Structural Diversity and Dynamic Evolution of Transnational Scientific Collaboration Networks: A Case Study in Knowledge Management (Post-print)

Authors: Xu Yuchan, Liang Qihua, Zhang Chunyang

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Abstract

[Purpose / Significance] To investigate the network structure and evolutionary characteristics of international scientific collaboration in knowledge management over the past 15 years, and to identify the current state and limitations of existing research.

[Method / Process] Integrating methods from statistics, ecology, scientometrics, and geography, this study analyzes the network structure and evolutionary features of the transnational collaboration network constituted by international collaborative papers on knowledge management indexed in the SSCI-E and SCI databases of Web of Science from 2001 to 2015.

[Results / Conclusion] Participants in transnational knowledge management collaboration are primarily distributed across Asia, Oceania, and Europe-America regions; bilateral cooperation represents the principal mode of international knowledge management collaboration; the United States and the United Kingdom dominate the international scientific collaboration network, with the United States being the most pivotal collaborating nation; China serves as the most important partner of the United States, though its leading capacity is disproportionate to its scientific productivity.

Full Text

Study on the Dynamic Evolution and Structural Diversity of Transnational Scientific Collaboration Networks—A Case Study of Knowledge Management

Xu Yuchan[1], Liang Qihua[2], Zhang Chunyang[1]

[1] School of Business Administration, Shandong Technology and Business University, Yantai 264005
[2] Research Department, Shandong Technology and Business University, Yantai 264005

Abstract

[**Purpose/Significance**] This study aims to understand the structural evolution and characteristics of transnational scientific collaboration networks in knowledge management over the past 15 years, identifying current research status, strengths, and deficiencies. [**Method/Process**] Employing integrated methods from statistics, ecology, scientometrics, and geography, we conducted a comprehensive analysis of the network structure and evolutionary features of transnational collaboration networks constructed from international co-authorship papers in knowledge management retrieved from the SSCI-E and SCI databases in Web of Science (2001-2015). [**Result/Conclusion**] Transnational collaboration participants in knowledge management are primarily distributed across Asia, Oceania, Europe, and North America. Bilateral cooperation constitutes the main mode of international collaboration. The United States and United Kingdom dominate the transnational scientific collaboration network, with the U.S. serving as the most critical collaborative partner. China represents America' s most important partner, yet its leading capacity remains disproportionate to its scientific productivity.

Keywords: knowledge management, transnational collaborative network, evolution characteristics
Classification Number: G250

1 Introduction

Over the past 15 years, knowledge management has remained one of the most significant topics of interest in management research. Evidence demonstrates that knowledge management is not merely a management fad but has evolved into a sustained management practice [1], recognized by the scientific community as one of the youngest management disciplines [2]. Sheng Xiaoping and colleagues have argued that knowledge management is not a transient trend but rather an emerging discipline that has grown by absorbing and integrating theories from economics, management, and philosophy [3]. Knowledge management and knowledge sharing are critical for organizational survival and development in today' s intensely competitive global environment and represent a key area for future research [4]. Numerous studies have established that knowledge management significantly impacts organizational learning, innovation, firm performance, and core competitiveness [5-9].

In recent years, the rapid advancement of internet technology and continuous progress in measurement science have led scholars worldwide to increasingly

value the application of scientometric methods based on massive network data in knowledge management research. Researchers have employed bibliometric approaches to conduct fruitful explorations into the developmental trajectory, practical foundations, stage characteristics, current status, applied methods, and future trends of knowledge management, facilitating objective and comprehensive understanding of its developmental basis, present condition, and dynamics [10-17]. However, no existing study has systematically collected and comprehensively measured bibliographic data to analyze the current state, characteristics, and fundamental patterns of international scientific collaboration in knowledge management research.

As scientific research has transitioned from "small science" to "big science" and with the emergence of e-science, the importance of international scientific collaboration has become increasingly prominent [18]. Scientific collaboration has become the primary mode of production in contemporary social science research activities, and international scientific cooperation has become a crucial component of national science and technology development strategies [19]. In light of this, we employ statistical, ecological, scientometric, and geographical methods to analyze the network structure and evolutionary characteristics of transnational collaboration networks formed by internationally co-authored knowledge management papers from the Web of Science SSCI-E and SCI databases (2001-2015). This study provides scientific quantitative evidence for understanding the structural features and developmental trends of transnational collaboration in knowledge management, offering important reference value for promoting transnational scientific cooperation and enhancing research standards in the field.

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Authors: Xu Yuchan (ORCID: 0000-0001-7431-5302), Master' s student, E-mail: 15684171680@163.com; Liang Qihua (ORCID: 0000-0001-6534-4750), Professor, Master' s supervisor; Zhang Chunyang (ORCID: 0000-0002-0215-4121), Master' s student.

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2 Data Sources, Research Methods, and Tools

We extracted bibliographic data on knowledge management research from the SSCI and SCI-E databases. Using advanced search in ISI Web of Science, the search query was (TS="knowledge managements"OR "knowledge management"). Several important limitations were applied: to understand transnational scientific collaboration in knowledge management during the 21st-century knowledge economy era, the timeframe was limited to 2001-2015; English was designated as the language limit since it serves as the international lingua franca for academic communication; and the document type was limited to Article, as research has shown that articles reflect substantive research content and exhibit higher originality than reviews, editorials, letters, and other document types. The literature search was conducted on April 10, 2016. After data cleaning, we obtained 5,549 knowledge management research papers based on network data from 2001-2015, of which 1,191 involved institutional addresses from two or more different countries/regions.

We conducted statistical analysis using methods and indicators from statistics, biological and ecological metrics, and social network analysis, employing software tools including Sci2 Tool, Pajek, and Excel 2007. The specific methods and tools were as follows: (1) For Section 3 "Overall Status of Transnational Scientific Collaboration in Knowledge Management,"we used statistical indicators and methods with Excel and Sci2 Tool to conduct multi-angle term frequency statistics on transnational collaboration papers, aiming to grasp the overall status of knowledge management transnational collaboration; (2) For Section 4 "Diversity of Transnational Scientific Collaboration Networks in Knowledge Management," we adapted relevant indicators from biology and ecology to measure the diversity of knowledge management transnational collaboration networks, revealing the dominance and richness of tacit knowledge transnational collaboration types; (3) For Section 5 "Transnational Scientific Collaboration Networks in Knowledge Management," we employed term frequency statistics, co-word analysis, and social network analysis using Sci2 Tool, Pajek, and Inkscape to conduct social network analysis and visualization of knowledge management transnational collaboration networks, intuitively demonstrating developmental trends.

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3 Overall Status of Transnational Scientific Collaboration in Knowledge Management

[Figure 1: see original paper] presents the geographic distribution of knowledge management transnational collaboration papers, using a digital world map to visually reflect the central regional layout characteristics of the knowledge management transnational collaboration network. Color intensity represents the volume of knowledge management transnational collaboration papers. The map shows that the United States, United Kingdom, China, and Australia are major producers of global knowledge management transnational collaboration

papers, with primary participants distributed mainly in Europe, North America, Oceania, and Asia.

[Figure 2: see original paper] indicates that in 2001, there were only 25 knowledge management transnational collaboration papers worldwide, accounting for 2.10% of the total collaboration papers from 2001-2015. During the study period, the curve fitting value for knowledge management transnational collaboration papers was 0.92, demonstrating approximately exponential growth, particularly after 2010 when annual international collaboration papers exceeded 100. In 2015, international collaboration papers reached 137, representing 11.50% of total collaborative output from 2001-2015, with an average annual growth rate of 12.92%. By 2015, cumulative knowledge management transnational collaboration papers totaled 1,191, accounting for 21.67% of total paper output, with 641 papers (53.82% of cumulative transnational collaboration papers from 2001-2015) published in the most recent five years (2011-2015). Compared with 2001, total knowledge management papers increased by 173.05% over 15 years, with co-authorship rates rising significantly. In the past five years, the proportion of knowledge management transnational collaboration papers exceeded 20% of total papers annually. These findings indicate that transnational scientific collaboration represents an inevitable trend in knowledge management research output, with considerable room for further development in knowledge management transnational collaboration research.

illustrates the dynamic evolution of transnational collaboration relationship structures in knowledge management during the study period. Bilateral collaboration papers refer to articles authored by multiple authors whose institutional addresses involve two different countries, assuming a scientific collaboration relationship exists between these countries. In 2015, bilateral collaboration papers reached 112, more than triple the 25 papers in 2001, indicating significant growth in the number of countries engaged in knowledge management transnational collaboration. Over the past five years, multilateral collaboration papers in knowledge management transnational cooperation have numbered over 20 annually, totaling 132 papers, but this remains far below bilateral collaboration papers—only about one-quarter of bilateral collaboration papers during the same five-year period. In 2015, bilateral collaboration papers were 4.48 times the number of multilateral collaboration papers. These figures demonstrate that bilateral cooperation currently dominates knowledge management transnational collaboration research, with three-or-more-party collaboration remaining relatively rare. Overall, this suggests that the scientific collaboration atmosphere in knowledge management transnational cooperation is not sufficiently robust and requires continued strengthening of multilateral collaboration.

[Figure 3: see original paper] presents the transnational collaboration paper counts, dominant international collaboration paper counts, dominant international collaboration ratios, and world shares of international collaboration papers for the 10 most productive countries. The figure clearly shows that the United States holds an absolutely dominant position in knowledge management

transnational collaboration research output, accounting for approximately two-fifths of total knowledge management transnational collaboration papers. Although the United Kingdom and China rank as the world' s second and third largest scientific producers in knowledge management transnational collaboration, with 24.85% and 20.74% of world knowledge management international collaboration papers respectively, these figures are only about half of the U.S. output. The other seven countries each hold less than 20% world share of knowledge management transnational collaboration papers. Following Chinese scholar Zhu Wentao et al.' s concept of dominance, a country is considered to dominate an international collaboration paper when an article with multiple authors from different countries/regions lists a first author from that country [20]. A country' s international collaboration paper dominance ratio refers to the proportion of papers with first authors from that country relative to its total published papers [21]. The knowledge management dominant international collaboration ratios for these 10 major countries are approximately 20%. Although emerging country China has higher numbers of dominant international collaboration papers than all countries except the United States, its dominant international collaboration ratio is lower than these countries, indicating weak leading capacity in knowledge management transnational collaboration research.

[Figure 4: see original paper] reports the dynamic evolution of world shares of knowledge management transnational collaboration papers for the 10 most productive countries. Overall, the U.S. world share of knowledge management transnational collaboration papers shows a significant declining trend. However, due to the overall growth in scientific productivity of knowledge management transnational collaboration papers during the study period, the United States maintains a world proportion far exceeding other countries, remaining the most dominant scientific actor in knowledge management transnational collaboration papers. The United Kingdom, as the world' s second-largest knowledge management transnational collaboration producer, has gradually narrowed its gap with the U.S. in recent years, indicating that the UK is catching up and becoming a new major contributor to knowledge management transnational collaboration papers. China' s world share of knowledge transnational collaboration papers demonstrates a growth trend, developing into the world' s third most important knowledge management transnational collaboration producer. Other countries have experienced relatively slow growth in knowledge management transnational collaboration papers.

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4 Diversity of Transnational Scientific Collaboration Networks in Knowledge Management

The diversity of knowledge management international scientific collaboration networks is comprehensively measured through species diversity indicators from biology and ecology to reveal the internal structure and developmental trends of knowledge management transnational scientific collaboration networks, as

shown in .

presents diversity indicator scores for knowledge management transnational scientific collaboration networks from 2001-2015. Cooperation richness scores were relatively high in 2011 and 2014, at 1.45 and 1.23 respectively, indicating rich types of knowledge management transnational collaboration during these years. Historical cooperation richness index scores show unstable development in knowledge management transnational collaboration types. Since 2009, Simpson and Shannon-Wiener indices have been significantly higher than before 2009, suggesting a gradual dispersion trend in knowledge management transnational collaboration paper output—namely, diversified and decentralized knowledge management transnational collaboration. After 2010, the annual dominance index was approximately 0.30, higher than the pre-2010 maximum of 0.28, indicating that the dominant position of advantageous collaboration types in knowledge management transnational cooperation has become more prominent.

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5 Transnational Scientific Collaboration Networks in Knowledge Management

Three 5-year time windows (2001-2005, 2006-2010, 2011-2015) were constructed to explore the dynamic evolution of knowledge management transnational scientific collaboration. Visualization results for the three-stage knowledge management transnational scientific collaboration networks are shown in [Figure 5: see original paper], [Figure 6: see original paper], and [Figure 7: see original paper]. It should be noted that node size and connection width are proportional to degree centrality and connection strength respectively, while color intensity represents total node degree.

As evident from Figures 5-7, the United States and United Kingdom occupy central positions in the scientific collaboration network across all three 5-year periods. These two countries exhibit higher degree centrality, betweenness centrality, and closeness centrality than other countries, corroborating their strong advantageous positions in the scientific collaboration network. Emerging countries China and South Korea have shown significant growth in network centrality indicators, yet their network influence remains far inferior to that of major powers like the United States.

lists the characteristics of knowledge management transnational scientific collaboration networks. The table clearly shows that the knowledge management transnational collaboration network has expanded steadily over the past 15 years. From 2001-2005, the knowledge management scientific collaboration network included only 59 countries; this increased by 20 countries in 2006-2010, and reached 101 countries by 2011-2015, indicating stable growth in scientific collaboration relationships between different countries. The number of connections increased from 158 in 2001-2005 to 721 in 2011-2015, demonstrating substantial expansion of scientific collaboration activities in knowledge management

worldwide. Average degree centrality grew from 5.36 in 2001-2005 to 14.28 in 2011-2015, indicating expanding national influence. Network densities for the three stages were 9.23%, 7.30%, and 14.28% respectively. Overall, the scientific collaboration network is not sufficiently dense, suggesting considerable room for improvement in knowledge management transnational scientific collaboration. Clustering coefficients for all three periods exceeded their corresponding network densities, indicating that the scientific collaboration network forms clusters centered around certain nodes. The clustering coefficient increased from 0.71 in 2001-2005 to 0.76 in 2011-2015, showing slowly increasing clustering levels in the scientific collaboration network. Average path length gradually decreased from 2.15 to 2.10, with a diameter of 4, indicating that the scientific collaboration network has short path lengths and strong connectivity. The betweenness centrality of the scientific collaboration network shows a slowly declining trend, reflecting gradually narrowing differences in scientific collaboration between countries.

As shown in , the vast majority of countries under study have established extremely close bilateral collaboration relationships with the United States, with China being America' s most active collaborator. From 2001-2005, the United States was the most important scientific collaborator for eight of the other nine countries (excluding Spain). During 2006-2010, the United States became Spain' s closest bilateral collaboration partner, with co-authored papers between the two countries accounting for 29.41% of Spain' s total collaboration papers. The United Kingdom was the most important collaboration partner for Germany, France, and Australia. From 2011-2015, the United States served as the primary partner for the United Kingdom, China, Germany, Canada, and South Korea. China became not only a key partner for the United States but also Australia' s most important collaborator, with 58 and 16 co-authored papers in China-U.S. and China-Australia collaborations respectively, accounting for 26.13% and 20.51% of total collaboration papers for the United States and Australia.

In summary, within the knowledge management research field, China must optimize its transnational collaboration structure in the future, particularly by strengthening academic exchanges with countries such as the United States and United Kingdom. Simultaneously, China should foster a favorable atmosphere for scientific collaboration, promote the formation of mechanisms and systems for multilateral cooperation in knowledge management research, and generate more innovative and forward-looking research outcomes in knowledge management, thereby continuously enhancing China' s research status and international influence in knowledge management during the knowledge economy era.

6 Research Conclusions

Through systematic analysis of the structure, diversity, and evolutionary characteristics of knowledge management transnational scientific collaboration net-

works constructed from knowledge management international collaboration papers, we obtained the following main conclusions:

(1) Both the total volume of knowledge management papers and transnational collaboration papers show consistent growth trends over time. Over the past 15 years, an increasing number of countries have engaged in knowledge management research. Overall, the distribution of knowledge management transnational scientific collaboration output is uneven, with major participants located in Europe, North America, Oceania, and Asia. The United States' world share of knowledge management transnational collaboration papers has declined during the study period, yet it remains the world' s primary scientific producer in knowledge management transnational collaboration. China has become the third-largest producer of knowledge management transnational collaboration papers after the United States and United Kingdom. However, China' s leading capacity in knowledge management transnational collaboration papers is not only lower than major powers such as the United States and United Kingdom but also lags behind emerging countries like South Korea, remaining disproportionate to its scientific productivity in knowledge management transnational collaboration papers.

(2) As reflected by diversity indicators of knowledge management transnational scientific collaboration networks, knowledge management international collaboration paper output shows a dispersion trend—namely, diversified and decentralized knowledge management transnational collaboration types. Simultaneously, the development of knowledge management transnational collaboration types is extremely unstable, while the dominant position of advantageous collaboration types has become more prominent. However, analysis of knowledge management transnational collaboration relationship structures reveals that bilateral cooperation remains the primary mode of international collaboration in knowledge management. Three-or-more-party collaboration remains relatively rare, and the overall atmosphere of knowledge management transnational scientific collaboration is insufficiently robust. Multilateral cooperation urgently requires further development and should be a key focus for future efforts to promote knowledge management transnational collaboration research.

(3) The knowledge management transnational scientific collaboration network has expanded steadily. Analysis of network centrality indicator trends and transnational collaboration network diagrams reveals an equalization trend in knowledge management transnational collaboration networks, with China moving from a peripheral to a core network position. The United States and United Kingdom have consistently occupied advantageous positions in knowledge management transnational collaboration networks. Emerging countries China and South Korea have shown significant growth in network centrality indicators, yet their network influence remains far inferior to that of major powers such as the United States and

United Kingdom. The United States continues to be the most important collaborative country in knowledge management, occupying an extremely important position in China's knowledge management transnational collaboration layout, while China is the United States' most important partner. China's knowledge management transnational collaboration demonstrates a broadening trend, with decreasing dependence on the United States and increasing emphasis on enhancing independent scientific research and innovation capabilities.

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Author Contributions:

Xu Yuchan: Data collection and processing, manuscript writing
Liang Qihua: Research topic determination, conceptual design, and revision guidance
Zhang Chunyang: Data processing and figure/table preparation

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