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Scientific Cooperation Dynamics and Development Strategies between China and Belt and Road Countries: A Postprint

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Abstract

[Purpose/Significance] Since its proposal in 2013, the Belt and Road Initiative has garnered international attention and presented new development opportunities for scientific cooperation between China and countries along the route. [Method/Process] This paper conducts scientometric and text analysis of scientific paper collaboration between China and Belt and Road Initiative countries since 1978, and performs quantitative and mapping analysis at three cooperative levels: between China and Belt and Road Initiative countries, as well as their disciplines and institutions. [Results/Conclusion] The study finds that: (1) cooperation between China and countries along the route has gradually shifted from relatively advanced countries with close geographical proximity, such as Singapore, Russia, and India, to Central Asia, European regions, and neighboring developing countries; (2) interdisciplinary cooperation has shifted from physics to disciplines such as electronic and electrical engineering, materials science, etc., and environmental science, biomedicine, and social sciences have become new hotspots for cooperation; (3) domestically, the Chinese Academy of Sciences and research universities are the main participants, collaborating institutions are concentrated in research institutions and universities in countries such as Singapore and Russia, while cooperation with institutions in other Belt and Road countries is relatively limited. Finally, based on these findings, the paper proposes policy recommendations for strengthening scientific cooperation between China and countries along the route.

Full Text

Preamble

Research on the Situation and Development Strategy of Scientific Collaboration Between China and Countries Along the "Belt and

Road" Initiative

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Abstract

[**Purpose/Significance**] Since its proposal in 2013, the "Belt and Road" Initiative has attracted international attention and created new opportunities for scientific cooperation between China and participating countries. [**Method/Process**] This paper employs scientometric and textual analysis methods to examine scientific paper collaborations between China and Belt and Road countries since 1978, conducting quantitative and mapping analyses across three dimensions: national, disciplinary, and institutional cooperation. [**Results/Conclusions**] The study reveals that: (1) China' s scientific cooperation has gradually shifted from relatively advanced neighboring countries such as Singapore, Russia, and India toward Central Asia, Europe, and surrounding developing nations; (2) Interdisciplinary collaboration has transitioned from physics to electrical engineering and materials science, with environmental science, biomedicine, and social sciences emerging as new hotspots; (3) Domestically, the Chinese Academy of Sciences and research universities dominate, with partnerships concentrated in research institutions from Singapore and Russia, while collaboration with other Belt and Road countries remains relatively limited. Based on these findings, the paper proposes strategies to strengthen scientific cooperation between China and Belt and Road countries.

Keywords: Belt and Road; scientific collaboration; scientometrics; knowledge mapping; Classification Number: G359.1

1. Introduction

Since General Secretary Xi Jinping proposed the "Silk Road Economic Belt" and "21st Century Maritime Silk Road" (the "Belt and Road" Initiative) in 2013, China' s energy, economic, and trade development with participating countries has further accelerated. The *Vision and Actions on Jointly Building Silk Road Economic Belt and 21st Century Maritime Silk Road* released in 2015 emphasized cooperation priorities, including not only trade, financial, and infrastructure connectivity, but also the establishment of joint laboratories, research centers, and technology transfer centers [1]. The 13th Five-Year Science and Technology Plan further proposed building a Belt and Road collaborative innovation community. At the Belt and Road Forum for International Cooperation on May 14, 2017, President Xi Jinping announced the launch of the Belt and Road Science and Technology Innovation Action Plan, which aims to strengthen the flow and exchange of scientific talent, including hosting 2,500 young scientists for short-term research in China within five years and training 5,000 scientific, technical, and managerial personnel. Clearly, the Belt and Road Initiative has become an important conduit for scientific cooperation and talent exchange.

Amid economic globalization and scientific integration, international scientific cooperation represents an inevitable trend. Whether for the development of "big science" or for addressing regional and global complex problems, collaboration among scientific organizations and researchers from multiple countries is essential. On one hand, the integration of modern science with technology and industry has become increasingly tight, with science playing a more prominent role in supporting and guiding technological innovation and industrial transformation, making scientific cooperation a key driver of national development. On the other hand, based on the scientific resource endowments and comparative advantages of Belt and Road countries, international cooperation can enable the sharing of talent, resources, equipment, and information, optimizing the allocation of research resources. Therefore, promoting scientific cooperation between China and Belt and Road countries can enhance research quality and efficiency, achieving mutual benefits.

Current research on scientific cooperation between China and Belt and Road countries remains preliminary, focusing primarily on national and disciplinary distributions, funding support, and paper quality, while paying insufficient attention to historical evolution and disciplinary development, and lacking studies on institutional cooperation patterns and networks. This paper employs scientometric and textual analysis methods, using knowledge mapping to quantitatively study scientific collaboration outputs—papers—between China and these countries. By deeply mining the historical processes, disciplinary evolution, and institutional cooperation patterns, this research helps grasp the historical trajectory and development trends of scientific cooperation at macro, meso, and micro levels, providing references for national science and technology policy formulation.

2. Literature Review

Scientific collaboration constitutes an important form of international scientific and technological cooperation, with collaborative papers serving as a key output and important indicator for measuring such cooperation. Scientific and technological cooperation represents a crucial pathway for knowledge dissemination and exchange, as well as for promoting national economic and social development. Cheng Ruyan summarized that China' s international scientific and technological cooperation strategies from 1978 to 2008 experienced three stages: recovery, comprehensive development, and mutual benefit, evolving into today' s multi-dimensional, multi-level, and wide-ranging forms of cooperation [2]. Yue Xiaoxu et al. measured China' s leading role in international scientific cooperation, finding that while China's dominance and the quality of its leading papers have improved, the depth and breadth of cooperation remain insufficient, with gaps still existing compared to Japan in terms of international cooperation rates, number of partner countries, and citation frequencies of leading papers [3]. Wang Xianwen et al. noted that 95% of China' s international scientific collaboration papers are concentrated in 20 countries, with the United States accounting for over 40% of this share, and that Chinese scientists, particularly in English-speaking countries, play important roles [4]. Additionally, many scholars have conducted comparative studies on scientific cooperation between China and specific countries, such as BRICS nations, Japan, and Russia.

Domestic research on scientific cooperation between China and Belt and Road countries is just emerging. Wu Jiannan and Yang Ruoyu published three studies examining cooperation patterns, NSFC-funded papers, and comparisons with developed countries. Their research indicates that collaborative papers between China and Belt and Road countries are gradually increasing, but both quantity and total citations remain lower than cooperation with developed countries. Cooperation spans broad disciplines, with the top ten NSFC-funded fields being materials science, applied physics, and electrical engineering. Collaboration with countries like Singapore, Russia, and India is more extensive and shows disciplinary differences. Multi-country collaborative papers involving three or more nations, such as China-Russia-India and China-Israel-Singapore, have relatively higher citation frequencies [5-7]. Ye Yangping et al. conducted a comprehensive comparison of cooperative patents and papers across 29 Belt and Road countries, finding that knowledge innovation cooperation is more active than technological innovation cooperation, with paper volumes exceeding patent collaborations by more than nine times. Technological cooperation concentrates in digital data processing, semiconductors, and wireless communications [8]. Examining changes in China' s dominance through corresponding authorship, Chinese scholars' leadership rate exceeded 60% in 2015, a significant improvement from 20% in 1980, indicating enhanced initiative and discourse power. However, in multi-country collaborations involving three or more nations, China remains in a subordinate position, with Chinese scholars' discourse power not yet prominent in high-quality international collaborative papers [9].

In summary, existing research has provided overall analysis of China' s scientific cooperation since the 1970s, statically presenting national, disciplinary, quality, intensity, and multi-country cooperation patterns between China and Belt and Road countries. This paper adopts a historical and dynamic perspective, using mapping analysis to examine the temporal processes, disciplinary evolution, and institutional networks of scientific cooperation, thereby understanding the historical trajectory and development trends at macro, meso, and micro levels.

3. Data Sources and Research Methods

To comprehensively understand scientific cooperation between China and Belt and Road countries, this paper focuses on papers as the primary research output. The Web of Science Core Collection database serves as the data source, which includes SCI, SSCI, A&HCI, CPCI-S, and other major citation indexes, widely recognized as the most authoritative scientific and technical literature indexing tool globally. The analysis covers 64 Belt and Road countries, using the search formula: CU=(PEOPLES R CHINA) AND CU=(ALBANIA

OR AFGHANISTAN OR……). The search yielded 102,013 papers, retrieved on May 18, 2017.

This study employs scientometric and textual analysis methods for data mining, visualized through knowledge mapping. Scientometrics studies research outputs such as papers and patents, addressing the "big data" explosion in scientific fields. It applies mathematical statistics and computational techniques to quantitatively analyze scientific activity inputs (personnel, funding) and outputs (paper counts, citation frequencies) to identify patterns in scientific activities [10]. Knowledge Mapping (Mapping Knowledge Domains) is a graphical representation displaying the development process and structural relationships of scientific knowledge. Based on literature and scientometrics, it uses text mining and complex network methods to visually present the evolution and structural relationships of scientific knowledge. As a serialized knowledge genealogy, it effectively demonstrates complex relationships such as networks, structures, interactions, intersections, and evolutions among knowledge clusters [11, 12]. Compared to traditional static statistical analysis, knowledge mapping enables understanding of scientific knowledge structure and development trends from macro, dynamic, and evolutionary perspectives. For the analysis, this paper utilizes two visualization software tools: CiteSpace and VOSviewer.

4.1 Scientific Cooperation Among Belt and Road Countries

According to Web of Science search results, scientific cooperation between China and Belt and Road countries began in the 1970s, but annual publications did not exceed 10 papers until 1983, after which rapid growth occurred. First, we constructed a cooperation network based on collaboration volumes to analyze cooperation patterns, as shown in Figure 1 [Figure 1: see original paper], where circle size represents the number of collaborative papers and colors indicate different clusters.

In terms of collaboration volume, Singapore ranks first with 32,389 papers, followed by Russia (12,135) and India (11,253). The combined total of 52,062 papers with these three countries accounts for 51% of all collaborations, likely due to their relatively advanced scientific standing among Belt and Road countries and geographical proximity to China. Regarding cooperation scope, China has collaborated with all Belt and Road countries, though given uneven scientific capabilities, cooperation with some countries has just begun, particularly neighboring nations like Turkmenistan, Laos, and Maldives, each with fewer than 100 collaborative papers. The network reveals four national cooperation clusters: (1) a yellow cluster containing only Singapore, highlighting its prominent position; (2) a blue cluster comprising West Asian countries such as Egypt, Iran, Pakistan, Qatar, and Sri Lanka; (3) a green cluster mainly including Eastern European countries like Belarus, Czech Republic, Hungary, Israel, Poland, Russia, Serbia, and Turkey; (4) a red cluster encompassing Southeast and South Asian countries like India, Thailand, Malaysia, and the Philippines. These clusters demonstrate China' s cooperation characteristics: Singapore-centric, with substantial collaboration with Russia, India, and Saudi Arabia, while cooperation with other Belt and Road countries requires strengthening.

To illustrate the historical evolution of scientific cooperation, Figure 2 [Figure 2: see original paper] visualizes papers from 1983-2016 in six-year intervals (pre-1983 annual volumes were below 10 papers), using co-occurrence analysis of author affiliations.

Temporally, China initiated scientific cooperation with Singapore and India in the early 1980s. Following reform and opening-up, cooperation expanded during the 1990s from Russia, Saudi Arabia, Pakistan, and Thailand to Turkey and Hungary. Since the 21st century, collaborations have increased with Central Asian and European countries like Egypt, Lithuania, Serbia, and Qatar, while extending to neighboring developing countries such as Myanmar, Uzbekistan, and Kyrgyzstan. Recent cooperation intensity shows greater engagement with Middle Eastern and European nations; for instance, collaborations with Serbia and Qatar began relatively late but concentrated heavily after 2010, with 85% and 94% of respective papers published during this period, marking them as rapidly growing partners.

Historically, Singapore, India, and Russia remain China' s key scientific partners in the Belt and Road Initiative, but their combined share in total collaborative papers has followed an inverted U-shaped curve: from under 20% in the 1980s, rising above 50% in the 1990s and peaking at 60% in 2003-2004, then declining to 46% by 2016. Overall, China' s scientific cooperation has evolved from neighboring advanced countries to European developed nations, then to West Asian, European, and neighboring developing countries.

Notably, developed countries play important roles in this cooperation network. In the 1980s, the United States participated in 41% of collaborative papers annually between China and Belt and Road countries, with England, Japan, France, and Sweden joining in the mid-to-late 1980s. The U.S., Germany, U.K., and Japan contributed 23,414, 10,880, 9,989, and 7,983 papers respectively, exhibiting high betweenness centrality and influence in Belt and Road collaborations.

In 2016, China ranked second globally in SCI paper publications at 63.4% of U.S. output, yet significantly lags in Belt and Road cooperation. The U.S. published 48,919 collaborative papers with Belt and Road countries (excluding China) in 2016, while China published only 16,077—just 32.9% of the U.S. figure—indicating an urgent need to strengthen cooperation.

4.2 Disciplinary Evolution in Belt and Road Scientific Cooperation

Given each country' s resource endowments and disciplinary characteristics, China' s scientific cooperation with Belt and Road countries shows targeted patterns: China-Singapore collaboration focuses on internal medicine and transportation engineering; China-Israel on agriculture; and China-Russia on geosciences [9]. For a macro and dynamic analysis of research theme evolution, we employed Web of Science' s more granular disciplinary classification system. Keyword frequency analysis and knowledge mapping are presented in Table 1 and Figure 3 [Figure 3: see original paper].

By collaboration volume, engineering, physics, and chemistry constitute the main cooperation fields and foundational disciplines for development. Key areas include electrical and electronic engineering (9,719 papers), materials science (8,305), and applied physics (6,455). Physics represents one of the earliest and most prolific cooperation disciplines. Before the 21st century, physics sub-disciplines occupied six of the top ten fields, including astrophysics, nuclear physics, particle physics, and condensed matter physics. Engineering and chemistry fields, such as electrical engineering, interdisciplinary chemistry, and chemical physics, have gained prominence alongside scientific development.

Temporally, 1980s cooperation was limited, focusing on physics, chemistry, and materials with few papers. The 1990s saw expansion into crystallography, electrical engineering, optics, and biosciences. After 2001, cooperation broadened to nanotechnology, computer artificial intelligence, energy fuels, and oncology, with paper volumes increasing exponentially. Overall, from early reform and opening-up through the end of the 20th century, cooperation centered on physics and materials, gradually expanding breadth. Since the 21st century, cooperation has extended to strategic emerging and interdisciplinary fields, with both breadth and depth increasing and volumes growing exponentially.

Regarding cooperation hotspots, 21st-century developments reflect scientific trends and regional socio-economic demands: (1) Environmental science has shifted from traditional water resource protection to green sustainable development, biodiversity conservation, and environmental engineering. (2) Biomedical fields have evolved from genetics, cell biology, and botany to genetic biotechnology, applied microbiology, and reproductive biology, with biochemistry and analytical biology (2,546 papers) showing over 50% published in the last five years. (3) Medical cooperation concentrates in neurology, dentistry, surgery, cardiovascular and peripheral vascular diseases, physiology, zoology, and endocrinology. (4) Social sciences, led by economics, connect with telecommunications through transportation studies while intersecting with healthcare services, business, and management. Additionally, geography' s evolution toward remote sensing, mineralogy, geochemistry, and geophysics, along with instrumentation automation, control technology, and robotics, represent recent cooperation hotspots.

4.3 Institutional Cooperation Between China and Belt and Road Countries

Research universities and institutes constitute the main research bodies, and institutional cooperation serves as a meso-level organization crucial for understanding national scientific collaboration. To examine cooperation patterns, we analyzed 56,299 collaborative papers published during 2013-2017 using VOSviewer for institutional co-occurrence mapping. Among the top 500 institutions, 177 (35.4%) are from Belt and Road countries, while 323 are non-participating countries, with only 46 Chinese institutions, indicating insufficient engagement from Chinese research institutions.

As shown in Figure 4 [Figure 4: see original paper] (displaying only Belt and Road institutions, with colors representing clusters), the Chinese Academy of Sciences leads with 9,214 papers, followed by Peking University, Shanghai Jiao Tong University, Zhejiang University, and Tsinghua University, each exceeding 2,000 papers. Among foreign partners, the National University of Singapore, Nanyang Technological University, and the Russian Academy of Sciences rank top with 6,991, 6,834, and 3,363 papers respectively.

The institutional network comprises five clusters, with Chinese institutions prominently featured in green and blue clusters: (1) The green cluster is the largest sub-network, comprising the Chinese Academy of Sciences and domestic universities like Tsinghua, Peking, and Hong Kong universities, partnering with the National University of Singapore, Nanyang Technological University, Russian Academy of Sciences, and King Abdullah University of Science and Technology, focusing on electrical engineering, materials, chemistry, and physics. (2) Blue and yellow clusters include the Chinese Academy of Sciences, University of Science and Technology of China, Tsinghua, and Shanghai Jiao Tong University cooperating with West Asian and Eastern European institutions like Tel Aviv University, Weizmann Institute of Science, Ankara University, Romania' s Institute of Physics and Nuclear Engineering, Azerbaijan National Academy of Sciences, and Czech Academy of Sciences, concentrating on physics subfields like particle physics, applied physics, and astrophysics. (3) Purple and red clusters feature dispersed institutions from Eastern Europe, South Asia, and West Asia with extensive inter-regional cooperation but limited Chinese participation, except for occasional involvement from Peking University, Tsinghua University, and the Russian Academy of Sciences.

Figure 4 provides a macro view of institutional cooperation. For a micro-level perspective, Figure 5 [Figure 5: see original paper] (threshold=200) reveals China' s sub-network. The Chinese Academy of Sciences shows the highest publication volume and international cooperation intensity, making it the most important participant, focusing on astronomy & astrophysics, particle physics, nuclear physics, materials, and environmental science, primarily with Russian institutions like the Russian Academy of Sciences and Alikhanov Institute for Theoretical and Experimental Physics. Domestic university networks show Hong Kong Chinese University, Zhejiang University, Peking University, Huazhong University of Science and Technology, and Fudan University cooperating mainly with the National University of Singapore and Nanyang Technological University. Science and engineering universities like Tsinghua, Shanghai Jiao Tong, Sun Yat-sen, and USTC collaborate with institutions from the blue and yellow clusters, such as the Polish and Russian Academies of Sciences in physics. Overall, few Chinese institutions participate, with limited breadth, concentrating on

Singapore, Russia, and Saudi Arabia.

5. Conclusions and Recommendations

(1) **Strengthen the depth and breadth of scientific cooperation while enhancing initiative and influence.** China' s cooperation has evolved from neighboring advanced countries to Middle Eastern, European, and developing nations. However, developed countries and their institutions remain prominent. As the Belt and Road initiator, China should play a leading role by actively guiding national and institutional participation in international cooperation. Aligning with domestic development needs and partner countries' resource endowments will enable complementary advantages, driving economic, trade, and industrial technology innovation cooperation for mutual benefit. Additionally, China should enhance cooperation with developing Belt and Road neighbors like Turkmenistan, Tajikistan, Kyrgyzstan, Laos, and Maldives to expand its network influence and promote broader economic, trade, and cultural exchanges.

(2) **Focus on forward-looking, fundamental, and emerging disciplines while promoting related science policy research.** Due to weaker scientific capacity during early reform and opening-up, China emphasized natural science and technology cooperation to improve research levels and accelerate talent development. With strengthened scientific capacity, China should now use disciplinary cooperation to advance domestic science: first, by focusing on disciplinary frontiers and maintaining cooperation in partner countries' advantageous fields beyond traditional physics, materials, and chemistry to include emerging disciplines like biomedicine, aerospace, environmental science, and population health; second, by promoting science policy research that combines economic, political, and cultural contexts to enhance cooperation quality and efficiency.

(3) **Expand and improve the comprehensiveness and proactivity of Chinese universities and research institutes.** While the Chinese Academy of Sciences shows highest participation, concentrating on Singapore and Russia, developed non-participating countries occupy important network positions, highlighting insufficient institutional cooperation. To promote institutional collaboration and enhance Belt and Road countries' discourse power, China should use joint centers or R&D platforms as engines for multilateral and interdisciplinary cooperation, expanding breadth and depth from traditional Singapore-Russia networks to institutions in Saudi Arabia, Romania, Turkey, Malaysia, and Thailand.

(4) **Promote researcher mobility between China and Belt and Road countries to facilitate "bringing in"and "going out."** Researchers are carriers of scientific knowledge flow, and their international mobility drives network formation rather than the reverse [13]. Promoting researcher mo-

bility can strengthen exchanges in science, technology, politics, economy, and culture. China should "bring in" researchers by encouraging students, doctoral candidates, and high-level talent from Belt and Road countries to study, train, work part-time, or work in China, enhancing mutual understanding and cooperation levels. Simultaneously, China should encourage its researchers to "go out" to understand partner countries' scientific and cultural contexts, track Belt and Road development issues, promote technology transfer, cultivate internationally-minded high-end talent, and support national Belt and Road development.

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Author Contributions

Liang Shuai: Data collection and analysis, drafting and revising the manuscript;
Wu Chenxiao: Literature review, qualitative discussion of results;
Li Zhengfeng: Problem formulation and research design, manuscript revision and finalization.

Note: Figure translations are in progress. See original paper for figures.

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