Industry–University–Research Collaborative Innovation Mechanism in China: A Review

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Abstracts: The main aim of this study is to analyze articles and trends relating to the industry-university-research (IUR) collaborative innovation mechanism in China; as well as determine key authors and journals focusing on this area; in addition to performing a cluster analysis of related authors and journals; analyze prominent research themes; and also understand the evolution of associated research hotspots. Based on a review of 451 articles linked to research on the IUR collaborative innovation mechanism in China that was obtained from the China National Knowledge Infrastructure (CNKI) database, this paper used the COOC software to analyze the co-occurrence of keywords, while the VOSviewer software was used to visualize the results of the ensuing text analysis. The results show that the research is divided into three phases as follows: the start-up phase (which is from 2007–2011), the high-speed development phase (which is from 2012-2014), and the slow development phase (which is from 2015–2022). Moreover, university and innovation-driven research, higher vocational colleges and industry-university-research-use, as well as innovation and IUR collaborative innovation research, and the evolutionary game and government-industry-university-research were the four main research themes that were identified in the CNKI database. Thus, this evolutionary trend divulges three main clues i.e., research theory, research subjects, and research methods.

Keywords: Industry–University–Research, Collaborative Innovation, Bibliometrics, Mechanism; CNKI; Review.

1. INTRODUCTION

Industry-university-research (IUR) collaborative innovation has drawn the attention of academia, industries, and governments worldwide. However, given that innovation is a complex process, achieving significant success in an enterprise, university, or research domain is becoming increasingly difficult. Hence, collaborative innovation between industries, universities, and research institutes has become an essential part of their operations that is used to promote scientific and technological progress.

Accordingly, international scholarly research on IUR collaborative innovation has focused on three main thematic areas. Firstly, scholarly attention has been devoted to innovation ecosystems and innovation subjects, among which several elements, such as networking, legal support, facilitating agents, and management practices, influencing university-industry interaction in the innovation ecosystem have gained tremendous significance (Bürger & Fiates, 2021). Expectedly, Cai et al. (2019) propose that in the context of a global innovation ecosystem, matching suitable industrial enterprises in various countries for collaboration is a cumbersome process, which becomes more complicated due to the integration of social science theory and artificial intelligence (AI) technologies via a standard linkage process with a transnational university/academic partnership. This is the reason why universities contribute significantly to local innovation ecosystems — to help them to ease the burden of developing these technologies (Klein et al., 2021). Taken together, the core topics of IUR include enterprises, universities, and research institutions. Interestingly, Ciliberti et al. (2016) observe that universities frequently facilitate knowledge transfer in the IUR process and are essential for collaboration, knowledge transfer, and product innovation. Nevertheless, companies play a more managerial role in the intermediation process (Goel et al., 2017). Similarly, incubators also play a significant role in technology transfer and commercialization (Lopes et al., 2018).

Secondly, the triple helix (TH) model of innovation is a critical academic research issue that dominates the study area in both the knowledge economy and society. Moreover, the TH theory blurs the lines between universities, government, and industry, allowing them to accomplish their conventional missions while concentrating on their sole mandate — in furtherance of economic and social development. For instance, Leydesdorff and Ivanova (2016)

revealed that three-dimensional university-industry-government synergies are more probable than two-dimensional university-industry or government-industry partnerships when enhancing an enterprises' research and development (R&D) productivity. On top of that, the TH theory has been applied to the region-specific analysis, such as in the Republic of Kazakhstan (Baimuratov et al., 2020), and Zhongguancun, China (Zhuang, 2015).

Thirdly, knowledge transfer and management constitute an integral part of the literature in this field of study. Evidently, in the knowledge economy, knowledge resources have become the building blocks of an economy's foundation. Equally, as partners in the knowledge economy, universities, and research institutes have a considerable amount of basic and applied research in the collaborative innovation process that can be shared across the board. Correspondingly, since knowledge transfer can take numerous forms, including the formation of Technology-Based Companies from higher education institutions such as Technology-Based Entrepreneurship Development Centers (Benavides-Sanchez et al., 2021), its role in the collaborative innovation mechanism process cannot be overemphasized. Contemporaneously, the enterprise is the party that acquires the knowledge and also transforms it into viable products and services. This constitutes an intrinsic outlook of the prospects of the organization. Given that knowledge acquisition favorably influences the application of knowledge in manufacturing small and medium enterprises (SMEs), it also has a significant and notable impact on sustainable performance (Al Koliby et al., 2022). In like manner, processes for knowledge management make it possible to seamlessly share knowledge to generate original ideas for differentiation and to efficiently make use of already-acquired knowledge. In addition, greater distinctiveness and cost-effectiveness work in concert to increase a company's capacity for innovation (Trivedi & Srivastava, 2022).

Conversely, some scholars have opposing viewpoints on the phenomenon. According to Grant (2001), IUR collaboration might prevent some universities and research institutions from carrying out their fundamental duties (Tao, 2019). Furthermore, Crespo and Dridi (2007) reveal that IUR collaborations tend to focus more on applied research with a specific interest in financial gains, which is incompatible with the mandate of universities and research institutions conducting basic research that is both forward-looking and strategic as a basis for an academic scholarship. Therefore, IUR collaborations should be handled with greater caution, to keep the parties along their foci areas. The presentation of university research in various forms, including industry-university, university-industry, university business, and university companies lives much to be desired.

Remarkably, China as a developing country attaches great importance to the IUR collaborative innovation mechanism to foster a knowledge-driven economy. Without mincing words, this innovation-driven development strategy proposed during the 18th National Congress of the Chinese Communist Party in 2012 has been very successful. Likewise, the establishment of a IUR collaborative innovation mechanism which was explicitly called for at the Third Plenary Session of the 18th Central Committee of the Communist Party of China in 2013 has been very effective. Apart from these government intervention schemes, some of China's leading enterprises, universities, and research institutes have jointly established pioneering innovative programs and practices, whose breakthroughs have motivated Chinese scholars to strive toward producing cutting-edge research. Taken together, relevant extant research has also achieved gratifying results. Intriguingly, the number of articles centered on the IUR innovation mechanism published in the China National Knowledge Infrastructure (CNKI) database has continued to grow over time. Yet, few articles have carried out a comprehensive study of recent development and/or trends using bibliometrics information datasets. Therefore, using applicable data from 451 research papers related to the IUR collaborative innovation mechanism obtained from the CNKI database, in addition to employing a bibliometric method, we conducted a visual knowledge graph analysis of the number and trends of publications, key authors, journals, keywords, research topics, and the evolution of research hotspots. Ultimately, it is envisaged that the application of this method will help researchers obtain more precise, as well as generate an intuitive knowledge and understanding of the developmental status and trends in this field of study since it provides direct guidance and convenience for follow-up research and in-depth discussions about the phenomenon.

The paper is structured as follows. Section 2 offers the theoretical background for the study. Section 3 describes the method employed. Section 4 presents the results, which is followed by a discussion about the findings of this study in Section 5. Lastly, the conclusions of this study were identified in Section 6.

2. THEORETICAL BACKGROUND

IUR collaborative innovation refers to the main body of IUR that invests its advantages of resources and technology and completes the coordinated activities of technological innovation under the synergy of government, intermediary, financial institutions, and other subjects. Universities frequently facilitate knowledge transfer in the IUR process and are essential for collaboration, knowledge transfer, and product innovation (Ciliberti et al., 2016). In contrast, companies play a more managerial role (Goel et al., 2017), According to Munir and Beh (2019) organizational creative climate and knowledge sharing play important role in fostering the individual innovative work behavior in startups.

IUR collaborative innovation takes numerous forms worldwide, depending on historical and cultural reasons. According to Xiao et al. (2019), typical models like the project-dependent, co-build, and industrial technology alliance models can categorize China's IUR collaborative innovation models. He and Zhang (2015) divided IUR collaborative innovation into two categories based on organizational cooperation's direction: one-way cooperation and two-way interaction. The two types of interaction are shallow two-way interaction such as joint R&D and co-establishment of research institutions, and deep two-way interaction such as co-founding new enterprises by enterprises and academic and research institutions and incubating new enterprises by academic and research institutions. One-way cooperation includes technology transfer and commissioned development.

The term "mechanism" initially referred to the design and operation of a machine. Later, it came to mean the design, operation, and interplay of a complex working system and the physical and chemical principles governing certain natural occurrences (Liu, 2015). Researchers have conducted a great deal of research and produced a wealth of findings about the IUR collaborative innovation process. The IUR collaborative innovation mechanism has been the subject of a comparatively thorough study by academics, which covered the entire process from innovation stimulation to innovation completion. The mechanisms involved in IUR collaborative innovation include those between IUR, such as the cooperation mode and innovation mechanism in the preparatory stage, the financing mechanism and incentive innovation mechanism during the process, and the benefit distribution mechanism after IUR Collaboration (Feng, 2014).

3. METHODOLOGY

3.1 Data Sources and Cleaning

The study data were obtained from the CNKI database on March 2nd, 2022. The retrieval conditions were as follows: "(theme = IUR) AND (theme = collaborative innovation) AND (theme = mechanism)." The resource scope included academic journals published in Chinese and English. The source categories included the Peking University core, Chinese Social Sciences Citation Index (CSSCI), the Chinese Science Citation Database (CSCD), and period default for all years to obtain 456-item data. First, we used COOC software (Academic-Tips, 2021) to eliminate the duplicates of the initially exported Chinese literature. Then, we manually excluded the irrelevant literature. A total of 451 Chinese articles were finally included.

3.2 Research Methods

The American scholar A. J. Lotka proposed the bibliometric method in the 1920s (Kumar et al., 1998). Bibliometric methods help quantitatively reveal the development process, research hotspots, and development direction of a field. Bibliometrics integrates statistics, mathematics, and philology and is a comprehensive knowledge system that focuses on quantitative analysis. It helps scholars efficiently obtain hidden value information from massive literature and predict the future development trends of a research field (Chen, 2001). Furthermore, a knowledge map can be generated, which graphically depicts the process and structural relationships of knowledge development in a particular area. We used COOC software to analyze the cooccurrence of keywords. VOSviewer software was used to verify and visualize the results of text analysis, including the number and trends of published papers, key authors, key journals, keywords, research topic analysis, and evolution of research hotspots. This

helped objectively analyze the research status in various related fields, clarify the current research frontiers and hot issues, and provide a reference for researchers and decision-makers in the field.

4. DATA ANALYSIS AND RESULTS

4.1 Analysis of the Number and Trends of Publications

To obtain a clear understanding of the research status of the IUR collaborative innovation mechanism, we conducted a visual analysis of the number of published articles and the cumulative number of published papers (Figure 1).

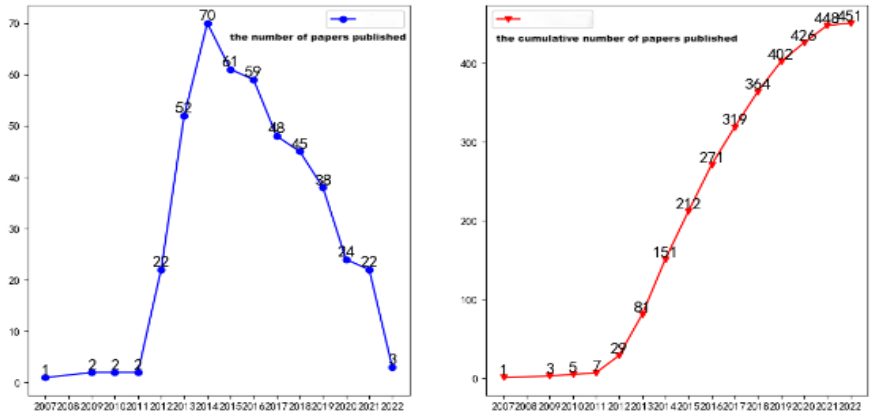

Figure 1. The Number of Papers and Cumulative Number of Papers on the IUR Collaborative Innovation Mechanism Published in the CNKI Database

Of note, the cumulative number of articles on the IUR collaborative innovation mechanisms increased slowly between 2007 and 2011 but showed an increasing upward trend from then. The number of publications showed the same trend as the cumulative number of publications in the beginning but exhibited a linear upward trend from 2011 onwards, reaching a peak in 2014 (70 articles); moreover, 22 articles were published in 2021, with three articles published within the first three months of 2022. Therefore, based on the trends of changes in the number of articles published in the CNKI database and the cumulative number of articles published, the research stages of the IUR collaborative innovation mechanism in China can be roughly divided into the following three steps.

From 2007 to 2011, the earliest research related to the IUR collaborative innovation mechanism appeared in 2007, with a total of seven related articles published until 2011, indicating that this research topic was still in its infancy at this stage. In January 2006, the State Council of the Central Committee of the Communist Party of China issued the "Decision on Implementing the Outline of Science and Technology Planning to Enhance Independent Innovation Capability." This act called for the formation of a dynamic national innovation system, vigorously promoting the integration of industry, academia, and research and encouraging and supporting enterprises to jointly establish research and development institutions, industrial technology alliances, and other technological innovation organizations with research institutes and higher educational institutions.

The period from 2012 to 2014 witnessed a rapid development in the number of articles published, reaching a peak in 2014, when the field was in high gear. In April 2011, General Secretary Hu Jintao, in his speech at the 100th Anniversary Conference of Tsinghua University, mentioned that he would actively promote collaborative innovation; encourage in-depth cooperation between universities, research institutes, and enterprises; establish strategic alliances for collaborative creation; and promote the sharing of resources through institutional and institutional innovation and policy guidance. In 2012, the Ministry of Education began implementing the "Innovation Capacity Enhancement Plan for Higher Education Institutions" (2011 Plan). This plan was aimed at establishing several "2011 Collaborative Innovation Centers" and vigorously promoting in-depth cooperation between universities, research

institutes, industrial enterprises, local governments, and foreign research institutions.

From 2015 to 2022, although the number of publications began to slow down or even decline, the cumulative number of publications showed an upward increasing trend year by year. Moreover, relevant research was continuously being developed. Thus, this phase is known as the slow development phase. In May 2015, the State Council of the Central Committee of the Communist Party of China (CPC) established the "Experiment on Systematically Promoting Comprehensive Innovation Reform in Some Regions." In May 2016, the State Council of the CPC Central Committee released the "Outline of the National Innovation-driven Development Strategy," which was focused on the development of new industries, training of innovation talent, construction of innovation bases, development of innovation systems, formation of innovation networks, and reformation and transformation of the economic development model's innovation systems. These were considered essential initiatives to comprehensively enhance China's independent innovation capabilities and build an innovative country.

4.2 Author and Journal Analysis

4.2.1 Analysis of the Top 10 Authors

As shown in Figure 2, the top 10 authors who published articles on the IUR collaborative innovation mechanism in the CNKI database were Wang Haijun, Gu Xin, Wu Zhongchao, Liu Zhou, Shen Yunci, Li Lin, Lan Xiaoxia, Jian Lirong, Zhu Guilong, and Zhong Wei.

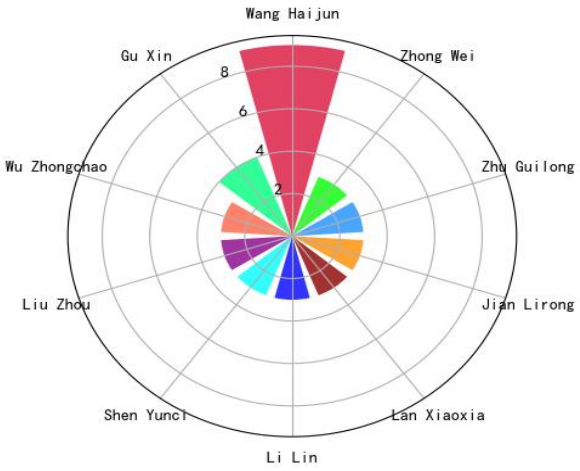

Figure 2. 10 Authors Who Published Research on the IUR Collaborative Innovation Mechanism in the CNKI Database

By publishing up to nine articles, Prof. Wang Haijun has made outstanding contributions. He belongs to the School of Management, Shenyang University of Technology, and is a doctoral supervisor, a Ph.D. in Mechanical Manufacturing and Automation from the Dalian University of Technology, a postdoctoral fellow in management from Zhejiang University, and a visiting scholar at Tsinghua University School of Economics and Management. His research interests include innovation ecosystems, collaborative innovation, disruptive innovation, modularity, etc. Before joining the Shenyang University of Technology in 2014, he worked with the Haier Group and Shenyang Yuanda Group for almost ten years. He has chaired two National Social Science Foundation projects and six provincial-level research projects and has undertaken 12 other research projects. He has also edited two books and contributed toone book. He has published more than 60 papers in important journals, core journals, and international academic conference proceedings both at home and internationally and has served as a reviewer for several SSCI/CSSCI journals.

Professor Gu Xin is a postdoctoral supervisor from the Business School of Sichuan University, a postdoctoral fellow in management, a doctorate in economics, the director of the Institute of Innovation and Entrepreneurship

Management at Sichuan University, and the director of the Institute of Soft Science at Sichuan University. Ever since he started teaching at the Sichuan University in July 1994, he has led more than 30 research projects, including the Ministry of Education's "New Century Excellent Talent Support Program" project, the National Social Science Foundation of China's key projects, the National Natural Science Foundation of China's key projects, the Sichuan Provincial Key Soft Science Program, and Sichuan Provincial Key Projects in Philosophy and Social Science Research. He has published more than 300 papers in critical academic journals and conferences and six scholarly monographs.

The remaining eight authors also possess a wealth of academic achievements. Four of them have PhDs in management, two have PhDs in education, five have PhDs in other domains, and a majority of them also hold important administrative positions.

4.2.2 Analysis of the Top 10 Journals

Periodical frequency statistics help quickly identify the type of journal articles and provide a reference for contributors. Based on the analysis of the research areas of journals reporting articles on the IUR collaborative innovation mechanism in the CNKI database, it can be seen that Chinese University Science & Technology, an authoritative journal headed by the Ministry of Education of the People's Republic of China and hosted by the Science and Technology Development Center of the Ministry of Education, has played an important guiding role (Figure 3). The number of published papers by these journals is approximately 63. The journals of "Science and Technology Management Research" and "Science & Technology Progress and Policy" focus on scientific and technological progress. By contrast, "Scientific Management Research," "China Higher Education," "China Higher Education Research," "Journal of Technical Economics & Management," "Forum on Science and Technology in China," "Research in Science of Science," and "Heilongjiang Research on Higher Education" published less than 15 papers each. All of these are excellent professional journals and publish papers of a high standard. They very well reflect the frontiers of research in IUR collaborative innovation mechanisms in China.

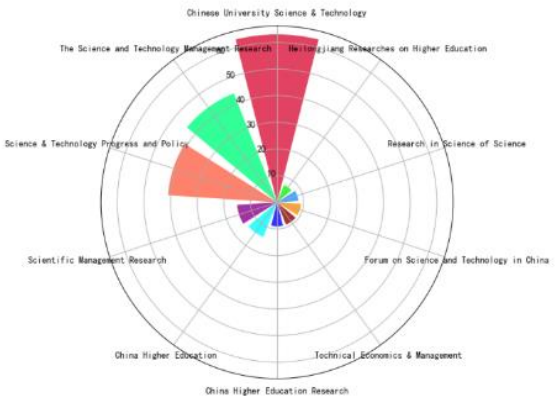

Figure 3. The top 10 Journals Publishing Research on the IUR Collaborative Innovation Mechanism in the CNKI Database

4.2.3 Author–Journal Clustering Analysis Based on the Two-Mode Matrix

Authors are the main suppliers of literature, and high-frequency authors in a research field often lead the development of certain disciplines, whereas journals may publish many scientific results in this research field, perhaps reflecting the main research content in this research field. Thus, linking authors and journals based on the two-mode matrix for cluster analysis can memorize the structure of a research field and their relationships with each other. The author–journal bimodal matrix primarily expresses the association between the two. When an author appears in a journal, an association is assumed between the two, and the more frequent the appearance, the stronger the association. For comprehensiveness and clarity of the analysis, authors with a frequency of 2 and journals with a frequency of 5 were intercepted as sources for the clustering analysis. The author–journal network

was presented visually in this paper using VOSviewer (Figure 4).

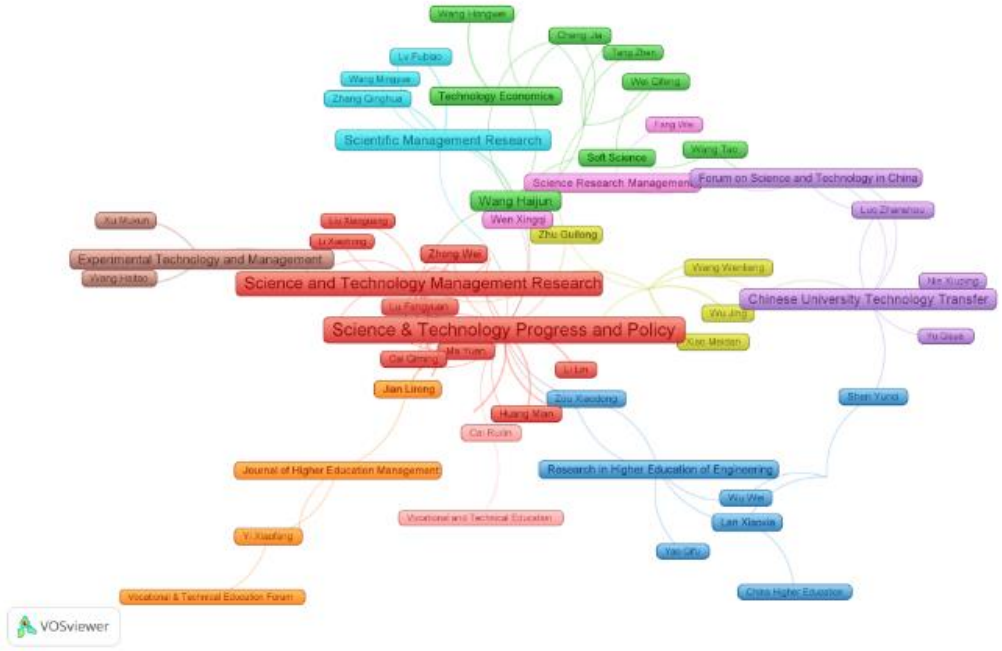

Figure 4. The Author–Journal Clustering Map for Research on the IUR Collaborative Innovation Mechanism in the CNKI Database

In the figure 4, the square entries indicate the authors and journals. The connecting lines represent the association between the authors and journals. The distribution of the author–journal relationship can be clearly identified from the structure of the different colors shown in Figure 4. Meanwhile, it is obvious that journals such as "Science and Technology Management Research," "Science & Technology Progress and Policy," "Technology Economics," "Scientific Management Research," and "Soft Science" and the network formed by their authors are in the middle core position. By contrast, the network created by the other journals such as "China Higher Education," "Vocational and Technical Education," "Vocational & Technical Education Forum," and "Journal of Higher Education Management" and their authors are further away from the core area and have little relevance to the other journals and authors. In short, these educational journals are not prominent and lack a transparent intra-network.

4.3 High-Frequency Keyword Analysis

A keyword is the author's concise theme reflecting the paper's key findings. For example, when the frequency of keywords in papers on the IUR collaborative innovation mechanism was measured, 16 keywords in the CNKI database had a frequency of≥10. Thus, 16 keywords with a frequency of ≥10 were selected as an indicator of high-frequency keywords in this paper (Table 1).

Table 1. High-Frequency Keywords in Research Papers on the IUR Collaborative Innovation Mechanism in the CNKI Database (Frequency ≥10)

Number	Keyword	Frequency	Number	Keyword	Frequency
1	Collaborative Innovation	215	9	I–U–R-U	13
2	IUR	80	10	Innovation	12
3	IUR Collaborative Innovation	52	11	Evolutionary Gaming	11
4	IUR Cooperation	47	12	Technological Innovation	11
5	Colleges and Universities	21	13	Mode	10
6	Mechanism	16	14	G–I–U–R	10
7	Innovation-Driven	13	15	Higher Vocational Colleges	10
8	Talent Development	13	16	Technological Innovation	10

In the CNKI database, "collaborative innovation" was the most frequently used keyword (215 times), followed by "IUR" (80 times). Thus, "collaborative innovation" and "industry–university–research" have been used as keywords in this paper.

4.4 Research Topic Analysis

To better identify the research topics in this field, we listed complete cooccurrence matrixes based on the high-frequency keywords (Table 2), calculated the cosine similarity, and recorded the similarity matrixes (Table 3). Finally, using COOC software, we drew a system clustering diagram (Figure 5). A cluster analysis of high-frequency keywords was also performed.

4.4.1 Construction of a Complete Cooccurrence Matrix

A complete cooccurrence matrix is a symmetric matrix containing pairs of high-frequency keywords. It counts the frequency of their common occurrence to form matrixes. The diagonal data in the table indicate the frequency of the keyword itself; however, only part of the data is given owing to the limited space (Table 2).

Table 2. The Complete Cooccurrence Matrix of the High-Frequency Keywords in the CNKI Database (Partial Data)

No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	215	60	2	28	9	11	3	6	10	0	8	4	6	9	4
2	60	80	0	0	6	5	1	2	0	3	4	0	2	0	2
3	2	0	52	2	0	1	1	1	0	1	1	0	1	0	1
4	28	0	2	47	4	1	1	1	0	3	2	1	1	0	0
5	9	6	0	4	21	1	1	1	0	1	0	0	0	0	0
6	11	5	1	1	1	16	0	0	0	0	0	0	5	1	0
7	3	1	1	1	1	0	13	0	0	0	0	2	0	1	0
8	6	2	1	1	1	0	0	13	2	0	0	0	0	0	3
9	10	0	0	0	0	0	0	2	13	1	0	0	0	0	1
10	0	3	1	3	1	0	0	0	1	12	0	0	1	0	0
11	8	4	1	2	0	0	0	0	0	0	11	0	0	2	0
12	4	0	0	1	0	0	2	0	0	0	0	11	0	0	0
13	6	2	1	1	0	5	0	0	0	1	0	0	10	0	0
14	9	0	0	0	0	1	1	0	0	0	2	0	0	10	1

15	4	2	1	0	0	0	0	3	1	0	0	0	0	1	10
16	3	2	0	0	2	0	0	0	0	0	0	0	0	0	0

4.4.2 Construction of a Similarity Matrix

In this study, the similarity between keywords was calculated based on the cosine similarity (the formula is given below). A and B are vectors corresponding to two different keywords in the procedure. The chord distance determines the similarity between the vectors based on their direction, which is related to the relative size of each dimension of the vector and not affected by the direct value of each dimension. The value in the similarity matrix ranges between 0 and 1. The closer the matter is to 1, the greater the similarity between the two keywords and vice versa. The data on the diagonal of the two words indicate the similarity between the keyword and the data itself, usually 1 (Table 3)..

$$\text{similarity} = \cos(\theta) = \frac{\boldsymbol{A} \cdot \boldsymbol{B}}{\|\boldsymbol{A}\|\|\boldsymbol{B}\|} = \frac{\sum_{i=1}^{n} \boldsymbol{A}_i \times \boldsymbol{B}_i}{\sqrt{\sum_{i=1}^{n} (\boldsymbol{A}_i)^2} \times \sqrt{\sum_{i=1}^{n} (\boldsymbol{B}_i)^2}}.$$

Table 3. The High-Frequency Keyword Similarity Matrix in the CNKI Database (Partial Data)

	1	2	3	4	5
1	1	0.786379689	0.053234896	0.595894471	0.480410586
2	0.786379689	1	0.026520702	0.312808772	0.478790529
3	0.053234896	0.026520702	1	0.091613226	0.023848175
4	0.595894471	0.312808772	0.091613226	1	0.399044573
5	0.480410586	0.478790529	0.023848175	0.399044573	1
6	0.621493847	0.553979919	0.089604227	0.33421948	0.339428882
7	0.258589304	0.202982325	0.102375834	0.201896977	0.215216742
8	0.459405542	0.370098874	0.104837822	0.283355489	0.287395913
9	0.611993642	0.365364013	0.02775494	0.312165961	0.23246368
10	0.099834424	0.219300246	0.105681678	0.259400501	0.202686589
11	0.647867566	0.579438867	0.109840839	0.428670394	0.297483032
12	0.34793654	0.202044028	0.019312232	0.262175018	0.146097783
13	0.530294504	0.435981959	0.121326203	0.329321628	0.243051026
14	0.663771797	0.403432323	0.0321695	0.341780919	0.250921385
15	0.407427527	0.368890488	0.121851615	0.184971973	0.18400165
16	0.332230109	0.34215653	0.010637846	0.154490553	0.387049892

4.4.3 Cluster Analysis

Clustering analysis is the process of dividing the data into different categories. Some data are clustered in the same category due to their similarities, whereas different categories of data may have significant differences.

Figure 5 shows that the research on the IUR collaborative innovation mechanism in the CNKI database focuses on four main topics: universities and innovation-driven; higher vocational colleges and IUR-use; innovation and IUR collaborative innovation; and evolutionary game and government–industry–university–research (GUIR).

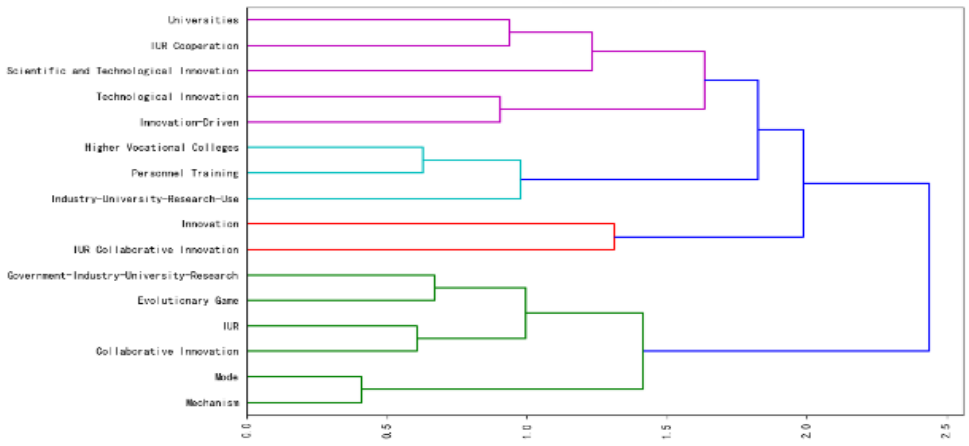

Figure 5. Keyword System Cluster Diagram in the CNKI Database

4.4.3.1 Universities and Innovation-Driven

The high-frequency keywords on this topic include "universities," "IUR cooperation," "scientific and technological innovation," "technological innovation," and "innovation-driven." These keywords mainly reflect the research topics of universities. They are innovation-driven in IUR collaborative innovation research. The 18th National Congress of the CPC, held toward the end of 2012, clearly implemented an innovation-driven development strategy, placing technological innovation at the core of national development. Technology innovation systems involving IUR cooperation play a massive role in scientific and technological innovation. Wang and Wang (2021) and Yu and Liu (2019) analyzed the problems and shortcomings associated with universities involved in IUR cooperation innovation and provided suggestions. Wang et al. (2016) and other scholars discussed the interest coordination mechanisms and guaranteed mechanisms for IUR cooperation using case studies. Li and Chen (2018) conducted a quantitative analysis of policy texts on IUR cooperation and collaborative innovation, clarified the shortcomings of certain laws, and provided corresponding suggestions. Luo and Wang (2015) discussed the operation mechanisms of IUR cooperation and analyzed the obstacles to knowledge management. Tian (2015) provided countermeasures and suggestions for enterprises to play a leading role in the IUR collaborative innovation mechanism.

4.4.3.2 Higher Vocational Colleges and Industry–University–Research–Use (IURU)

The high-frequency keywords in this topic include "higher vocational colleges," "personnel training," and "industry–university–research–use." Higher vocational colleges are an essential type of higher educational institutes in China; these institutes primarily cultivate skilled and applied talents for society. Higher vocational colleges emphasize the collaborative innovation mode of production, learning, and research. The collective innovation platforms of production, education, and research in higher vocational colleges are an essential form of school personnel training and social service. Speaking from practice, summarizing case experience is often adopted by scholars. Through certain case studies, Guo and Xie (2014) and Fan (2014) have summed up, experienced, and discussed the operation mechanisms of collaborative innovation platforms in higher vocational colleges. Zhang (2017) analyzed the rampant problems in the service of higher vocational colleges to regional economic and social development and provided policy suggestions. Xiao (2015) investigated the issues faced by local universities in the collaborative innovation of the government–industry–university–research, constructed an information management platform for collaborative innovation, and proposed a path for local universities to realize the collaborative innovations of GUIR. Some scholars have also conducted further in-depth theoretical research. Wang and Cheng (2017) designed a performance evaluation index system for IUR collaborative innovation mechanisms and expounded an interest coordination mechanism for enterprises despite the existing partners.

4.4.3.3 Innovation and IUR Collaborative Innovation

The high-frequency keywords in this topic included "innovation" and "collaborative innovation." In 2013, the Third Plenary Session of the 18th Central Committee of the CPC clearly established a mechanism for IUR collaborative innovation. Lan (2014) explored the safeguard mechanism for collaborative innovation among the American government, enterprises, and universities. Zhang (2013) analyzed the mechanism of IUR collaborative innovation from the perspective of open science. Wang and Ai (2015) established a technology-transfer signal game model for IUR collaborative innovation, analyzed the factors affecting the successful operation of the technology transfer, and provided corresponding countermeasures and suggestions. Yu and Jian (2013) analyzed constraints in terms of innovation ability and laid a path toward the improvement of collaborative innovation abilities.

4.4.3.4 Evolutionary Game and Government–Industry–University–Research (GIUR)

The high-frequency keywords in this topic included "GIUR," "evolutionary game," "IUR," and "collaborative innovation, mode, and mechanism." The traditional game theory assumes that a participant is entirely rational and that the participation is performed under the conditions of complete information. The evolutionary game is no longer modeled as a super-rational game party, and the evolutionary game emphasizes a dynamic equilibrium methodologically. Wang et al. (2015) summarized a collaborative innovation model of "government, industry, learning, research, and use" by analyzing the practical experiences of the Beijing University of Technology. Pan and Li (2014) analyzed the development dilemmas faced in terms of the traditional IUR cooperation in the era of university science and constructed a structural regional GIUR collaborative innovation mechanism model based on the three aspects of strategy, mechanism, and environment. Wu et al. (2019) produced a tripartite evolutionary game model of collaborative innovation, analyzed the strategy selection of the GIUR tripartite in collaborative innovation, and studied the factors influencing the selection of GIUR collaborative innovation strategies through simulation analysis. Xue et al. (2014) applied the evolutionary game theory to construct an evolutionary game model of trust relationships in IUR collaborative innovation based on bounded rationality; they also deeply studied the trust relationships of IUR collaborative innovation. Li et al. (2018) first studied the evolutionary game laws of cooperative innovation by adopting suitable strategies under anarchy intervention based on an evolutionary game theory; moreover, based on the theory of system dynamics, this paper analyzed the evolutionary game of cooperative innovation subjects adopting cooperative strategies under governmental intervention.

4.5 Evolutionary Analysis of Research Hotspots

Based on the above analysis, we further organized the theme evolution path, including the keywords of papers related to the IUR collaborative innovation mechanism in the CNKI database. The first six keywords for each year (2007–2022) are shown in the bubble in Figure 6. The larger the bubble in the bubble diagram, the higher the frequency of keywords; moreover, the frequency of the keywords in the table reduces as we move from the bottom to the top. The position of the keywords can be determined based on the year in which the keywords first appeared. The number of subsequent appearances is accumulated in the year they first appeared.

Figure 6. Cumulative Evolutionary Path of the CNKI Research Themes on Collaborative Innovation Mechanisms between IUR

Herein, we also analyzed the evolution of research hotspots based on three stages of research on the IUR collaborative innovation mechanism.

4.5.1 Start-Up Phase (2007–2011)

The high-frequency keywords in this stage included "IUR" in 2007; "collaborative innovation," which appeared for the first time in 2009 and took the shape of a giant bubble; "innovation system"; "regional innovation network"; and "basic research," appeared for the first time in 2010 but with a smaller bubble. "Collaborative development" was a high-frequency keyword in 2011. Although there were fewer articles in this stage, there were also clear characteristics, and the "social capital" and "national innovation system" theories began entering the research horizon, "Zhongguancun" and "Haidian Science and Technology Park" were all high-frequency keywords. In this period, the scholars conducted exploratory research on the "training of innovative talents" and "allocation of information resources" as well as their "linkage mechanisms" and "organizational mechanisms." Generally speaking, the research objects in this period were relatively homogeneous, and the research mechanisms were not really in-depth.

4.5.2 High-Speed Development Stage (2012–2014)

In 2012, the theme of this study—"IUR collaborative innovation"—began to emerge, and "universities" and "higher vocational institutions" became essential objects of research. "Talent cultivation," "scientific and technological innovation," and "innovation performance" were the focus of scholars and included the mechanisms studied. The main theories included the "evolutionary game" theory and the "knowledge map" research method. At this stage, although research related to the IUR collaborative innovation mechanism was developed at high speed, the researchers mainly focused on the academic–research side of the IUR triad; by contrast, the theoretical and methodological aspects were relatively simple. Therefore, no comprehensive analysis of the IUR collaborative innovation mechanism was undertaken.

4.5.3 Slow Development Phase (2015–2022)

From 2015 to the present day is a relatively long period, and the speed of research on the collaborative innovation mechanism between industries, universities, and institutes has declined significantly. The relevant eyes have become increasingly mature and complex. From a theoretical perspective, the following theories have emerged (in order): "root theory," "system dynamics," "knowledge management," "open innovation," "knowledge spillover," and "ecosystem theory." From a methodological perspective, the keywords that appear are as follows (in

order): "comparison," "simulation," "text quantitative analysis," and "heterogeneity analysis." The research objects included "agricultural enterprises," "innovation ecology," "innovative cities," "new R&D institutions," "applied universities," "industrial alliances," "green technology," "smart industries," "governmental functions," "metropolitan areas," and "financial institutions." The research included the "development model," "teaching model," "coordinating mechanism," "transformation of scientific and technological achievements," "knowledge innovation process," "knowledge flow efficiency," and "risk compensation." Generally speaking, the theories and methods of research on the IUR collaborative innovation mechanism are becoming more and more diversified at this stage. With China's developments, social phenomena such as intelligent technology and green technology are captivating the society as a whole to a greater extent; accordingly, the research horizons related to the IUR collaborative innovation mechanism are also becoming more and more open, making enterprises, cities, and the ecology the main focus of scholars' attention.

In summary, this review summarizes three clues to the evolutionary trends of the research hotspots of the IUR collaborative innovation mechanism. First, the theoretical research clues of the IUR collaborative innovation mechanism: social capital → national innovation system → evolutionary game → rooting theory → system dynamics → knowledge management → open innovation → ecosystem theory. Second, the innovation subject clues of the IUR collaborative innovation mechanism; with the development of the Chinese society, the research focus now evolves into the following: science and technology parks → universities → higher education institutions → enterprises → innovation ecology → industrial alliances → intelligent industries → government functions → metropolitan areas → financial institutions. Third, the methodological clues for research on the IUR collaborative innovation mechanism: knowledge mapping analysis → rooting theory → comparison → simulation → text quantification analysis → heterogeneity analysis.

5. DISCUSSION

5.1 Findings

The findings of the above analysis show that research related to IUR collaborative innovation mechanism based on information obtained from the CNKI database began at the initial stage between 2007 to 2011. Surprisingly, our findings reveal that comparatively, China started late when compared to developed countries. However, China has achieved positive and significant results in this area after adopting and accumulating IUR collaborative innovation mechanisms in the rapid development stage (i.e., between 2012 to 2014) and the slow development stage (i.e., between 2015 to 2022). Besides, the Chinese government has issued important documents guiding the development of innovation at different stages, which is reinforced by the fact that China is rapidly on the path of economic transformation and development.

Furthermore, a knowledge map was drawn using the statistical analysis of the key authors and journal keywords. Fascinatingly, the map indicated that most of the key authors in the relevant field of research were senior scholars in the fields of management and education, who have previously published several high-quality articles. Thus, these findings reflect the frontiers of research on the IUR collaborative innovation mechanism in China. What’s more, the cluster analysis of authors–journals based on the two-mode matrix revealed that the journals of "Science and Technology Management Research," "Science & Technology Progress and Policy," "Technology Economics," "Scientific Management Research," and "Soft Science" were the most prominent journals where notable authors published in this area of research. Moreover, the author networks of these journals were located in the central core of the mappings. In contrast, the journals of "China Higher Education," "Vocational and Technical Education," "Vocational & Technical Education Forum," and "Journal of Higher Education Management" and their associated authors lie farther away from the core area, indicating that they have barely any relevance to the other related journals and authors. Consequently, these educational journals did not form a prominent network with each other. Nevertheless, relevant research is almost insignificant in other disciplinary areas outside the fields of economic management and education, which therefore limits the richness of the contribution and innovation intended by the researcher in this area. Aside from this, since there are significant regional differences between the regions of

China, we propose that new studies should adopt a locally adapted strategy to highlight these differences, which will help to further deepen research in this area.

Correspondingly, cluster analysis based on the similarity matrix was constructed using relevant keywords. The results uncovered that research on the IUR collaborative innovation mechanism in the CNKI database focuses on four research topics: universities and innovation-driven higher vocational colleges; industry–university–research–use; innovation, as well as IUR collaborative innovation and evolutionary game and GUIR. These four research themes, therefore, reflect the focus of Chinese scholars' attention and deserve further in-depth research by future scholars. This is because it can be used as a basis to summarize the research paradigm of Chinese scholars, as well as motivate researchers to make theoretical contributions that can lead to the development of research related to the IUR collaborative innovation mechanism. Similarly, the experience of international scholars from other countries in this area can be relied upon when the foci area of this study.

Likewise, three clues were summarized in the further analysis of the evolution of the research hotspots of the IUR collaborative innovation mechanism in China. First, the theoretical research clues of the IUR collaborative innovation mechanism can be represented as social capital → national innovation system → evolutionary game → rooting theory → system dynamics → knowledge management → open innovation → ecosystem theory. Second, the innovation subject clues of the IUR collaborative innovation mechanism (accentuates that the development of the Chinese society can lead to a change in the research focus and clues to): science and technology parks → universities → higher education institutions → enterprises → innovation ecology → industrial alliances → intelligent industries → government functions → metropolitan areas → financial institutions. Finally, the methodological clues for research on the IUR collaborative innovation mechanisms can be represented as knowledge mapping analysis → rooting theory → comparison → simulation → text quantification analysis → heterogeneity analysis. Interestingly, it can be seen that Chinese scholars are more willing to keep up with the times, just as extant research has been keeping up with the hot spots, while researchers try out new theories, new subjects, and new methods. However, despite the methodological issues confronting this stream of research, carrying out basic research in this area is still a very important endeavor.

5.2 Practical and Theoretical Contributions and Implications

Studying the coordinated innovation mechanism is of great theoretical and practical value. This study systematically reviews China's research on IUR collaborative innovation mechanisms to deepen the understanding of the IUR collaborative innovation mechanism. Although Chinese scholars have made rich achievements in related fields, papers that systematically quantify their research are relatively rare. Therefore, analyzing the Chinese IUR collaborative innovation mechanism literature from different perspectives aligns more with the current Chinese reality and provides a solid foundation for further theoretical exploration.

This study understands the activities that promote or hinder the improvement of Innovation capacity by studying the IUR coordination innovation mechanism so that policymakers can shape the innovation process through policy guidance and provide a theoretical basis for formulating regional innovation development strategies. At the same time, the ultimate purpose of the research on the IUR coordination innovation mechanism is to promote innovation progress, enhance the innovation ability of universities, enterprises, and research institutes, and cultivate the capabilities of universities and research institutes in market judgment, resource integration, communication, and coordination. Help universities with interdisciplinary cooperation and innovative personnel training, enhance their comprehensive competitiveness, accelerate the diffusion of technology and knowledge, promote the commercialization of research results, promote regional economic development, establish a dynamic regional innovation system, and contribute to the country's development. Last but not least, this study will help to improve the efficiency of collaborative research and development between enterprises and universities. Scientific research institutes help enterprise managers gather innovation advantages and resources more effectively, realize the compelling connection between scientific research and industry, improve the cluster economic structure, enhance the innovation ability of enterprises, and improve management performance.

Based on the review of existing research and the current status of IUR research in China, this study obtains the following implications: Firstly, there are currently more case studies on economically and technologically developed regions, and less focus is placed on underdeveloped regions. It is appropriate to do in-depth studies and summaries of certain unsuccessful cases, as well as research on the collaborative innovation mechanism of IUR in underdeveloped nations; Secondly, research on individual actors is lacking, individuals have a crucial role in research, management, and policy-making and have the ability to have a significant impact on the IUR collaborative innovation mechanism. Therefore, strengthening research at the individual level can help improve the quality of IUR research in general; Thirdly, the 19th Party Congress announced that China's economic development has shifted to a stage of high-quality development, and that the 14th Five-Year Plan period saw complex changes to China's internal and external environments, which calls for IUR research to pay more attention to new changes and challenges and to broaden its scope.

CONCLUSION

In furtherance of China’s vision to promote IUR collaborative innovation, the available literature review points out that the country is on course to become a major player globally. Congruently, this lofty objective is being supported (policy-wise) by the 14th Five-Year Plan for National Economic and Social Development of the People's Republic of China, which is also buttressed by the Outline of the Vision Goals for 2035. Accordingly, it points out that China should promote an optimal resource-sharing allocation of scientific research forces in core scientific research institutes, universities, and enterprises across the nation. We also envisage that the policy will be successful because it supports the development of new innovative subjects such as new research universities, and new R&D institutions, as well as promote the diversification of investment subjects, in addition to the modernization of management systems, the marketization of operating mechanisms, and the flexibility of employment mechanisms. Thus, IUR collaborative innovation plays an important role in the development of China's national innovation system over the coming decades.

Lastly, as an important part of IUR collaborative innovation, the innovation mechanism system deserves special attention. Based on the papers related to the IUR collaborative innovation mechanism that was mined from the CNKI database, this paper analyzes the research status and development trend of relevant articles in this field of study, this informs the complex methods of analysis via mapping which led to important theoretical and practical contributions. To the best of our knowledge, there is no quantitative literature review of the IUR collaborative innovation mechanism in the CNKI database. Hence, this study helps to objectively summarize extant research in China, as well as establish the changing trends in this area, to provide options and convenience for future researchers, who can use our findings as a starting point to launch more impactful and valuable research. Given that this study helps policymakers shape the innovation process through policy guidance and provide a theoretical basis for formulating regional innovation development strategies, we can predict that research in the IUR collaborative innovation mechanism would increase geometrically over time. Consequently, we anticipate that it would promote China’s innovation progress, as well as concomitantly enhance the innovation ability of universities, enterprises, and research institutes. Above and beyond, it will help to improve the efficiency of collaborative R&D existing between enterprises and universities, and scientific research institutes, as well as assist enterprise managers to garner innovation advantages and resources more effectively, to realize the compelling connection between scientific research and industry.

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