IEEE Access
Multidisciplinary | Rapid Review | Open Access Journal

Received 20 February 2024, accepted 26 February 2024, date of publication 27 February 2024, date of current version 5 March 2024.

Digital Object Identifier 10.1109/ACCESS.2024.3371258

RESEARCH ARTICLE

Looking Back to Move Forward: Bibliometric and Visual Analysis of Knowledge Transfer in University-Industry Collaboration

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This work was supported in part by Shanghai Philosophy and Social Science Planning Project Fund under Grant 2020BGL029.

ABSTRACT Knowledge transfer in university-industry collaboration (KTUIC) has been a hot issue of concern in recent years. Based on 874 articles published in the core collection of Web of Science, this paper conducts an in-depth bibliometric and visual analysis in terms of literature distribution, cooperation network, co-citation, knowledge base, and research hotspots analysis. The results show that the number of annual publications has shown an approximate exponential growth in the past decades. The UK is the most critical node in cross-border cooperation. Alessandro Muscio, with 11 publications, and Henry Etzkowitz, with 793 citations, are the most prolific and cited authors respectively. Research Policy has the highest frequency of citations. The knowledge base of KTUIC includes UIC and knowledge transfer, basic theories of U-I relationships, university TTOs, Bayh-Dole Act and university patenting, and individuals in university technology transfer. Research hotspots mainly focus on the related issues of third mission and entrepreneurial universities. Additionally, we also propose the future research agenda of KTUIC from the perspective of five knowledge bases. These findings contribute to a deeper understanding of the development status and core issues in KTUIC, and offer valuable guidance for future research directions.

INDEX TERMS Knowledge transfer in university-industry collaboration (KTUIC), knowledge transfer, university-industry collaboration, bibliometric analysis, visual analysis.

I. INTRODUCTION

It is an indisputable fact that the creation, transfer, and application of knowledge can drive innovation and economic growth [1], [2]. Universities with scientific research missions have always been an important source of new knowledge. Take China as an example, in 2020, the number of authorized invention patents in Chinese universities has reached 116,633 [3]. Exploring how to fully utilize this new knowledge to enhance the development of universities, thereby increasing their social and economic impact, has become a focal point in relevant fields.

In recent decades, an increasing number of scholars agree that in addition to teaching and scientific research, universities are also responsible for the third mission, which is to apply new knowledge and new technology to industry and give full play to their commercial value to benefit society [4]. The interaction and knowledge collaboration between universities and industries has been widely recognized as a core mechanism in the innovation system, and many theories and models regard it as the core component of innovation development [5], [6].

In this context, governments and universities worldwide have implemented measures to bolster university-industry collaboration (UIC), such as establishing university technology transfer offices (TTOs), and providing rewards and funding. These initiatives aim to accelerate knowledge transfer (KT) between universities and industries, thereby fostering industry innovation and stimulating rapid economic development [7], [8]. These measures have greatly accelerated the KT

The associate editor coordinating the review of this manuscript and approving it for publication was Jolanta Mizera-Pietraszko.

activities of universities and industries and set off a research boom in the field of knowledge transfer in university-industry collaboration (KTUIC) [9], [10], [11]. Based on the definition by Bloedon [12], this article defines KTUIC as the process by which knowledge concerning the making or doing of useful things generated by one party of the university or industry is brought into use in the other party through collaboration.

As the field of KTUIC has received increasing attention from scholars, with a corresponding surge in related research outcomes, some scholars tried to summarize the research progress and explore the development context of this field from the perspective of review. Based on the sociopolitical perspective and the contextual perspective, Vick and Robertson [13] summarized four core contents of KT research in universities and industries in the UK, namely motivations; activities; barriers; and outcomes. By systematically reviewing existing literature, Wit-de Vries et al. [1] refined the main obstacles and facilitating factors of KT in university-industry (U-I) research partnerships. He believed that differences in knowledge and goals, arising from diverse institutional cultures, are significant barriers to KT. Additionally, he considered trust, communication, intermediary organizations, and experience as key factors that facilitate the transfer of U-I knowledge and help overcome these identified obstacles. Perkmann et al. [14] reviewed the literature involving two important patterns of KTUIC published before 2011: academic engagement and commercialization. He compared the antecedents and consequences of the two and concluded that there are obvious differences between them: compared with commercialization, academic engagement is more closely related to traditional academic research activities. Later, he launched a follow-up study and analyzed the literature on academic engagement after 2011, and believed that academic engagement is positively correlated with scientific productivity in academia [15].

Numerous review studies have comprehensively condensed and summarized the KTUIC literature from multiple perspectives. Their conclusions offer valuable references and directional guidance for understanding the research progress in modes, channels, obstacles, and facilitating factors of KTUIC. However, there is still a noticeable gap in the field: a lack of systematic and comprehensive bibliometric analysis. Most of these review studies on KTUIC are conducted through manual reading, involving the understanding and descriptive summarization of selected literature content. The degree to which these conclusions reflect actual research progress in the field is subject to debate. Furthermore, traditional literature reviews also have limitations in revealing cooperative relationships and identifying hot topics. However, studies have confirmed the importance of exploring the current research status and predicting future research directions in the field from a quantitative perspective [7], [16]. Hence, this paper poses the following research questions:

(1) What is the trend in research popularity in KTUIC?

(2) What are the characteristics of the cooperation networks in KTUIC?

(3) What are the high-impact journals, authors, and the knowledge bases in KTUIC?

(4) What are the research hotspots and future research agendas in KTUIC?

Compared with general literature reviews, bibliometric research focuses on quantitative data and can efficiently analyze large volumes of literature data. This approach minimizes the influence of subjective judgment, thereby enhancing the objectivity of the research. It extracts and analyzes the information units of the literature, such as publication year, author, journal, institution, and keywords, which will be helpful for scholars to understand the quantitative characteristics, cooperation networks, and hot topics of KTUIC field, and provide a reference for subsequent researchers to promote the continuous development of the field [16], [17].

With the rise of analytics software based on citation and knowledge graph visualization technology, such as VOSviewer, Bibexcel, and BICOMB, bibliometrics is usually combined with knowledge mapping analysis technology to obtain the structural characteristics of the literature, identify the frontiers and hotspots of research fields and predict the development trends of disciplines or research fields [16], [18], [19]. Consequently, to address the research questions, we conduct a systematic review of the literature in KTUIC from the perspective of bibliometric analysis and visual analysis, and a total of 874 academic articles ranging from 1996 to 2021 are analyzed from the database of Web of Science (WOS).

This article mainly analyzes the literature in KTUIC from the following four aspects: (1) Calculate the trend of changes in the number of articles issued in the year to grasp the development and changes in popularity; (2) Identify the most productive authors, institutions, countries and their cooperation relationships; (3) Analyze the authoritative journals, authors and knowledge base in the field; (4) Explore the research hotspots and future research agenda. The methodological contribution of this paper lies in the use of bibliometric and visualization analysis to provide a novel research perspective in reviewing the literature in KTUIC. Furthermore, this study reveals the knowledge base and research hotspots in KTUIC and proposes potential future research agendas. The findings are significant in understanding the research dynamics within KTUIC and enhancing its theoretical framework.

The remaining part of this paper is structured as follows: In section II, the research methodology and data processing of this study are introduced. In section III, publication trend analysis, cooperation network analysis, co-citation analysis, knowledge base and structure analysis, and research hotspots and future research agenda analysis are carried out. Specifically, cooperation network analysis includes the perspectives of countries, institutions, and authors, and

co-citation analysis includes journal co-citation, author co-citation. Finally, we conclude the findings and discuss the contributions and limitations of the research.

II. METHODOLOGY AND DATA

A. RESEARCH METHODS

Bibliometric analysis is a popular technology text mining method and a research field focusing on the quantitative study of science and technology, which can quantitatively analyze the basic information contained in an academic paper (e.g., author, title, journal, publication year), and explore the potential knowledge structure of the literature published in a specific field [20]. In bibliometric research, software such as VOSviewer, and Bibexcel are often used to identify and display the basic characteristics and trends in scientific development of the literature, helping researchers to explore the research progress, research hotspots, and corresponding knowledge bases of the field in a clear, intuitive and profound way [21]. This article comprehensively uses bibliometric and knowledge mapping visualization analysis methods to describe and analyze the selected literature information in the field of KTUIC. Specifically, first of all, we use VOSviewer to analyze the number of publications and the distribution of published journals, countries and institutions, and core author groups in KTUIC. Secondly, by using Bibexcel software, we construct a co-occurrence matrix of high-cited documents. Then, we use SPSS software to conduct factor analysis and multi-dimensional scaling analysis on co-cited documents to sort out the knowledge base and structure in this field. Finally, we map KTUIC's strategic coordinates using keyword co-occurrence and cluster analysis, while combining literature content analysis to discuss the research hotspots and future research agenda in KTUIC.

B. DATA

1) DATA SOURCES

To accurately grasp the research trends in KTUIC, it's crucial to analyze the literature that has undergone rigorous peer review. In comparison with other databases, the WOS core collection database is widely regarded as one of the highest quality academic resources. It includes a multitude of peer-reviewed, high-impact journal articles. Analyses based on this database are more representative and persuasive in reflecting the progress of research in the field. Additionally, the standardized citation information it contains is vital for enhancing the quality and reliability of bibliometric studies. Hence, the data source in this study is selected as " WOS core collection database", the document type is set to "article", and the language of publication is limited to English.

In bibliometric analysis, differences in the coverage of literature databases subscribed by researchers' institutions may lead to variations in the extent to which different studies reflect the actual development of the field. In this study, we examined the subscription scope of literature databases available to our institution. Firstly, we confirmed that our institution subscribes to all sub-database categories under the WOS core collection. Additionally, we compared the publication years of the earliest literature in our search results with those of similar review studies to ensure the representativeness of the time range covered by our study's search results.

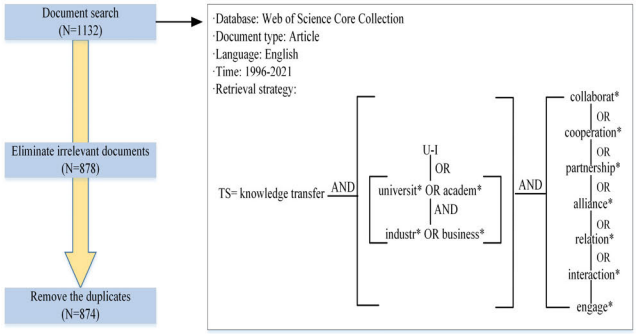

FIGURE 1. Retrieval process of the study.

In terms of retrieval strategy, some literature review studies in the KTUIC field have provided detailed introductions [1], [7], [15]. To ensure comprehensive coverage of KTUIC literature, we referred to the search terms mentioned in these studies and, in line with the actual needs of our research, enriched the search terms that are synonymous with the themes in KTUIC. Specifically, we used Boolean search strings and set it to TS=(U I OR (universit* OR academ*) AND (industr* OR business)) AND TS= (collaborat* OR cooperation* OR partnership* OR engage* OR alliance* OR relation* OR interaction*) AND TS= (knowledge transfer). The transfer of university knowledge and technology has become an increasingly important issue since the implementation of the Bayh-Dole Act since 1980s [22]. To ensure the comprehensiveness of the research, the start date of the published literature is not limited, and the deadline is set to December 31, 2021. In the existing similar studies, Perkmann et al. [14] found that research on industry-university collaboration was primarily published after 2006, while Wit-de Vries et al. [1] only retrieved literature in KTUIC after 2002. Based on the scope of literature indexed in the WOS core collection database subscribed by our institution, we conducted a literature search in the field of KTUIC, and the earliest publication date in the resulting dataset was 1996. By comparing with existing relevant studies, it can be observed that although selecting literature published from 1996 cannot cover all KTUIC studies, it can still reflect the actual development of the field well. Therefore, the period for publications in this study was set as "1996-2021". Under these conditions, in total, we found 1132 related papers. After removing duplicates and eliminating irrelevant documents by reading the title and abstract of each article, the information of 874 unique documents was finally obtained. Figure 1 shows the data retrieval process and the detailed steps to obtain the final database.

2) DATA PROCESSING

In bibliometric research, author name disambiguation is a crucial step to ensure the accuracy of data and the reliability of analytical results. In this study, we first manually checked the information like ORCID and email address of each author in the dataset, especially key authors, to address the issue of different authors having identical names. Secondly, to avoid misidentifying the same author as different individuals due to affiliations with various institutions, we verified the identities of authors by visiting Google Scholar, LinkedIn, or institutional or personal home pages. Finally, we imported the cleaned dataset into VOSviewer software and individually compared and checked the information in the author name statistics preview box to ensure that the same author does not use different name expressions in various publications.

Compared to other bibliometric software, such as CiteSpace, VOSviewer not only supports multiple types of network analysis (including co-citation, co-occurrence, and co-authorship) but also generates clear and intuitive visualizations. Therefore, it is widely used in bibliometric research [17]. In this study, we use VOSviewer to perform bibliometric and visual analysis of the basic characteristics of literature in KTUIC. We select the author, institution, country, reference, journal, and keyword for the node type. The visual knowledge mapping generated by VOSviewer is composed of nodes and links. The size of a node represents the frequency of entries such as authors and keywords. The higher the frequency, the larger the node. The link of the nodes indicates the frequency of co-occurrence or co-citation, and the thicker the link, the closer the relationship between nodes.

III. RESULTS AND DISCUSSION

A. PUBLICATION TREND ANALYSIS

To a certain extent, the publication trends in a specific subject or field can, to a significant extent, reflect the level of research and the degree of enthusiasm within that field. These trends serve as a vital indicator for assessing the field's maturity. Figure 2 illustrates the distribution and trend of the selected 874 articles published from 1996 to 2021. In this figure, the blue line represents the actual number of articles published each year, and the black curve is a rough depiction of the overall publishing trend. As can be seen, the number of publications between 1996 and 2006 was at a low level, indicating that researches on KTUIC have not risen yet in that decade [14]. Since 2007, the annual number of publications has increased significantly. As is shown by the black curve, in general, the studies on KTUIC have shown an exponential growth trend in the past few decades. This indicates that research in KTUIC is advancing towards a higher level of maturity. Based on the publication trends reflected in the figure, it is foreseeable that in the coming years, the field of KTUIC will likely continue to garner significant attention, with the number of publications potentially experiencing a rapid growth.

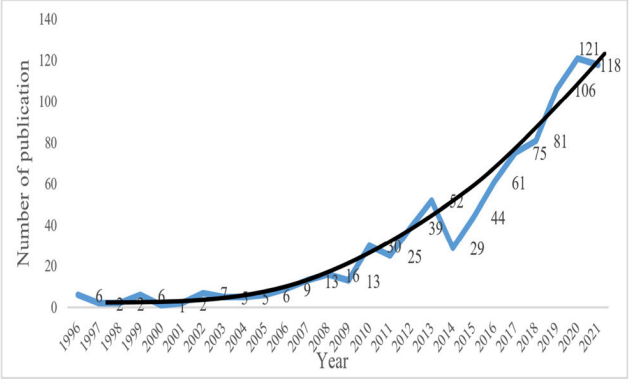

FIGURE 2. Publications distribution by year.

B. COOPERATION NETWORK ANALYSIS OF KTUIC

In this section, the country cooperation network, institution cooperation network, and author cooperation network of the selected articles in KTUIC are elaborated to clarify the leading countries, prolific institutions, and productive authors.

1) COUNTRY COOPERATION NETWORK

First, in VOSviewer, we specify the type of analysis as "Co-authorship" and the type of node as "Country". The resulting country cooperation network is shown in Figure 3. In the network, the size of each node represents the frequency of a country's collaborations within the network. The thickness of the edges indicates the strength of connections between two nodes. Thicker edges denote more frequent or closer collaborative relationships between the countries. The color of the nodes and edges respectively represent the average publication year of the literature associated with each country and the collaborations between two countries.

As shown in the figure, there are 106 nodes and 347 edges in the country collaboration network and the UK occupies a core position. After collating and summarizing the literature data, the ranking of the top 10 countries by the number of publications is obtained (as shown in Table 6 of Appendix A). Combining the contents of Figure 3 and Table 6, it can be seen that the UK not only leads in the volume of literature production but also engages in extensive collaboration with many countries, thereby holding a dominant position in the field of KTUIC. The thickness of the links indicates that the UK's collaboration with Italy and Spain is particularly close. Additionally, the color of the nodes reveals that among the top ten prolific countries, the United States has the earliest average publication year (2012), while China has the latest (2018). This reflects the fact that research in KTUIC began earlier and is more mature in the United States. In contrast, China, despite its later start, has shown rapid development in this field. However, unlike other prolific countries, China has fewer connections with other countries, indicating that despite its recent active participation in KTUIC research, its collaborative network remains relatively closed and limited.

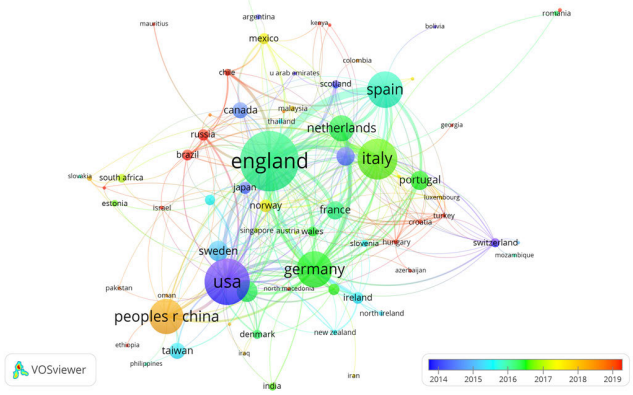

FIGURE 3. Country cooperation network.

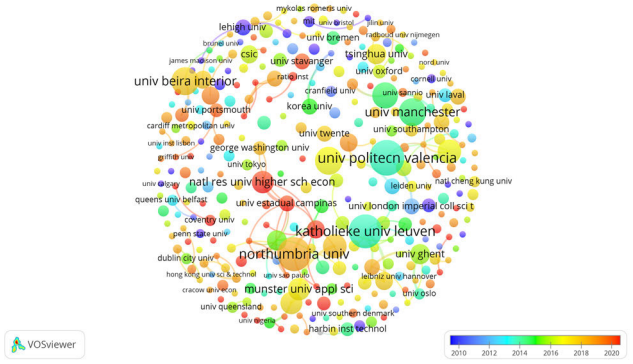

FIGURE 4. Institution cooperation network.

2) INSTITUTION COOPERATION NETWORK

The institution cooperation network can reflect the highly productive institutions and assess the breadth and depth of cooperation between different institutions in KTUIC.

Analyzing this network enables future researchers to understand the focus and expertise of each institution in the field. Additionally, it aids in exploring opportunities for cross-institutional collaboration. In this section, we set the node type to ''Organization'', and the institution cooperation network is obtained after running the software, as is shown in Figure 4. The figure shows that the network has 411 nodes, but only 299 edges and the network density is only 0.0035, which shows that the cooperation between institutions is not close and frequent.

Similarly, we summarized information on the top 10 most productive institutions (As shown in Table 7 of Appendix A). Combining the contents of Figure 4 and Table 7, we observe that the two most prolific institutions in the network, Polytechnic University of Valencia and Catholic University of Leuven, have an early average publication year (2013). This indicates that these institutions were highly active in KTUIC research in the past, but their output in recent years has diminished. Additionally, among the top 10 most productive institutions, the National Research University Higher School of Economics stands out with the latest average publication year (2019), signifying its recent emergence as a significant force in KTUIC research. Through further analysis, we find that, among these productive institutions, 9 of which are located in Europe and have obvious geographical distribution characteristics, indicating that European countries, especially the UK and Spain, are at the forefront of research in KTUIC.

3) AUTHOR COOPERATION NETWORK

Author cooperation network effectively reflects active contributors within a field and reveals the structure of academic communities. Identifying the principal contributors to existing research and their focal research areas can guide the direction of future studies. In this section, we set the node type to ''Author'' and the threshold for the number of published articles to 2 or more to generate a cooperation network diagram of authors in the field of KTUIC, and the visualization results are shown in Figure 5. The figure indicates that the author cooperation network has a total of 516 nodes and 321 connections, and the network density is 0.0024.

Alessandro Muscio, who is from the Faculty of Agriculture, Food and Environmental Sciences of the University of Foggia, is the largest node, which means he is the most prolific author in the network. By analyzing his node details, we found that all his 11 articles have been published in the past 10 years. Among them, he has cooperated with Vallanti and Davide, who are from Luiss Guido Carli University and University of G. d' Annunzio Chieti and Pescara for 4 times and 5 times respectively, which is the most closely connected network in the field. Additionally, from the color of the nodes, it is evident that the second most prolific author in the network, Maribel Guerrero, has an average publication year of 2019 for her articles. This indicates that she has been highly active in the KTUIC field in recent years. Further analysis of her publications reveals that her research interests encompass entrepreneurship and technology transfer. Currently, she is an associate professor at the School of Public Affairs and Global Center for Technology Transfer at Arizona State University, USA. Prior to this, she held positions at Lund University in Sweden, Universidad del Desarrollo in Chile, and Northumbria University in UK. Through further analysis, it can be found that most of the other authors are not connected, the positions between each other are scattered, and the cooperation between them is not close or continuous. This may impede the further development of related theories, methods, and practices in KTUIC.

C. CO-CITATION ANALYSIS OF KTUIC

Co-citation analysis generally includes journal co-citation analysis, author co-citation analysis, and document co-citation analysis. The node size in the co-citation network reflects the citation frequency of the journal, author, or document, while the edge thickness represents the co-citation frequency between two nodes. The varying colors of the nodes and edges signify their belonging to different clusters.

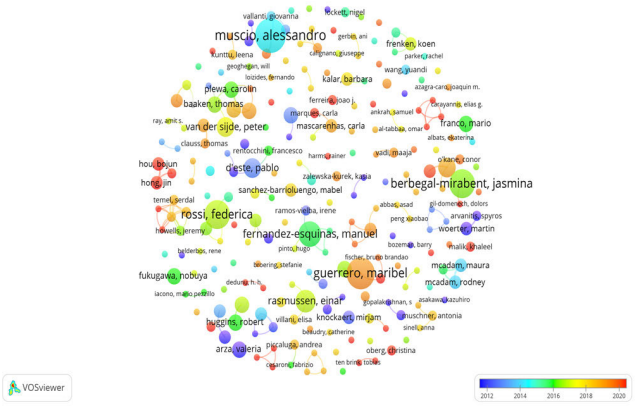

FIGURE 5. Author cooperation network.

1) JOURNAL CO-CITATION ANALYSIS

Journals are the carriers of papers. Authoritative journals will attract more rigorous and innovative papers. The co-citation analysis of journals can not only reveal the cross-relationships between related journals in the discipline but also reveal the status of journals and infer authoritative journals in this field [23].

Given the extensive size of the journal co-citation network, we established a minimum citation threshold of 50 for the journals. Consequently, we derived a journal co-citation network comprising 120 nodes and 6957 edges, as depicted in Figure 6. It is observable that Research Policy, Journal of Technology Transfer, and Technovation, which are all in Quartile 1 (Q1) of the management discipline in the Journal Citation Reports (JCR) division, are the three largest nodes. This means that they are cited the most frequently and have an important influence in the field. The thickness and color of the links indicate that ''Research Policy'' and ''Journal of Technology Transfer'' have the highest number of co-citations, and they belong to the same cluster. This suggests that these two journals exhibit a strong knowledge connectivity and make significant academic contributions in KTUIC. The top 10 highly cited journals are also listed (As shown in Table 8 of Appendix B). It shows that most of these journals have highimpact factors and are important international journals, and all of these journals belong to management and business disciplines.

2) AUTHOR CO-CITATION ANALYSIS

The author co-citation analysis can reveal influential researchers in a certain discipline field. By tracking related documents, we can understand the research progress and hotspots in this field. In this section, we set the minimum number of citations of an author at 50, resulting in an author co-citation network comprising 124 nodes and 7525 edges, as illustrated in Figure 7. The color of the nodes in the figure reflects that the author co-citation network in KTUIC is mainly divided into four clusters.

The top 10 highly cited authors are also listed (As shown in Table 9 of Appendix B). Combining the contents of Figure 7 and Table 9, we can see that, Henry Etzkowitz, the proponent of the triple helix innovation model of university-industry-government, is cited 793 times and is the most highly cited author. Additionally, Markus Perkmann, with 589 citations, is ranked as the second most cited author. The figure reveals that these two authors belong to different clusters. Henry Etzkowitz primarily focuses on entrepreneurial universities and the Triple Helix model and currently serves as the CEO of the International Triple Helix Institute. Meanwhile,

Markus Perkmann's research focuses on employee entrepreneurship and scientific entrepreneurship, and he is currently affiliated with Imperial College London. Furthermore, it can be found that among the top 10 highly cited authors, scholars from the United States occupy seven of them, reflecting the high authority of American scholars in KTUIC research.

D. KNOWLEDGE BASE AND STRUCTURE ANALYSIS

If two or more documents are cited by one or more later documents at the same time, the former is said to constitute a co-citation relationship. The more co-cited times, the more important these two documents are in the field. The co-citation analysis of scientific research documents can clearly analyze the knowledge base and research structure. When a few papers are cited many times by scholars of the subject, the importance of these articles in the subject can be judged, and the theories put forward in these articles can serve as the cornerstone of the field.

To show the knowledge base and structure of KTUIC field, we first described the basic characteristics of highly cited documents. Second, we screened 40 core documents with more than 60 citations among all citations of 874 source documents. Then, Bibexcel software was used to construct a co-cited literature correlation matrix, and Excel was use to convert it into a dissimilarity matrix. Finally, we used SPSS software for factor analysis and multi-dimensional scaling analysis to draw the subject knowledge base map in KTUIC.

1) BASIC CHARACTERISTICS OF HIGHLY CITED REFERENCE

Table 1 listed the specific information of the top 10 highly cited references. As can be seen from the table, the study by Perkmann et al. [14], which is published in Research Policy and has been cited 87 times in total, is the most cited document. This article provided a systematic review of the research on academic engagement, compared the antecedents and consequences of academic engagement and commercialization, and summarized their similarities and differences. Similar to this article, the second most cited article, is also a review article. In this article, the author summarized five key aspects of U-I knowledge cooperation, and integrated these aspects into an overall process framework [24]. The research by D'Este and Perkmann [25], which explores the reasons for the interaction between academics and industry from the perspective of entrepreneurial universities and individual motivation, is ranked third with 30 citations.

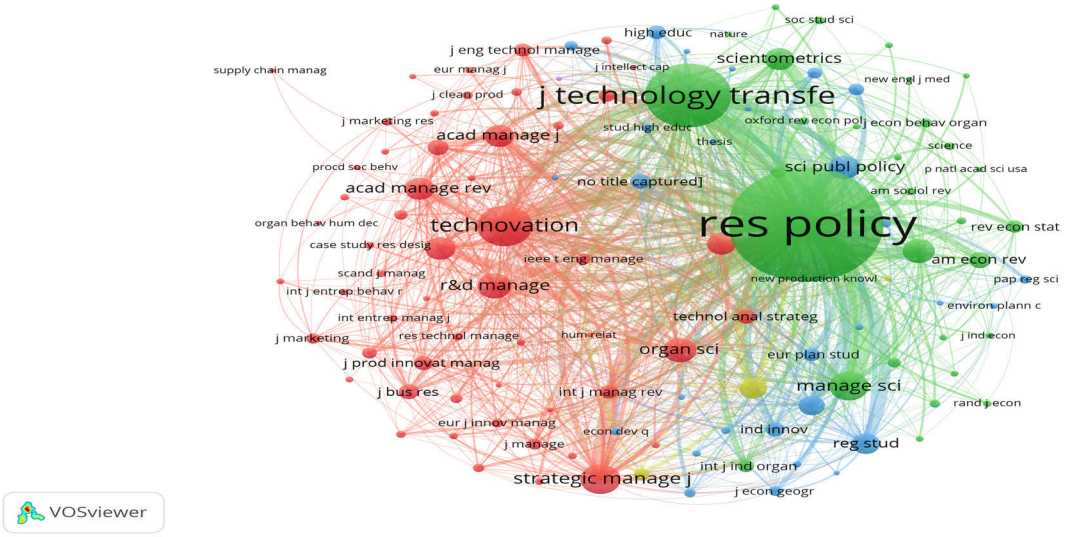

FIGURE 6. Journal co-citation network.

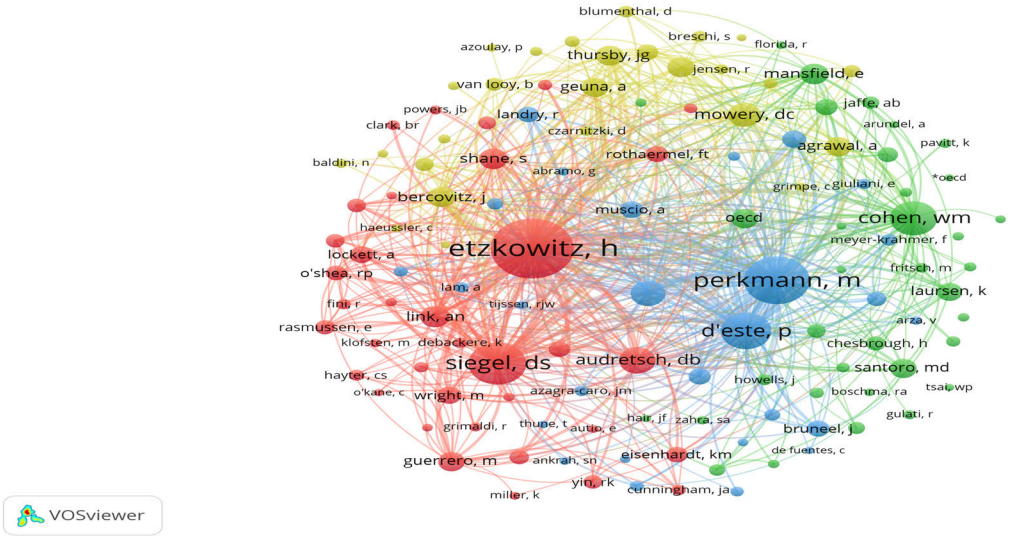

FIGURE 7. Author co-citation network.

From reviewing and categorizing the highly-cited documents listed in Table 1, it can be concluded that, in addition to the reviews on university-industry collaboration [1], [14], [24], these highly cited documents are mainly concentrated in the research areas of entrepreneurial universities [25], [26], [27], and the motivation, factors, and performance indicators of U-I collaboration [28], [29], [30].

2) FACTOR ANALYSIS

In statistics, it is essential to comprehensively consider and fully analyze various influential factors. These factors can be represented as high-dimensional vectors that reflect specific information to different degrees. When two space vectors exhibit a certain level of correlation, it is reasonable to assume that they contain overlapping information. To address this, principal component analysis (PCA) is a mathematical method that utilizes orthogonal transformation to convert high-dimensional, correlated vectors into a group of linear, uncorrelated, low-dimensional vectors [31], [32]. These low-dimensional vectors can reflect the principal research topics in the field, that is, the knowledge structure in KTUIC field. Therefore, in this section, PCA is used to perform factor analysis on the correlation matrix of highly cited documents, and 10 principal component factors with eigenvalues greater than 1 are extracted, as shown in Table 2. It can be seen from the table that 10 factors can explain 81.68% of the

TABLE 1. Top 10 highly cited references.

Ranking	Citation	Author	Year	Cited Reference	Journal
1	87	Perkmann M	2013	Academic engagement and commercialization: A review of the literature on university-industry relations	RES POLICY
2	40	Ankrah S	2015	Universities–industry collaboration: A systematic review	SCAND J MANAG
3	30	D'Este P	2011	Why do academics engage with industry? The entrepreneurial university and individual motivations	J TECHNOL TRANSFER
4	26	OKane C	2015	University technology transfer offices: The search for identity to build legitimacy	RES POLICY
5	26	D'Este P	2007	University-industry linkages in the UK: What are the factors underlying the variety of interactions with industry?	RES POLICY
6	26	Ankrah S	2013	Asking both university and industry actors about their engagement in knowledge transfer: What single-group studies of motives omit	TECHNOVATION
7	25	Guerrero M	2015	Economic impact of entrepreneurial universities' activities: An exploratory study of the United Kingdom	RES POLICY
8	25	de Wit-de Vries E	2019	Knowledge transfer in university–industry research partnerships: a review	J TECHNOL TRANSFER
9	23	Siegel DS	2015	Academic Entrepreneurship: Time for a Rethink?	BRIT J MANAGE
10	21	Villani E	2017	How intermediary organizations facilitate university–industry technology transfer: A proximity approach	TECHNOL FORECAST SOC

total information, of which the variance explained by the first factor is 18.9%, indicating that the information explained by this factor is the core of KTUIC research.

The combination of factor analysis and content analysis can improve the rationality and scientificity of the classification [32]. Therefore, based on the results of factor analysis, this paper systematically reviewed the specific content of the literature under each component, performed thematic classification based on the results of content coding, and thus summarized the knowledge structure of the highly co-cited literature, as shown in Table 3.

3) MULTIDIMENSIONAL SCALING ANALYSIS

PCA can help reduce the dimensionality of data and identify major variables and patterns, while multidimensional scaling (MDS) analysis can present similarities between observational units in a more intuitive space [33]. These two methods are often used in combination to provide more comprehensive interpretation and visualization of the knowledge network structure in a field [34]. Therefore, in this section, the dissimilarity matrix of highly cited documents is imported into SPSS, and the Euclidean distance is selected in the MDS analysis method to obtain the knowledge base map. The results are shown in Figure 8.

To ensure the scientificity of the classification, we summarize the contents of the documents under each cluster in the map one by one. By comparing the results of MDS and PCA, we found that the different clusters formed in MDS analysis and some principal components in the results of PCA overlap to a certain extent. This shows that some knowledge groups have been formed during the research process in the field of KTUIC. A knowledge group refers to a collection of literature gathered around a specific topic or concept. These groups represent major topics in academic research. Based on the principle that the closer the distance, the higher the similarity, and referring to the naming results of each component in Table 3, we divide KTUIC research into the following five knowledge groups: ① UIC and knowledge transfer, ② Basic theories of U-I relationships, ③ University TTOs, ④ Bayh-Dole Act and university patenting, ⑤ Individuals in university technology transfer.

Knowledge group ①: UIC and knowledge transfer

Representative scholars of knowledge group ① include Perkmann, Ankrah, D'Este, etc. It mainly covers related issues involved in UIC, such as forms, channels, obstacles, factors, etc. There are also review papers that summarize the organizational forms, motivations, factors, outcomes, and operating mechanisms of UIC, and integrate these key aspects into an overall process framework [24]. Additionally, some literature also studied the knowledge interaction and transfer in UIC. For example, as the earliest study in this knowledge group, Meyer and Schmoch [35] found that the two-way knowledge exchange between universities and industry is a key element of the interaction by studying the patent application information of German universities. Following this, Agrawal and Henderson [36] explored the degree to which patents are representative of the magnitude, direction, and impact of the knowledge spilling out of the university by focusing on MIT. Schartinger et al. [37] further explored the role of nine knowledge interaction mechanisms between industry and academia in the Austrian national innovation system. Knowledge group ① analyzed the core issues of UIC and laid the foundation for further in-depth research in the field of KTUIC.

TABLE 2. Principal component analysis results.

Component	Initial Eigenvalues			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	9.47	23.67	23.67	7.56	18.90	18.90
2	5.56	13.92	37.59	4.12	10.34	29.24
3	3.46	8.60	46.19	4.13	10.30	39.54
4	2.61	6.51	52.70	3.16	7.91	47.44
5	2.25	5.63	58.33	2.60	6.49	53.93
6	2.16	5.39	63.72	2.32	5.86	59.79
7	2.04	5.05	68.76	2.31	5.83	65.62
8	1.82	4.53	73.29	2.29	5.73	71.35
9	1.73	4.34	77.62	2.09	5.22	76.57
10	1.62	4.05	81.68	2.04	5.11	81.68

Knowledge group ② Basic theories of U-I relationships

Representative scholars of this knowledge group include Etzkowitz, Cohen, etc. It mainly covers the basic theories and methods involved in the study of U-I relations. Among them, Eisenhardt [38] described the process of inducting theory using case studies, and this research approach has been widely applied to the study of U-I relationships [30], [39]. Cohen and Levinthal [40] discussed the relationship between a firm's knowledge absorptive capacity and innovation performance, emphasizing that R&D investment contributes to a firm's absorptive capacity, which makes absorptive capacity an important consideration for subsequent scholars to explore the knowledge transfer performance of UIC from the perspective of firms [41], [42]. The triple helix model established by Etzkowitz and Leydesdorff [43] to study the relationship between universities, industry and government has played a crucial role in the theoretical development of UIC and regional innovation. This knowledge group constitutes an important knowledge base and theoretical basis for KTUIC research.

Knowledge group ③ University TTOs

TTOs are primarily responsible for the protection of university created intellectual property (IP) and the management of the commercialization process [44], [45].

Since the 1990s, when TTOs began to emerge in American universities, related research quickly became a focus of scholarly attention. Some argue that TTOs are instrumental in generating more academic patents [46], and has brought about critical elements in fostering an effective commercialization of the academic science base [47]. Some other scholars believe that the absolute efficiency of TTOs is low, which is not conducive to university technology transfer and commercialization [48], [49]. With the deepening of research, it has become the consensus of more and more scholars that whether academic knowledge can be successfully commercialized depends on the characteristics and capabilities of TTOs [50], [51], [52]. On the basis of this knowledge group, subsequent scholars have carried out further research on the role, performance, influencing factors, development barriers and policies of university TTOs.

Knowledge group ④ Bayh-Dole Act and university patenting.

This knowledge group focuses on universities' patenting behavior before and after the Bayh-Dole Act, assessing the legislation's impact on university patenting and licensing activities. These studies often employed quantitative methods to analyze patent data and other indicators of university innovation and commercialization. Some scholars argue that the implementation of the Bayh-Dole Act, on the one hand, facilitated the patenting of research outcomes by universities, promoted the transfer of technology from universities to industry, and made universities more commercially productive than in the past [53]. On the other hand, it delayed the publication of research outcomes, thereby hindering the dissemination of scientific knowledge [54]. In fact, the debate on the act has never stopped in the academic circles. Proponents of Bayh-Dole argue that university licensing accelerates the timing of commercialization and that, with the rapid growth in university TTOs and patenting, businesses have better information on university inventions. The opposing view is that much of the increase in patenting involves low-quality patents and that exclusive licensing is not required for commercialization of high-quality patents [55]. Nonetheless, there is empirical support for the view that Bayh-Dole has increased industrial application of university inventions [56].

Knowledge group ⑤ Individuals in university technology transfer

This knowledge group mainly studies the participation of faculty members in university technology transfer activities at the micro-individual level. Gulbrandsen and Smeby [57] found a significant relationship between university professors' industry funding and their research performance, with no clear positive or negative correlation between academic publishing and entrepreneurial outputs. On this basis,

TABLE 3. Knowledge structure of KTUIC identified by principal component analysis.

Component	Highly cited references	Factor loadings	Research topics	Component	Highly cited references	Factor loadings	Research topics
1.UIC and knowledge transfer	D'Este P, 2007	.832	The channels and factors of U-I linkages in the UK	4.UIC and related theories	Gulbrandsen M, 2005	.508	Industry funding and university professors' research performance
	Cohen WM, 2002	.820	The influence of public research on industrial R&D		Rothaermel FT, 2007	.474	Literature taxonomy of university entrepreneurship
	Bekkers R, 2008	.784	The channels in KTUIC		Cohen WM, 1990	-.471	Absorptive capacity and innovative performance
	Meyer-Krahmer F, 1998	.759	The forms of U-I interaction		Ankrah S, 2015	.751	Systematic review of UIC
	Schartinger D, 2002	.697	Knowledge interactions in U-I		Bruneel J, 2010	.638	The obstacles to UIC
	Lee Y. S., 2000	.596	The sustainability of UIC		Perkmann M, 2013	.613	Antecedents and consequences of academic engagement and commercialisation
	Perkmann M, 2007	.585	U-I relationships and open innovation		Eisenhardt KM, 1989	.467	Building theories from case study research
	D'Este P, 2011	.574	The entrepreneurial university and individual motivations	5.Characteristics and promotional policies of U-I interaction	Dasgupta P, 1994	-.775	The impact of policies for promoting industry-academia knowledge transfer
	Agrawal A, 2002	.559	Representation of patents on MIT knowledge transfer		Santoro MD, 2002	.491	Firm size and technology centrality in U-I interactions
2.University TTOs and intellectual property	Siegel D S, 2003	.777	The relative productivity of university TTOs	6.Academic entrepreneurship and commercial-ization	Siegel D S, 2004	.719	U-I technology transfer and commercialization
	Di Gregorio D, 2003	.697	Universities' intellectual property and their start-ups		Siegel D S., 2003	.527	Rethink of academic entrepreneurship
	Thursby JG, 2002	.671	Productive efficiency of university intellectual property licensing		Mansfield E, 1995	-.380	Academic research underlying industrial innovations
	O'Shea RP, 2005	.638	University spinoff outcome	7.University technology transfer strategy	Siegel DS, 2007	.753	TTOs and commercialization of university intellectual property
	Chapple W, 2005	.584	The relative performance of U.K. university TTOs		Wright M, 2008	.575	Mid-range universities' linkages with industry
	Debackere K, 2005	.491	Academic TTOs in improving industry-science links	8.University technology transfer	Bozeman B, 2000	.738	A review of technology transfer and public policy
	Jensen R, 2001	.471	Bayh-Dole Act and the licensing of university inventions		Link AN, 2007	.598	Faculty members' informal technology transfer
3.Effect and performance in academic entrepreneurship	Bercovitz J, 2008	.742	Faculty members in university technology transfer	9.The triple helix	Bercovitz J., 2006	.770	The role of universities in innovation systems
	Fontana R, 2006	-.649	Factors affecting university–SMEs R&D projects		Etzkowitz H, 2000	.475	Triple helix
	Laursen K, 2004	-.601	Firms' innovative activities and U-I links		Etzkowitz H, 2000	.351	Triple helix and entrepreneurial paradigm
	Shane S, 2004	.564	The effect of the Bayh-Dole Act on university patenting	10.University knowledge transfer governance	Geuna A, 2009	.802	University knowledge transfer governance

scholars have carried out further research on the knowledge/technology transfer behaviors of doctoral students [58], professors [59], star scientists [60], TTO staff [61] and other individuals in UIC, which has further expanded the scope of research. Furthermore, some studies also discussed ways in which faculty members can participate in university technology transfer activities and incentives for faculty members to participate in these activities [25], [28].

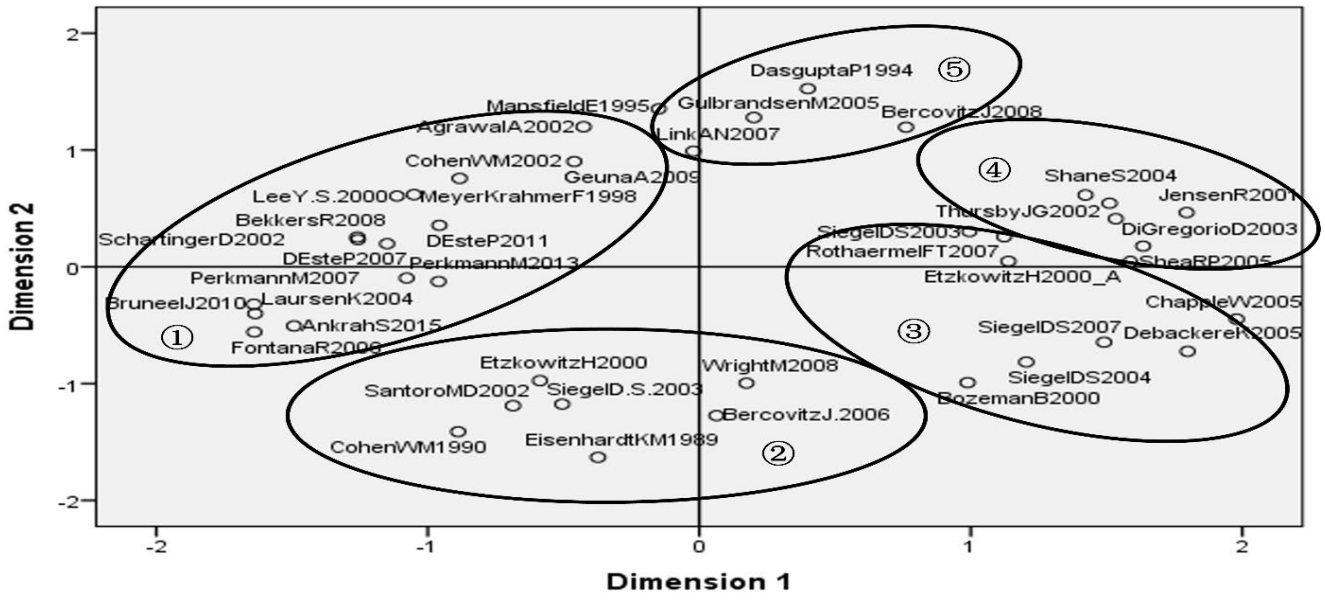

FIGURE 8. MDS analysis result.

E. RESEARCH HOTSPOTS ANALYSIS

To present the research hotspots in KTUIC, this study selects the keyword analysis method. First, a KTUIC keyword co-occurrence network is constructed using VOSviewer software to visualize the key paths of research topics in this field. Secondly, with the help of SPSS, cluster analysis is carried out on the keywords of the research literature, and the internal structure of hot topics is further clarified. Finally, the strategic coordinate analysis is employed to effectively reveal the strategic position of each research hotspot.

1) KEYWORD CO-OCCURRENCE ANALYSIS

Keywords serve as high-level summaries of topics and literature content, and are also vital components of academic papers. They reflect the primary research themes within a research field. By counting the high-frequency keywords in a certain research field and conducting word co-occurrence analysis, we can analyze the hot spots of the subject field [62].

Given the vast scale of the keyword co-occurrence network in KTUIC, to ensure a clear and representative visualization output, we set the minimum frequency of keyword co-occurrence to 5. Consequently, we obtained a keyword co-occurrence network comprising 134 nodes and 4724 edges, as illustrated in Figure 9. The number of nodes represents the number of keywords in the selected document collection. As long as two keywords appear in the same article, there will be a link between them. It is clear that keywords such as ''knowledge transfer'', ''innovation'', ''technology transfer'', ''industry'' have higher degree of co-occurrence, mainly due to our search constraints.

Additionally, the colors of the nodes and edges respectively indicate the average years of occurrence of each keyword and the co-occurrence of two keywords. A node's color becomes progressively bluer as the keyword appeared earlier, indicating that the topic has been studied less or has disappeared in recent years. Conversely, a node's color becomes redder if the topic has been emerging in recent years.

From Figure 9, it can be observed that in the early stages of research in KTUIC (blue nodes), scholars explored themes reflected by keywords such as ''trust'', ''growth'', ''spillovers'', ''biotechnology'', ''intellectual property'' and ''academic research''. However, it is evident from the size and color of these nodes that although this research started early, it had a short duration. Research in these subfields began to decline or disappear after 2014, possibly indicating that these areas had matured. In recent years (orange and red nodes), themes related to ''commercialization'', ''entrepreneurial university'', ''engagement'' and ''open innovation'' have been emerging continuously. Among them, the theme of ''commercialization'' has emerged late but has already reached a considerable scale, indicating its high popularity in the field of KTUIC in recent years.

To present the research hotspots in the field of KTUIC more accurately, we removed keywords related to search terms such as ''university'', ''industry'', ''collaboration'', ''knowledge transfer'', ''technology transfer'', and count the remaining high-frequency keywords. Table 4 lists the top 20 high-frequency keywords in KTUIC. ''innovation'' is the most frequent keyword with a frequency of 280. ''performance'' and ''research and development'' rank second and third with frequencies of 187 and 125 respectively. From the table, we can roughly find that the research hotspots in KTUIC mainly focus on factors and performance analysis (performance, impact, absorptive capacity, determinant, productivity), academic entrepreneurship (commercialization,

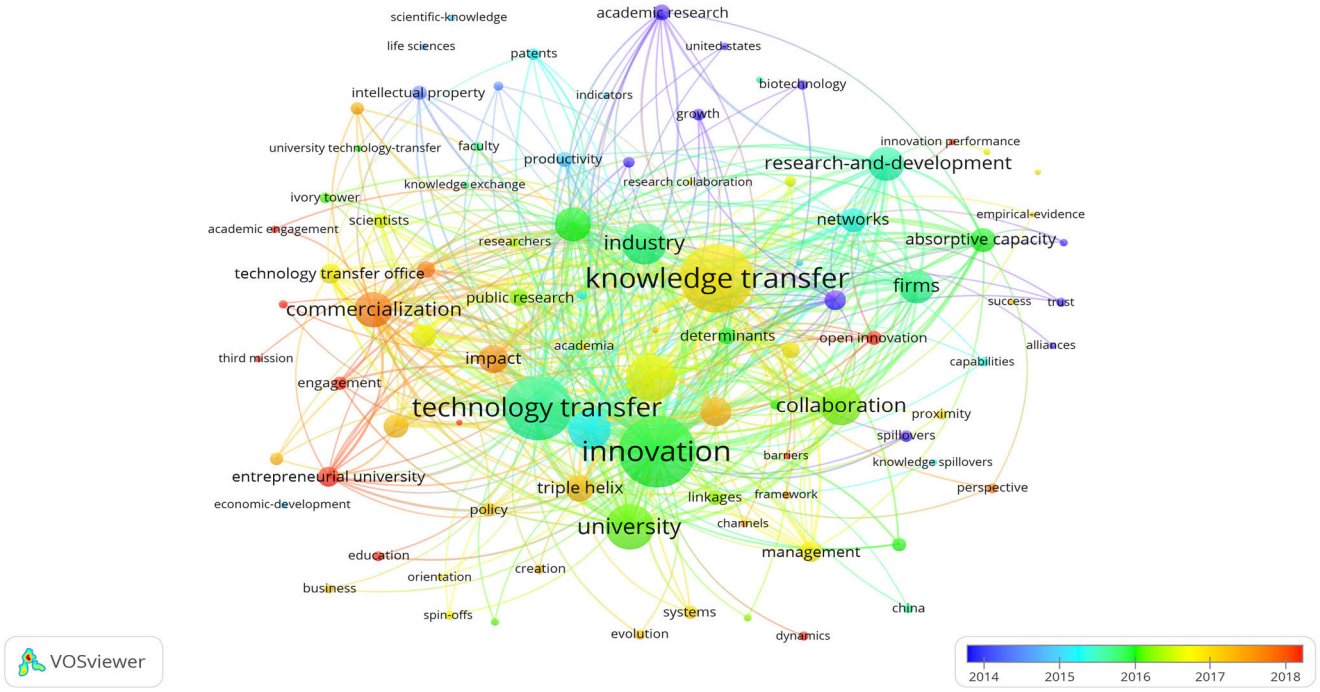

FIGURE 9. Keyword co-occurrence network.

TABLE 4. Top 20 high-frequency keywords.

Ranking	Frequency	Keywords	Ranking	Frequency	Keywords
1	280	innovation	11	53	entrepreneurial university
2	187	performance	12	50	Determinant
3	125	research and development	13	46	public research
4	108	commercialization	14	45	UK
5	93	impact	15	45	intellectual property
6	88	triple helix	16	43	Productivity
7	82	absorptive capacity	17	33	spin-off
8	71	network	18	26	Bayh Dole Act
9	70	academic entrepreneurship	19	22	Biotechnology
10	62	technology transfer office	20	18	third mission

spin-off, academic entrepreneurship, entrepreneurial university), and network analysis. In addition, TTOs, intellectual property, biotechnology and KTUIC issues in the UK context have also received extensive attention.

2) KEYWORD CLUSTER ANALYSIS

Bibliographic Items Co-occurrence Matrix Builder (BICOMB) is a text mining tool that can quickly read and count the bibliographic information of the literature data, and generate the word matrix and co-occurrence matrix, which can provide comprehensive and accurate basic data for further research. We first use BICOMB software to screen out keywords with a co-occurrence frequency higher than 5, and generate the word matrix required for cluster analysis, and then use SPSS to systematically cluster the matrix. Finally, we obtain 10 clusters. After analyzing and summarizing the frequency of keywords in each cluster and the degree of connection between them, we name each cluster separately. The clustering results obtained are shown in Table 5.

3) STRATEGIC COORDINATE ANALYSIS

Based on the co-occurrence and cluster analysis of high-frequency keywords in KTUIC, this study selects the strategic coordinate graph to further explore the strategic position of various research hotspots.

Law et al. [63] proposed the strategic coordinate graph composed of two index measurement dimensions: density and centrality. The density reflects the connection strength of each topic within a certain type of cluster, and the centrality reflects the degree of correlation between research clusters. In this study, the centrality is set as the X-axis, the density is set as the Y-axis, and the intersection of the mean of the two is used as the coordinate origin to draw the strategic coordinate diagram of the KTUIC research, as shown in Figure 10.

TABLE 5. Keyword clustering results.

#	cluster name	cluster member
1	entrepreneurial university	entrepreneurial university, academic entrepreneurship, spin-off, networks, bibliometrics, scientific productivity, Italy, education, patenting
2	commercialization	commercialization, intellectual property, social capital, knowledge exchange, case study, university technology transfer, academic patenting, technology commercialization, sustainability, nanotechnology, start-ups, technological innovation, innovation ecosystem
3	triple helix	triple helix, China, knowledge, R&D, cooperation, higher education institutions, strategy, human capital, product innovation
4	technology transfer offices	technology transfer offices, SMEs, knowledge and technology transfer, efficiency academia, barriers, principal investigators
5	entrepreneurship	entrepreneurship, higher education, open innovation, social network analysis, economic development, biotechnology, knowledge economy, Taiwan, quadruple helix
6	third mission	third mission, patent, academic engagement, research collaboration, research commercialization, licensing, motivation, collaborative research, entrepreneurial orientation
7	absorptive capacity	absorptive capacity, innovation performance, innovation policy, developing countries, knowledge diffusion, entrepreneurship education, complementarity, Mexico
8	innovation networks	innovation networks, regional innovation system, Japan, R&D collaboration, innovation intermediaries, network analysis, knowledge spillover
9	knowledge management	knowledge management, performance, proximity, research, knowledge sharing, firms
10	emerging economies	emerging economies, Brazil, university research, sustainable development, academic patent

It can be seen from the figure that the 10 clusters are scattered in four quadrants, among which the third quadrant has more clusters, and the first, second, and fourth quadrants have fewer clusters. There are two clusters in the first quadrant, in which the centrality and density of #1 entrepreneurial university are both high, indicating that this research topic occupies the core position in KTUIC, which has been widely concerned by researchers for a long time. The density of #2 commercialization is at a high level, and the centrality is above the average level, indicating that the subject has a relatively close internal relationship, more research results, and a more mature development path. #3 triple helix is located in the second quadrant, with above-average density

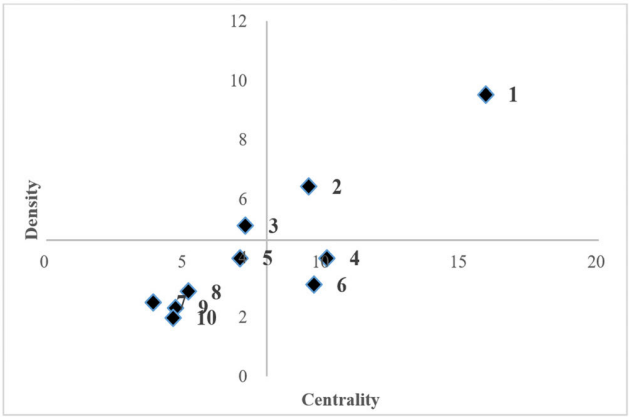

FIGURE 10. strategic coordinate analysis result.

but below-average centrality, indicating that this cluster was once a core subject area of research. It is relatively well researched, but has weak links with other areas and is now on the fringes of the overall research field. The third quadrant has five clusters, where #5 entrepreneurship has near-average density and centrality levels, while #7 absorptive capacity, #8 innovation networks, #9 knowledge management, and #10 emerging economies have lower density and centrality levels. It shows that the internal structure of these studies is relatively scattered, and the research is not yet mature. #4 technology transfer offices and #6 third mission are located in the fourth quadrant. They are closely related to other topics, but the research obtained is insufficient, indicating that this branch belongs to the core but immature position of KTUIC research, and needs further exploration and enrichment by scholars.

Based on the above analysis, we find that the hotspots of KTUIC research mainly focus on the related issues of third mission and entrepreneurial universities. The third mission of the university refers to the mission of the university to have the commercial application of new knowledge in addition to the inheritance of knowledge (education) and the creation of knowledge (research) [64]. In the 1990s, with the implementation of the Bayh-Dole Act and reduced government funding for higher education institutions, many universities began to seek support from industry to obtain funds through technology transfer and commercialization of university research results. During this period, university-industry technology transfer became an important part of the third mission of universities, and departmental institutions such as university TTOs, innovation incubators and spin-offs have been established, which also set off a large number of corresponding research [48], [65], [66]. Subsequently, the concepts of the triple helix and entrepreneurial university were further proposed. These concepts assert that, as active participants in the innovation ecosystem, universities should participate in the commercialization of research results and the formation of spin-off companies. Additionally, the interaction and collaboration among universities, industries and governments can promote the transfer and application of

knowledge and technology, thereby promoting economic and social development [43], [67].

In the 21st century, the research of entrepreneurial universities began to rise rapidly. Similar to the third mission, entrepreneurial universities aim to integrate innovation and entrepreneurship into university teaching, research and social services to promote university knowledge transfer and industrial technology innovation [68]. Its initial research scope focused on the characteristics and evaluation indicators of entrepreneurial universities, and then gradually expanded to development paths, cooperation networks, and their impact on innovation systems and regional economies [69]. Some studies illustrated that entrepreneurial universities that are committed to commercializing academic knowledge can have a positive spillover effect on economic and social development by fulfilling their multiple missions, including entrepreneurial activities [26], [70], while some other scholars have different views on this. Philpott et al. [71] adopted an exploratory case study method and conducted semi-structured interviews with key professors in some European universities and found that vigorously promoting the construction of entrepreneurial universities will reduce the overall entrepreneurial activities of the entire university.

As an important institution in many entrepreneurial universities, issues related to TTOs has naturally attracted the attention of many researchers. In the early stages, the literature on TTOs mainly focused on the study of their organizational structure and management model, and then the research scope gradually extended to areas such as performance evaluation and influencing factors, and this trend has continued up to the present day [44], [72], [73]. For example, Schoen et al. [73] summarized four main types of TTOs, and based on the results of 16 case studies in 6 European countries, he proposed countermeasures for different types of TTOs governance. O'Kane et al. [74] believed that the entrepreneurial performance of universities depends to a certain extent on the ability of their respective TTOs to commercialize academic creations. By studying six TTOs cases in the UK, Weckowska [52] found two commercialization methods, namely transaction-centric practice and relationship-centric practice, coexist in some TTOs and develop together. Hewitt [75] found that the difference in business application performance between universities is reflected in their knowledge transfer activities, and university knowledge transfer is affected by the system, organizational resources, and research quality, rather than the TTOs' ability.

Moreover, the strategic coordinate analysis reveals that certain clusters, such as innovation networks and performance, knowledge management, and KTUIC issues in emerging economies, have started to take shape. However, due to the relatively late formation of these clusters, the research intensity within each cluster and the connection strength between clusters are comparatively weak. In recent years, numerous studies begin to consider the influence of network in the process of KTUIC research. Some regard network characteristics, such as network density, network heterogeneity, etc., as factors affecting knowledge transfer performance [76], and some use social network analysis based on data such as patent citation and patent transfer, etc. to study the network structure characteristics and dynamic efficiency of KTUIC [77]. Additionally, through the previous analysis, it can be concluded that research on KTUIC issues first began in Europe and the United States, and after decades of development, its research framework system has been continuously enriched [8]. Since the 21st century, with the rapid development of emerging economies such as China, Brazil, and Mexico, it has become an increasingly urgent task for these countries to solve the problem of knowledge transfer between academia and industry in their own contexts, and to promote the transformation of university scientific and technological achievements into actual economic benefits. Against this background, research on KTUIC issues in emerging economies, especially in China, has emerged and grown rapidly [78], [79].

F. FUTURE RESEARCH AGENDA

Based on bibliometric and visual analysis of keywords and cited documents in the KTUIC field, this paper presents distinct advantages in depicting the research status of hotspots within this field. These advantages are determined by the suitability of the research methods employed in this study. In the KTUIC research, in addition to looking back and visually displaying the literature research topics and clustering characteristics, it is also necessary to further summarize the research agenda and point out possible directions for future research. Therefore, based on the five knowledge groups proposed above, this paper collects questions that have research significance but have not been answered or the research conclusions are not yet clear, and proposes the future research agenda of KTUIC.

First, in terms of research on UIC and knowledge transfer, the existing literature mainly adopted a perspective based on knowledge transfer processes from academia to industry [7], [78]. In fact, some UIC projects have been shown to have knowledge flows that are reciprocal and bidirectional [80], [81]. Therefore, it is a possible future research agenda to explore the obstacles, incentives, and sustainable cooperation mechanisms between industry and academia from an industrial perspective. In addition, some international UIC projects, such as joint R&D centers established by multinational companies in foreign universities, have emerged in recent years [82], but their knowledge transfer performance and their impact on the innovation capabilities of both industry and academia are still unclear. Furthermore, we have observed that the phenomenon of abnormal termination of certain international UIC projects is becoming increasingly prevalent [83]. It is crucial to further investigate the underlying causes and the impacts it imposes on both the academia and industry parties involved.

Second, in terms of basic theories of U-I relationships, connecting the Triple Helix model, as well as the subsequent development of the Quadruple or Quintuple Helix theories considering elements such as civil society [84], [85] and

the environment [86], with the concept of regional innovation ecosystems to explore how the interactions among universities, industries, and other key stakeholders facilitate knowledge transfer and innovation within specific regions, could be a potential research agenda. Moreover, in terms of research methods, qualitative and narrative research have played an important role in exploring KTUIC issues [46], [87]. With the increasing emphasis on mixed research methods, in future research, in addition to structured/semi-structured interviews and case studies, the comprehensive use of other qualitative and quantitative methods can provide new ideas for more in-depth explanations of complex issues in KTUIC. For instance, social network theory has gained significant attention in the study of interpersonal relationships and collaborative networks in recent years [76]. By integrating social network theory with other approaches, a more comprehensive understanding of the evolution and effectiveness of KTUIC can be attained.

As an important intermediary organization in KTUIC, University TTOs play an important role in promoting the transformation of scientific research results to commercialization and social application [74]. Relevant literature has fully explored its mechanism, performance, influencing factors, and developmental obstacles, but its role in cooperation networks and industrial linkages and its efficiency issues need to be further answered [88], [89]. Additionally, as formal administrative departments within universities, TTOs operate based on well-defined rules and regulations. In this context, employees' experience is considered a more important quality than their creativity [90]. Therefore, it is also of great significance to explore the impact of the capacity, experience and service quality of TTOs employees on U-I linkages [91], [92].

In addition, in terms of research related to the Bayh-Dole Act and university patenting, there is almost no doubt that the Act can increase the patent output of universities [7]. However, further research is needed on the quality of university patents and the impact of university patent transfer and licensing on industrial benefit growth [93], [94]. Especially in some emerging economies, such as China, under the framework of government planning, the number of patents is included in the university development assessment system, and financial incentives are implemented for university patent applications. The impact of these measures on the technicality and practicality of university patents is yet to be demonstrated. Furthermore, the social responsibility and sustainable development of university patenting may also be a future research agenda. Especially during public crises, such as the COVID-19 pandemic, it remains to be seen whether the university's rights under the Bayh-Dole Act to patents derived from government funding should be limited [22], [95].

Finally, in the study of individuals in university technology transfer, the impact of university or department quality on the extent to which individuals engage in technology transfer or commercialization is unclear. The conflict between academic focus and social capital is considered to be the possible reason for this phenomenon, but the mechanism needs to be further explored [15]. Moreover, in addition to university professors, the importance of postdoctoral scholars (postdocs) and PhD students in the U-I connection has also become increasingly prominent, and they often have direct contact with the industry as core members of cooperative projects [58]. There may also be some interesting findings on their role in the maintenance and expansion of social relations between universities and industries, as well as in explaining the relationship between university quality and the scale of individual technology transfer [96].

IV. CONCLUSION AND CONTRIBUTION

Based on the core collection of Web of Science database, we carried out the bibliometric and visual analysis of 874 high-quality documents in the field of KTUIC published between 1996 and 2021 from the following aspects: literature distribution and development trends, cooperation network, co-citation, knowledge base, research hotspots, and future research agenda. The findings and conclusions obtained are as follows:

First, since the enactment of the Bayh-Dole Act, universities have strengthened their cooperation with industry and accelerated the commercialization of research results [53]. Research related to KTUIC also began to increase substantially. Our research finds that the number of annual publications in KTUIC has shown an approximate exponential growth from 1996 to 2021. The development of innovation-driven economy, the support of policies and the acceleration of technological progress are considered as the possible reasons for the rapid growth of related research [26], [68], [70]. It is expected that the publications will continue to grow in the next few years, and the field of KTUIC will still have high research value and enthusiasm.

Second, we found that institutions and scholars in developed countries such as the US, UK, Spain, and Italy are at the forefront of research in KTUIC. In fact, KTUIC-related research first started in the US [8], and the UK conducted intensive research in this field subsequently and became the core node in the network. Alessandro Muscio from the University of Foggia is the most prolific author, yet most of the authors in the network are not connected, and the cooperation between them is not close or continuous. This may hinder the further development of related theories, methods, and practices in KTUIC.

Additionally, we identified important journals and authors in KTUIC through co-citation analysis, and found in further analysis of cited documents that the knowledge base and structure of KTUIC field contains five knowledge groups: UIC and knowledge transfer, basic theories of U-I relationships, university TTOs, Bayh-Dole Act and university patenting, and individuals in university technology transfer. These five knowledge groups represent the core questions of KTUIC research and provide a fundamental theoretical framework for the field. Based on these knowledge groups, we consider issues related to U-I linkages from an industrial

perspective, the efficiency of TTOs in networks, the quality of university patenting, the role of postdocs and PhD students, and the application of mixed research methods in KTUIC as possible future research agendas. In terms of research hotspots, KTUIC research has primarily focused on issues related to the third mission and academic entrepreneurship. Besides, emerging areas of interest include innovation networks and performance, knowledge management, and KTUIC issues in emerging economies.

In the past decades, KTUIC has attracted the attention of a large number of scholars and has produced many significant and valuable results. For this reason, some scholars summarized past research topics through literature review, trying to combine fragmented research topics and integrate new research directions in the past period [1], [14], [15]. These documents provide useful guidance and contributions to help us understand the research direction and progress in the field. However, these literature reviews are limited by the author's personal preference and the number of analyzed documents, which may lead to certain deviations and defects between the conclusions drawn from the literature analysis and the actual development of the field [97], [98]. In contrast, bibliometrics and visual analysis overcome these barriers in traditional literature reviews. According to their own research needs, scholars can obtain all the document information that meets the requirements and avoid the omission of key representative documents under the condition of the reasonable setting of search conditions. In addition, with the help of visualization software, the knowledge structure and research hotspots of certain scientific fields can be obtained more clearly [62].

Based on this, this paper offers a thorough discussion and analysis of significant documents in the field of KTUIC using bibliometric and visual analysis software such as VOSviewer, Bibexcel, and BICOMB. Specifically, the main contributions of this study can be summarized as follows: First, the paper presents information on knowledge maps, collaboration networks, and literature clustering in KTUIC through figures and tables with the help of visual analysis tools, enabling researchers to grasp relevant research dynamics in a more intuitive way. Second, through a systematic collection and analysis of relevant literature, the paper reveals the knowledge base and research hotspots in the field. Finally, combining the results of software analysis and literature reading, this study proposes a future research agenda from the perspective of five knowledge groups. In summary, this paper enriches the research results in the field of KTUIC and the findings are of great significance for recognizing the development characteristics and establishing the theoretical framework of the literature in KTUIC.

Furthermore, this study presents the following implications. Firstly, by analyzing cooperation networks and co-citation networks, this paper identifies the prolific authors, institutions, as well as highly-cited documents and authors in the field of KTUIC. This offers guidance for future scholars and research institutions in seeking potential academic collaborations, facilitating faster scientific discoveries and innovation within this field. Additionally, the analysis of research hotspots and future research agendas provides subsequent researchers with an understanding of the current state of the field and focuses on promising research themes. Moreover, the findings of this study, derived from high-quality literature data, can serve as evidence and reference for policymakers in developing more effective strategies to improve KTUIC performance and promote the commercialization of university technology.

Despite the above-mentioned contributions, there are still some limitations which need to be improved in the future research. The accuracy and credibility of bibliometric and visual analysis results are highly dependent on the quality of the data [98]. Although this article tries to ensure the quality of the literature in the setting of the retrieval rules, there may also be situations where some literature that is not important but has an advantage in quantity is highly concerned. Additionally, due to the constraints of WOS database literature collection scope and retrieval conditions, the data collected may not fully represent all high-quality literature, and therefore may not fully reflect the actual state of KTUIC research. Moreover, the cleaning and screening of documents is a heavy and complicated work. While reading and eliminating irrelevant documents individually, researchers' subjective factors may lead to mistakenly deleting some documents related to the topic or retaining and analyzing some irrelevant documents. Furthermore, the analysis results based on published literature often lagged several years behind the actual research progress at that time [1], [13]. Therefore, to clearly grasp the development of research in the field of KTUIC, accurately identify the dynamic evolution of each cluster over time, and predict the development trend of future research topics, it may be necessary to further integrate text analysis, data mining, and survey interviews on the basis of bibliometric and visual analysis [31]. For example, a synthetic knowledge synthesis methodology can be used to conduct a more in-depth qualitative and quantitative analysis of the literature in the field [19], [21]. These are the directions that we are working on in our future research.

APPENDIX A

TABLE 6. Top 10 productive countries.

Ranking	Frequency	Country	Betweenness centralities
1	145	England	0.30
2	106	USA	0.18
3	77	Germany	0.13
4	76	Spain	0.13
5	75	Italy	0.12
6	70	China	0.06
7	47	Netherland	0.07
8	34	Australia	0.07
9	32	Sweden	0.04
10	31	France	0.08

TABLE 7. Top 10 productive institutions.

Ranking	Frequency	Institution	Country
1	11	Polytechnic University of Valencia	Spain
2	11	Catholic University of Leuven	Belgium
3	10	Northumbria University	UK
4	8	University of Valencia	Spain
5	8	University of Manchester	UK
6	7	Spanish National Research Council (CSIC)	Spain
7	7	Cardiff University	UK
8	7	National Research University Higher School of Economics	Russia
9	6	University of Foggia	Italy
10	6	Lehigh University	USA

APPENDIX B

TABLE 8. Top 10 highly cited journals.

Ranking	Citation	Journal	Impact factor
1	723	Research Policy	8.110
2	573	Journal of Technology Transfer	5.783
3	476	Technovation	6.606
4	379	Management Science	4.883
5	325	Industrial and Corporate Change	3.085
6	314	R&D Management	2.908
7	303	Organization Science	5.000
8	285	Science and Public Policy	2.725
9	282	Strategic Management Journal	8.641
10	272	Administrative Science Quarterly	11.113

TABLE 9. Top 10 highly cited authors.

Ranking	Citation	Author	Institution	Country
1	372	Etzkowitz H	Int Triple Helix Inst	USA
2	319	Perkmann M	Imperial College London	England
3	277	Cohen WM	Duke University	USA
4	260	D'Este P	Polytechnic University of Valencia	Spain
5	242	Siegel DS	Arizona State University	USA
6	176	Bozeman B	Arizona State University	USA
7	156	Bercovitz J	University of Colorado System	USA
8	153	Agrawal A	Queens University	Canada
9	151	Audretsch DB	Indiana University Bloomington	USA
10	142	Mansfield E	University of Pennsylvania	USA

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