST	51.3	53.1	50.8	50.9	52.5	27.6	30.7	31.7	33.1	32.7
BNU	51	53	53.6	51.8	52.4	25.3	24.2	26.8	27.8	29.5
TJU-S	44.7	45.9	46.3	47.9	52.4	26.1	26.5	27.8	26.9	29.5
USTC	60.5	59.4	54.2	54	52.4	31	30.1	30.7	31.4	30.5
UESTC	47.5	50.9	48.4	47.3	52.2	23.8	26.1	28.8	29.2	28.1
FDU	52.1	52.2	52.8	49.9	52.2	29.8	28.2	29.3	29.5	29.6
CQU	47.6	44.8	46.9	48.8	52	27.9	27	30.1	31.2	31.1
ZJU	51.6	51.2	50.8	50.5	51.7	26.8	27.9	29.7	31.4	28.4
SCU	48.7	50.5	49.3	47.5	51.2	27.5	30.4	29.6	30.2	28.2
SEU	45	45.2	45.8	47.7	50.8	27.2	28.6	30.2	28.9	27.2
LZU	49.6	48.6	52.9	51.1	50.8	24.1	24.9	29	27.1	24.6
ECNU	46.5	48.8	49.7	46	50.6	25	31.3	25	25	25.5
SJTU	48.4	50.9	49	47.2	49.8	27.7	27.1	28.3	27.8	28.8
BIT	50.5	50.5	49.2	48	49.6	25.7	26.3	28.6	28.7	28.7
XJTU	46.6	51.6	48.7	47.8	49.4	25.7	28.3	28	27.6	25.3
HIT	47	48.7	45.7	48.5	49.3	26.7	28	28.2	26.3	28.7
OUC	38.8	40.7	45.9	45.1	48.4	21.1	19.8	25	27.2	24.2
CSU	43.3	44	46.9	46.1	47.6	29.6	32.1	34.8	35.3	31.3
SDU	48.2	49.1	47.4	47.4	47.5	27.2	27.4	26.6	28.4	27.5
JLU	44.1	47.7	44.2	43.3	46.2	24.1	25.7	24.1	28.6	29.4
NEU	40.1	39.9	37.4	42.9	45.5	21.4	25.4	24.5	25.9	25.9
RUC	40.4	41.2	47.8	37.7	44.9	20.1	19	18.8	20.7	19.1
NUDT	39.1	37	38.8	42.2	42.1	19.2	16.6	23.4	19.2	18.9
MUC	41.3	52.5	31.4	28.4	41.6	14.8	26.1	17.6	11.6	19.1
XJU	28.2	32.3	37.3	42.6	39.8	15.2	14.3	22.8	22.9	24
YNU	36.4	46.2	42.4	36.9	39	18	20.2	24	20.2	26.9

4.2. International Research Collaboration Network

4.2.1. China's Main Country Collaborators in Research

According to the data on international research collaborations from 2016 to 2020, China's world-class universities have collaborated with 172 countries and regions around the world. Among them, China has collaborated on 158,157 publications with the United States, accounting for more than 40% of all international research collaboration outputs; 41,432 publications with the United Kingdom, accounting for approximately 10% of the total output; and 30,517 co-authored outputs with Hong Kong, China's third-largest research collaboration region. The United States has been China's closest collaborator, playing a vital role in integrating China into global science and advancing the global agenda. The national research collaboration network led by China's world-class universities is shown in Figure 3. Influenced by the English language, economic and technological development, geographic location, and policy support, China has maintained a dense and intertwined network of long-term stable and close collaborations with Europe, the United States, and Southeast Asia.

4.2.2. Changing Trends in Intercountry Research Collaboration

As shown in Table 5, a comparison of the international research collaborations in 2016 and 2020 revealed that the 20 countries with which China collaborated most frequently were almost solidified, and the size of publications expanded significantly with an increase of nearly 50%. Since FWCI values are influenced by citations in the following three years, which were significantly lower in 2020 than in 2016, the percentage of publications in the top 1% journals was used to measure the quality of international research collaborations. In 2016 and 2020, more than 10% of the output of China's research collaborations with Denmark and Singapore were published in the top 1% of journals, thereby exhibiting excellent research performance. While the scale of international collaboration that China

engages in with Europe is much smaller than that of the United States, China generally maintains high-quality research collaborations with European countries, and the quality of research has improved over time. Pakistan and Russia, as partners in China's "One Belt, One Road" policy, collaborated extensively with China in recent years. However, research collaborations with Pakistan (top 1% journal percentiles: 2.5) and Russia (top 1% journal percentiles: 5.4) seemed to lack quality review in terms of the metrics published in the top 1% journals in 2020. This means that China can achieve a better research performance by collaborating with countries that have a high level of higher education.

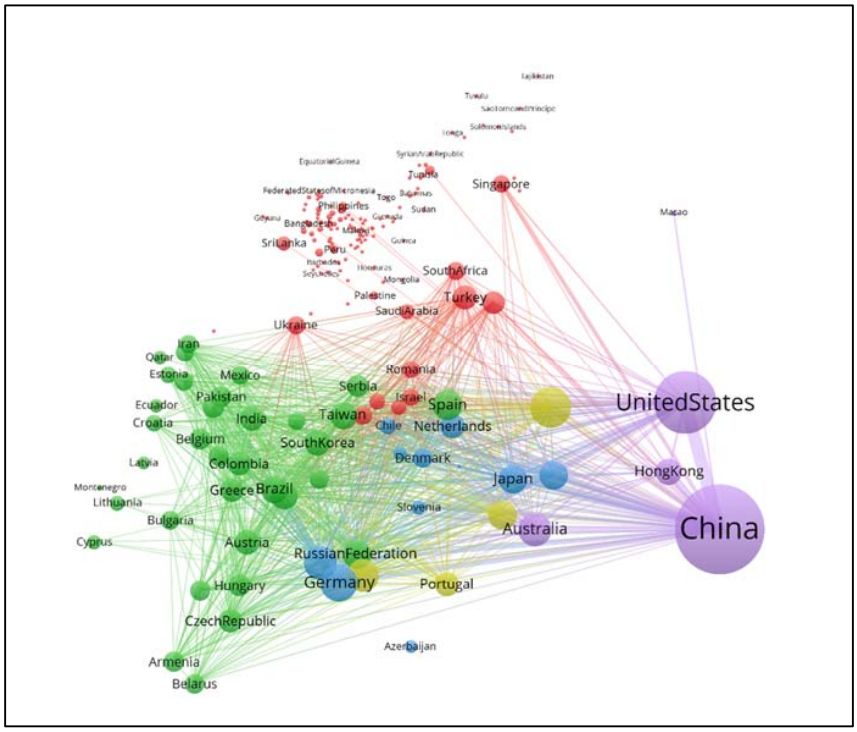

Figure 3. China's world-class university cluster with 172 countries/regions in its collaboration network.

Table 5. Changes in the international country collaborators of China's world-class universities.

2016				2020			
Rank	**Country/Region**	**Publication**	**Top 1% Journal Percentiles**	**Rank**	**Country/Region**	**Publication**	**Top 1% Journal Percentiles**
1	United States	25,391	7.1	1	United States	36,173	7.8
2	United Kingdom	5656	8.5	2	United Kingdom	11,232	8.3
3	Hong Kong	4928	7.2	3	Australia	9011	9.4
4	Australia	4695	7.3	4	Hong Kong	7152	9.6
5	Canada	3773	6.7	5	Germany	6118	7.6
6	Germany	3593	6.6	6	Canada	6050	8.8
7	Japan	3432	6.9	7	Japan	5179	6.7
8	Singapore	2429	11.3	8	Singapore	4210	11.9
9	France	2321	7.0	9	France	3785	6.9
10	Taiwan	1616	5.7	10	South Korea	2761	8.9
11	South Korea	1597	7.4	11	Pakistan	2726	2.5
12	Italy	1398	7.2	12	Italy	2660	7.0
13	Netherlands	1332	8.0	13	Netherlands	2458	9.1
14	Sweden	1293	8.5	14	Taiwan	2408	6.7
15	Spain	1177	7.8	15	Sweden	2230	9.7
16	Switzerland	1017	7.7	16	Spain	2009	8.6
17	Russian Federation	945	4.8	17	India	1947	5.5
18	Denmark	774	10.4	18	Russian Federation	1771	5.4
19	Saudi Arabia	773	8.3	19	Switzerland	1763	8.9
20	Pakistan	760	3.5	20	Denmark	1530	10.2

4.3. Subject Areas in International Research Collaboration

4.3.1. Research Collaboration Output in Subject Areas

China's world-class university clusters were highly differentiated in terms of international research collaboration in their subject areas, as can be clearly demonstrated in Table 6. The five subject areas with the largest international research collaboration output were all under the physical sciences category and had the largest research output and highest impact, with less than 30% of international research. Engineering alone had more international research collaboration publications than the health sciences and social sciences combined. Among the research output in the physical sciences in 2020, only environmental science and earth and planetary sciences had more than 30% international research collaboration. It is well known that China is growing rapidly in STEM subject areas and that the scale of international research collaborations has had little impact on it but has maintained its inherent advantages.

Table 6. Current status of research areas of international collaboration in China's world-class universities.

Subject	Subject Area	Percentage of Total Publications		Publication	FWCI	Citation per Publication
		2016	2020			
Physical Sciences	Engineering	21.3%	24.6%	108,965	1.92	22.6
Physical Sciences	Computer Science	27.7%	28.8%	71,553	2.04	15.2
Physical Sciences	Materials Science	22.8%	24.9%	65,972	1.99	23.1
Physical Sciences	Physics and Astronomy	24.5%	27.0%	60,001	1.85	19.1
Physical Sciences	Chemistry	21.7%	25.1%	46,928	2.02	27.2
Health Sciences	Medicine	22.5%	20.9%	46,629	2.25	20
Life Sciences	Biochemistry, Genetics and Molecular Biology	24.7%	24.3%	44,633	1.87	23.2
Physical Sciences	Mathematics	25.0%	26.1%	35,716	1.63	10.5
Physical Sciences	Environmental Science	29.4%	30.6%	32,291	2.03	22.8
Physical Sciences	Chemical Engineering	20.7%	25.2%	27,777	2.04	26.6
Physical Sciences	Energy	22.0%	26.0%	25,724	2.07	25.9
Physical Sciences	Earth and Planetary Sciences	28.4%	33.0%	24,476	1.62	15.4
Life Sciences	Agricultural and Biological Sciences	28.1%	31.2%	19,404	1.71	15.3
Social Sciences & Humanities	Social Sciences	36.7%	36.7%	16,041	1.84	12
Multidisciplinary	Multidisciplinary	29.7%	32.7%	10,625	1.93	31
Social Sciences & Humanities	Business, Management and Accounting	42.2%	45.0%	9656	1.98	17.1
Life Sciences	Neuroscience	33.8%	30.5%	9219	1.47	16.6
Life Sciences	Immunology and Microbiology	27.5%	25.0%	8848	1.73	20.1
Social Sciences & Humanities	Decision Sciences	36.1%	28.3%	8368	1.65	12
Life Sciences	Pharmacology, Toxicology and Pharmaceutics	21.1%	19.1%	8346	1.68	17
Social Sciences & Humanities	Economics, Econometrics and Finance	48.1%	44.3%	5683	1.76	12.2
Social Sciences & Humanities	Psychology	57.0%	43.7%	3913	1.61	12.1
Social Sciences & Humanities	Arts and Humanities	32.4%	32.4%	2972	2.46	11.2
Health Sciences	Nursing	33.9%	32.0%	1945	1.87	14.2
Health Sciences	Health Professions	39.6%	29.7%	1876	1.83	14.1
Health Sciences	Dentistry	31.3%	25.7%	987	1.6	12.1
Health Sciences	Veterinary	17.9%	27.2%	667	1.51	8.7

By contrast, all six subject areas under the social sciences and humanities had more than 30% international research collaboration, with psychology accounting for 57% of all international research collaboration outputs in 2016. However, the extensive research collaboration did not bring favorable research performance to the social sciences and humanities. The total five-year output of international research collaboration publications in subject areas other than the social sciences did not exceed 10,000. Meanwhile, health sciences showed some polarization, as pharmacy had only 20.9% international research collabora-

tion but with 46,629 publications and a high FWCI value of 2.25, whereas nursing, health professions dentistry, and veterinary were at the bottom of the ranks of research outputs.

4.3.2. Chinese Characteristics in International Research Collaboration

Based on a word-frequency analysis of international research collaboration publications from China's world-class universities, the word 'China' appears most frequently, with 5068 international research collaboration output mentioning China in their titles, abstracts, or keywords in 2016, growing to 9401 in 2020. To explore the expression of Chinese characteristics in international research collaboration, this study used "China" as a keyword to search the main subject areas involved, as shown in Figure 4. Medicine, environmental science, social sciences, earth and planetary sciences, and agricultural and biological sciences often conducted research with China as the target of international research collaboration. Medicine, immunology and microbiology, and multidisciplinary programs had a significant scientific performance in international research collaborations involving China in 2020, which was also related to China's prominent academic contribution to COVID-19 [71]. In the international research collaboration of China's world-class universities, whether in the field of global science or social science, more and more studies are involving China's cases, problem solutions, and history, which is a feasible strategy for building a world-class university based in China to promote international exchange and global integration.

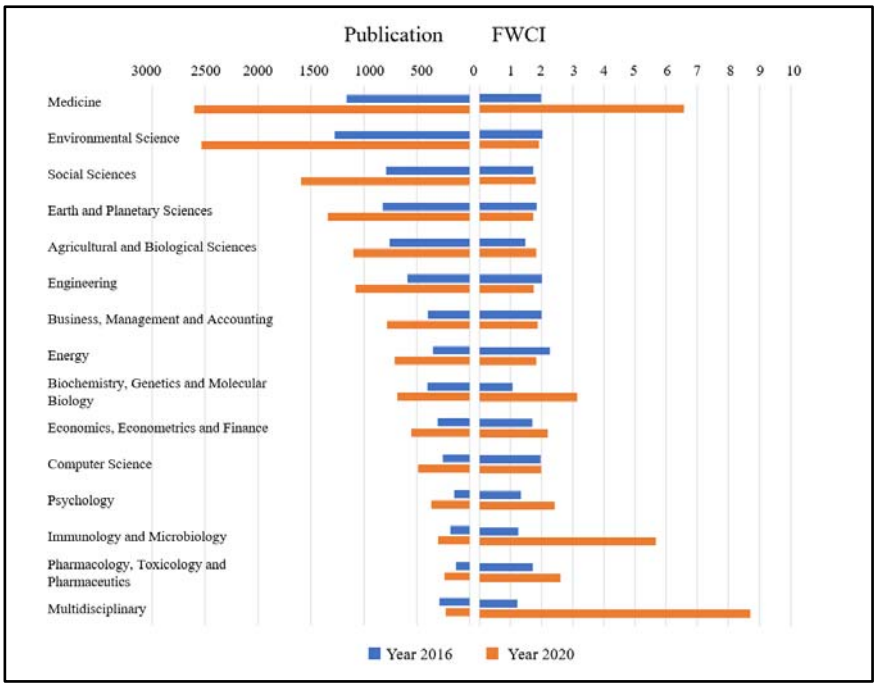

Figure 4. Changes in the distribution of subject areas, with a focus on studies from China.

5. Discussion

Based on the above exploration of international research collaboration in China's world-class university cluster, this study summarizes the main roles played by international research collaboration in building world-class universities with Chinese characteristics in terms of impact, collaboration network, and subject area characteristics.

International collaborative publications of China's world-class universities have demonstrated remarkable research performance in terms of quality and impact. The cluster of world-class universities represents China's top scientific strength, and high-quality international research collaboration has brought considerable prestige to both the universities and the country. The study shows that the universities in China's world-class university clusters are unevenly distributed, but the overall international research level has increased during the world-class university construction cycle. Xinjiang University, Yunnan University, and

Minzu University of China do not show favorable academic performance in the cluster and are far from the standards of world-class universities in terms of indicators. Zhao pointed out that the selection of these as world-class universities stems from the consideration of balanced regional development and educational equity [72]. However, from the perspective of international research collaboration, supporting these universities with a strong national identity and local characteristics and increasing their visibility in the world is a new way of sharing Chinese culture and the nation's story to the world.

The development of research collaboration with high-level countries in the world is conducive to the expansion of academic networks. The United States, the United Kingdom, and Australia have been China's closest partners due to their strong economic and scientific power. Hong Kong, South Korea, Japan, and Singapore are also prioritized due to their similar cultural backgrounds and advantageous geographical locations. China has maintained stable collaborative relations with these countries and regions, a fact that has also been verified by previous studies [70,73]. Furthermore, the "One Belt One Road" initiative launched in 2015 has deepened international collaboration with Russia, Central Asia, and Africa and increased research output [74] but has not brought the desired benefits to China compared with developed Europe. This national strategy of economic and political collaboration with Chinese characteristics has also strengthened the intensity of scientific collaboration, extending a more-open path beyond the international collaboration network centered on the United States and the United Kingdom.

International research collaboration in subject areas is highly heterogeneous, with physical sciences leading the way internationally; notably, a lower proportion of international collaborations does not affect the research performance of the subject areas. Life sciences and health sciences are growing rapidly, with new ideas at the forefront of basic disciplines [75]. Social sciences and humanities research, which is dominated by the English language and Western thought, is one of China's weaknesses [76]. Even though the proportion of international research collaboration is much higher than the overall level, it is still limited in terms of research scale and impact. Discussions of local issues and cases in China are now clearly increasing in international research collaboration; thus, research in medicine and environmental science has drawn attention in the context of the global health crisis.

Hence, international research collaboration plays an important role in building China's world-class universities, effectively improving research performance, expanding collaboration networks, increasing international visibility, and introducing local issues to the world. There is no doubt that this quantitative, scientific, metrics-oriented performance evaluation approach has enabled China's scientific research to grow tremendously over the past two decades, and as a result, China has become part of the global scientific community. Furthermore, this study has attempted to explain the specific manifestations of Chinese characteristics in the process of the internationalization of higher education. At the institutional level, China protects relatively disadvantaged universities with national characteristics and supports the national culture of global science; at the national level, it deepens scientific collaboration rooted in a foreign policy with Chinese characteristics. In addition, it grasps global public events, introducing solutions to China's local problems to the world.

Based on the above analysis of international research collaboration in China's world-class universities, we found that the coordination of the global scientific system with the development of Chinese characteristics is an inevitable trend for the sustainability of Chinese higher education. However, it does not seem to work well in practice. Many studies have not looked favorably at the sustainability of China's world-class universities influenced by Western models [77,78], which has long been in a state of catching up with the world's advanced science [59]. Chinese faculties argue that it is difficult to integrate international paradigms with the local issues in their research [48]. On the road to a world-class university with Chinese characteristics, international mainstream ideologies and practices pose challenges to international dialogue in the humanities and social sciences [79].

Constrained by language and culture, Chinese humanities and social science research lacks dialogue with the international community [80]. Although international collaborative publications involving local and national issues are growing, based on our study, they are still limited. The pressure of university ranking targets makes faculties intent to pursue SSCI and SCI publications [81], which constrains the innovation and development of local research. China seems to be caught in a quandary in the process of moving toward global scientific centers, that is, striking a balance between internationalization and local issues.

The development of international research collaboration in medicine and social sciences in the context of the epidemic can provide insights into the above situation. China, as the first country to manifest the disease, has shared advanced research and local solutions with the world. The international research collaboration based on the COVID-19 pandemic has achieved a positive impact. For China, using advanced science to solve problems rooted in the local context is a fundamental task in national and regional development. On this basis, China is building a bridge to global scientific dialogue through international research collaboration, contributing the Chinese experience to the world, mastering international discourse, and leading cutting-edge science and technology, thereby showcasing a cluster of China's world-class universities.

6. Conclusions

The present study examined the international collaborative publications of China's world-class universities in the first construction cycle of the "Double First-Class" initiative. We have found that international research collaboration can effectively improve the quality and impact of scientific research and has connected China to global science networks. There is no doubt that Chinese universities are increasingly moving closer to the center from the periphery of the Western academic world through international research collaboration. Furthermore, while China has engaged in intensive collaborations with developed countries, it has also extended a China-centered path of scientific collaboration through diplomatic ties. China's medicine, humanities, and social sciences have seized the opportunity in the context of the global epidemic to engage in international conversations and enhance their international impacts through local issues and solutions.

The concept and pathways of a world-class university are still being explored, and our research confirms that international collaboration can improve the international display of world-class universities, which also enriches the research on world-class universities serving local and regional development. In this process, we realized the need for world-class universities to provide more opportunities for international collaboration and to offer international insights and solutions based on local issues, in order to build a community with a shared future for mankind.

Global scientific networks are expanding, and the center–periphery theory is no longer able to explain the complex networks and development dynamics. In the process of modernizing higher education, peripheral countries should build their national cultural identity while understanding and participating in the international discourse system. For instance, the government should establish national evaluation criteria to support local academic innovation and introduce research outputs to international databases.

Finally, there are limitations to measuring international collaboration by research indicators alone. The construction of China's world-class universities requires not only world leadership in research indicators but also research capacity and academic autonomy. If the socialist university governance model with Chinese characteristics is further explored, focusing on the interaction between faculties, students, and functional departments, it may provide a more systematic explanation for building world-class universities with international perspectives and Chinese traditions.

Author Contributions: Overall research design and conceptualization, D.Z. and W.D.; methodology, D.Z. and W.D.; formal analysis, D.Z.; resources, Y.W.; data curation, W.D. and Y.W.; writing—original draft preparation, D.Z., W.D., and S.L. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: Publicly available datasets were analyzed in this study. These data can be found here: https://www.scopus.com (accessed from 1 to 3 November 2021).

Conflicts of Interest: The authors declare no conflict of interest.

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