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TOPICAL REVIEW

Mapping the Research on University-Industry Collaborative Innovation of Individuals: A Scientometric Analysis

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ABSTRACT As university-industry collaborative innovation becomes an important driving force for technological development, the role of individuals in promoting knowledge production and innovation performance is becoming increasingly prominent. Research on individuals in this field has attracted a wide range of attention from scholars, however, scientometric analysis and visualization are inadequate. This study is based on scientific publications from 2000 to 2022 obtained from the Web of Science database. The Bibliometrix-R package and VOSviewer software were used to conduct quantitative analysis and visualization of bibliometric indicators, and to explore the current progress and leading trends of research on university-industry collaborative innovation of individuals. The results show growing academic interest in this topic, with the United States, the United Kingdom, the Netherlands, and Italy being the most productive countries, and the geographical scope of research expanding to emerging economies. The current research focuses on the channels, attitudes, and influencing factors of different individuals in collaborative innovation as well as their relationship with scientific productivity. Through scientometric analysis, it is possible to intuitively understand scientific performance, core journals, author clusters, collaborative networks, research hotspots, and thematic evolution, which helps to systematically recognize and focus research in this field, and provides a holistic view and potential directions for future research.

INDEX TERMS Collaborative innovation, university-industry, individual behavior, bibliometric analysis, visualization analysis.

I. INTRODUCTION

As a critical driving force for scientific creation and industrial advancement, collaborative innovation between universities and industry contributes to the innovation competitiveness of countries and regions [1]. On the one hand, collaboration with industry is a channel for academic scientists to obtain funding and experimental equipment, as well as to supplement theoretical knowledge through practice and achieve commercialization [2], [3]. On the other hand, collaboration with academia can help industry acquire advanced knowledge, enhance research and product development, and improve corporate innovation performance [4].

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Recently, university-industry collaborative innovation has been increasingly hailed as a key policy tool for fostering industrial innovation and economic growth, and various countries have actively established and improved collaborative innovation systems [5]. Academics are extensively involved in knowledge transfer activities, and industry is also actively linked with academia. The frequency and depth of university-industry collaboration are constantly increasing [6], which has attracted great interest.

University-industry collaborative innovation is a broad range of technological innovation activities jointly carried out by universities and enterprises with the support of the government, intermediary agencies, and other relevant organizations to exchange and expand resources and capabilities [7]. The individual is the most basic element in university-industry collaborative innovation, and the functions of each part are undertaken and realized by individuals. The key to collaborative innovation lies in the interaction and integration of different innovation resources through various modes of collaboration between universities and industry [8], such as research collaboration, joint patents, spin-offs, and personnel mobility. It is a social behavior that usually involves non-linear and human-to-human interaction, driven by the relationship network of individuals to establish cross-border linkages among organizations and facilitate knowledge production and technology transfer [9].

Given the relevance of individual interactions between universities and industry for the transfer of academic research into social progress, an increasing number of studies have focused on the university-industry collaborative innovation of individuals. Academic scientists and faculty members have been the most widely studied subjects. As research commercialization funded by the government and industry was permitted, professional norms in academia gradually changed. Academic scientists involved in university-industry collaborative innovation have created new revenue streams that offset rising research costs. More profoundly, the academic engagement of these individuals has led to the development of knowledge and society in the form of new products and enterprises. In this context, more and more faculty members are turning to technology transfer as a third mission, apart from teaching and research [10]. In addition, students are encouraged to become "triple helix workers" to adapt to changes in the labor market, which also leads to improved prestige and better employment opportunities [11], [12], [13]. Several studies have focused on other roles and stakeholders such as firm employees and researchers [14], managers [15], university administrators [16], and technology transfer officers [17], providing various perspectives for exploring individual interactions across organizations. Their actions are not only related to the linkage and performance of collaboration between universities and industry but also affect the development of innovation systems.

Several scholars have reviewed the individual-level literature on university-industry collaborative innovation with different goals and priorities. For example, Perkmann et al. reviewed the literature on academic engagement and intellectual collaboration between academic scientists and industry [10]. Skute et al. also provided an important individual perspective in their content analysis of university-industry collaboration research [7]. However, these studies emphasize the analysis of specific roles and lack systematic attention to individuals in university-industry collaborative innovation. Most of these are qualitative analyses, and bibliometric analysis is rarely used to provide a macro view of the development process and trends in the current literature. Although individual-level research on university-industry collaborative innovation has become an interesting topic, we still lack analysis of the structure, evolution, collaboration, and potential research directions of the present literature.

Bibliometric analysis is a computerized technique used for quantitative and content analysis of scientific publications. It can extensively combine multiple disciplines such as bibliography, informatics, and statistics, quickly uncover research progress in specific fields, intuitively evaluate topic trends, and identify research hotspots [18]. Relevant software tools can automatically identify and extract the large amount of data needed and present it in tables or images, helping to visualize the rich intrinsic connections in the information [19]. Therefore, the motivation and purpose of this study are to use bibliometrics and relevant tools to review research on university-industry collaborative innovation of individuals, fill the research gap, and provide directions for future research. Specifically, we used the Bibliometrix R-package and VOSviewer software to systematically review and evaluate publications in this field from 2000 to 2022. This study focuses on several main bibliometric indicators (including publication trends, sources, authors, institutions, countries, relevant articles, and keywords) and analyzes the citation, co-citation, co-authorship, and co-occurrence of current literature. The results contribute to the following three aspects. First, the results provide insights into the research status and patterns in this field, such as growth trends, the most influential authors, core journals, and national collaborative networks. Second, through the analysis of cited publications and keywords, this study maps the intellectual structure of the university-industry collaborative innovation of individuals. Finally, based on thematic evolution, this study provides potential research directions that can help scholars pursue emerging trends.

II. MATERIALS AND METHODS

This study applied bibliometric analysis to explore the research on university-industry collaborative innovation of individuals and quantitatively analyzed publications in this specific field [20], providing an objective, scientific, transparent, and reproducible process [21]. By structuring a large amount of scientific data into various categories, such as sources, authors, institutions, national networks, articles, and keywords, and performing citation, co-citation, co-authorship, co-occurrence, and content analysis, we can mine the relationships among the bibliometric indicators. It helps to measure the publication performance of authors and journals, evaluate collaborative linkages, and reveal intellectual structures of specific topics [22], thus remedying the limitations of conventional literature reviews in assessing academic contributions and scientific value, and identifying research trends.

A. DATA SEARCH STRATEGY

The bibliographic data for this study were obtained from the Web of Science Core Collection of the Thomson Reuters online database, which includes three citation index databases: Science Citation Index Expanded, Social Sciences Citation Index and Arts and Humanities. With its strict selection criteria and effective indexing mechanism,

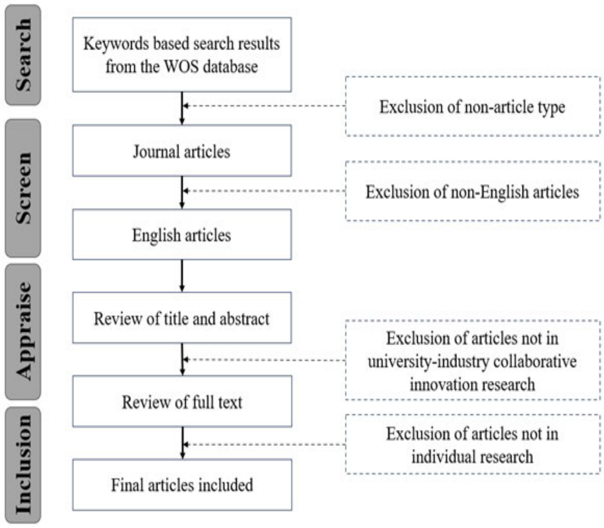

FIGURE 1. Process of literature searching and screening.

the Web of Science includes a large number of authoritative and influential journals in various subjects and is considered to be the most suitable database for bibliometric analysis [23]. Based on previous research [1], [24], we searched publications for titles, abstracts, and keywords with the formula: TS = (''university-industry'' or ''industry-university'' or ''university-firm'' or ''firm-university'' or ''university-business'' or ''business-university'') and TS = (coopera* or collabor* or relation* or link* or interaction* or innovation* or ''academ* engag*'' or ''academ* entrep*''), where ''*'' indicates a fuzzy search. We limited the publication period from January 1, 2000, to December 31, 2022, to systematically review the developments in this research field. After excluding non-article types and non-English articles, 1829 articles were retained. Duplicates, literature reviews, and irrelevant articles were excluded by reading and reviewing the titles, abstracts and full text of each article. Because of our interest in individuals in university-industry collaborative innovation, articles that were not individual-level research, such as national or departmental studies, were removed and 166 articles were eventually retained for bibliometric mapping and content analysis. FIGURE 1 shows the literature search and the screening process.

B. SOFTWARE AND TECHNIQUE

Scientometric methods were applied to the analysis of scientific mapping using the Bibliometrix R-package and VOSviewer, two of the most commonly used bibliometric tools [25]. Bibliometrix is written in R language and is a set of integrated programs for data manipulation, computation, and graphical display. Users perform scientific measurements and visual analysis on an interactive web interface, which facilitates more sophisticated bibliometric analysis for literature content analysis and scientometric quantitative research [26]. VOSviewer adopts the method of data standardization based on probability theory and provides various visual analyses such as network visualization, overlay visualization, and density visualization of sources, authors, countries, and keywords. The outstanding features of concise drawings and beautiful images are conducive to accurately locating research focuses and future trends in this field [27].

III. RESULTS

A. PUBLICATION TREND

The number of publications each year can reflect the overall trend and speed of development in the research field as well as the interest of academia. As shown in FIGURE 2, 166 studies on university-industry collaborative innovation of individuals were published from 2000 to 2022, showing a significant increase. Since 2019, the number of publications on this topic has reached its highest value, reflecting the fact that individual-level research has gradually become a hot topic in university-industry collaborative innovation in recent years. In terms of the annual number of publications, 2006 and earlier can be regarded as the initial stage of research, during which the number of publications was less than 5 papers annually. The research at this stage started with the qualitative analysis of university faculty, researchers, and firm employees involved in university-industry collaboration, including interviews, surveys, and case studies, and provided a preliminary discussion of the phenomenon and impact of academic entrepreneurship and university-industry collaboration [11], [28], [29]. The number of annual publications has exceeded 5 papers since 2007, and in the following decade, this figure has fluctuated and hovered around 5-10 papers. With the increasing engagement of individuals in university-industry collaborative innovation, scholars' interest has also increased significantly. This stage focuses on extensively exploring and enriching the understanding of individual collaborative innovation, including multiple channels of university-industry collaboration [30], [31], obstacles and driving factors of cooperation [32], [33], [34], individual perceptions and attitudes [2], [35], [36], [37], and the impact of collaboration on scientific productivity [38], [39] through a combination of qualitative analysis and quantitative methods such as questionnaire surveys, network analysis, and scientific publication analysis. The number of publications has stabilized since 2017 and remains at approximately 13 papers annually in 2022. This shows that research on university-industry collaborative innovation of individuals is relatively stable, but there is still room for growth, and it is necessary to pursue meaningful potential directions. Currently, the geographical and national scope of research in this field is expanding to emerging economies as university-industry collaborations grow in importance [40], [41], [42], [43]. In addition, the influencing factors and complex mechanisms in various models of individual collaborative innovation, such as individual needs, research types, and experience [44], [45], as well as the relationship with knowledge production and

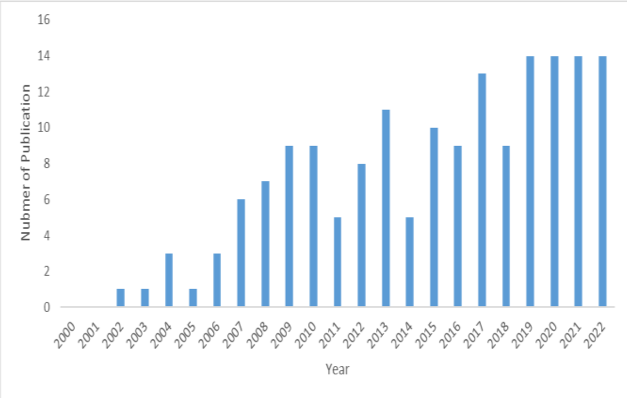

FIGURE 2. Annual publication output.

TABLE 1. Top 10 productive journals.

Journal	Category	Index	Publications	Average Citations
Journal of Technology Transfer	Management	SSCI	29	46.55
Research Policy	Management	SSCI	24	160.92
Technovation	Management	SCIE/ SSCI	7	78.71
R & D management	Business	SSCI	5	41.80
Higher Education	Education & Educational Research	SSCI	5	32.40
Scientometrics	Information Science & Library Science	SCIE/ SSCI	5	19.00
Technological Forecasting and Social Change	Business	SSCI	5	18.40
Studies in Higher Education	Education & Educational Research	SSCI	5	10.60
Technology Analysis & Strategic Management	Management	SSCI	4	20.75
Research Evaluation	Information Science & Library Science	SSCI	4	17.25

transfer [46], [47], [48], have been more systematically and deeply analyzed in recent studies.

B. RELEVANT SOURCES

The 166 papers identified in this study were published in 63 journals. TABLE 1 presents the top 10 most productive journals and reports their categories and average citations. The journals that contributed the most were in the categories of management, business, information science, and educational research, among which management journals have made outstanding contributions to the literature. According to Bradford's law [49], if journals in a research field are sorted in descending order of publications, then journals with an equal number of publications are divided into each zone in accordance with the law of $1:a:a^2$. The results of the division of journal zones in the research on the university-industry collaborative innovation of individuals are presented in TABLE 2. The number of publications in the three zones is roughly the same, with the ratio of the number of journals being approximately 1:4:16, which is consistent with the formula described by Bradford's law.

The most important journals on individual research in university-industry collaborative innovation can be identified in the core zone in FIGURE 3. The core journal contains three management journals: Journal of Technology Transfer, Research Policy, and Technovation. These three journals cover multiple aspects of innovation, focusing on social innovation, technology, knowledge, and economy, the interrelationship between society and organization and the corresponding policy research, thus also covering the most relevant research that explores the topic of individual collaborative innovation with high research quality. Therefore, special attention should be paid when exploring relevant topics.

Co-citation analysis is an important part of journal analysis. Co-citation occurs when papers belonging to different journals are cited jointly in other papers. The scientific mapping of journal articles reflects the specialization and importance of a journal on a specific topic. We analyzed the source co-citations of 166 articles and mapped them using network visualization. There were 4 clusters in the network, including 45 different journals, with a minimum of 30 citations. As shown in FIGURE 4, each node represents a journal and its size is proportional to its number of publications. The link between nodes represents the strength of the co-citation and its thickness is proportional to the link strength. The most obvious cluster in the link network is green, containing 14 nodes, of which the most prominent journal is the Research Policy. It is at the center of the link network, with massive linkages with other clusters, and a total link strength of 52416, which proves its core position in research on university-industry collaborative innovation of individuals. The red cluster includes 17 nodes, and the journals in this cluster are primarily related to the theories of organization and management. Relevant articles provide important insights into the relationship between the different organizational structures, cultures, norms, and cross-organizational individual behaviors of universities and enterprises in collaborative innovation. The blue cluster consists of 7 nodes, which are related to area studies that focus on the collaborative behavior of individuals within or across regions and further explore their relationship to regional development and innovation. The yellow cluster, which also contains 7 nodes, explores the frontiers of technology development and management as well as innovation public policy, and emphasizes the impact of technology advancement and knowledge transfer caused by individual behavior in collaborative innovation.

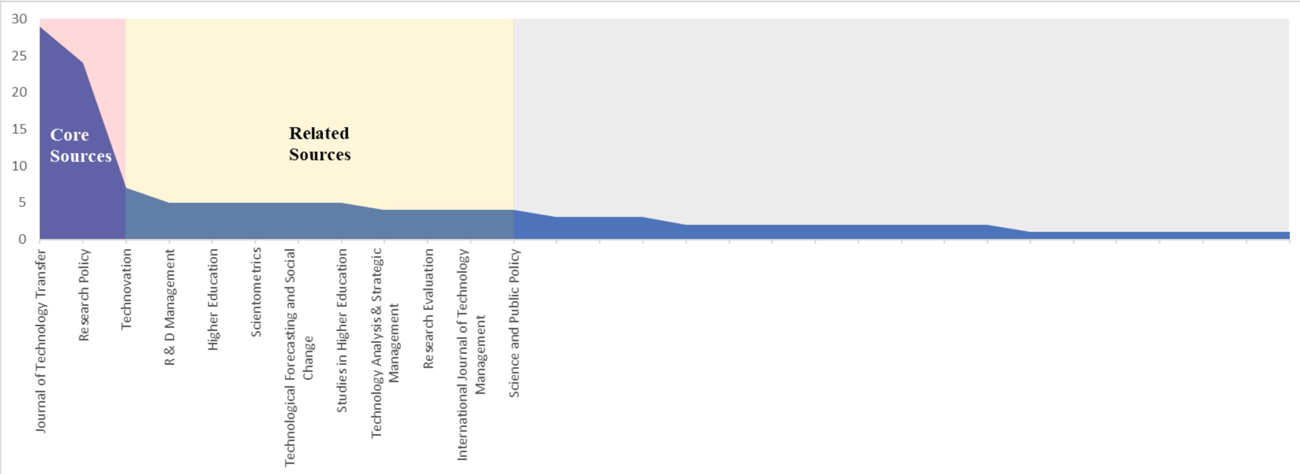

FIGURE 3. Core journals distribution.

TABLE 2. Zones of journals.

Zone	Publications	Number of Journals	Number of Publications
First Zone	≥7	3	60
Second Zone	3-5	12	50
Third Zone	1-2	48	56

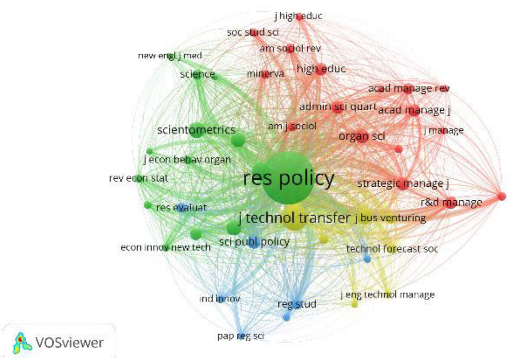

FIGURE 4. Annual publication output.

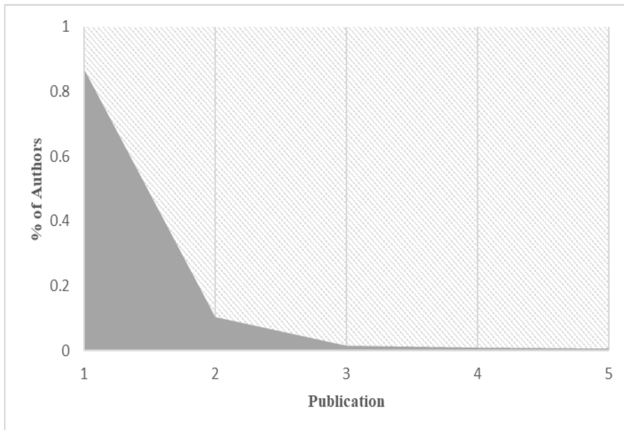

FIGURE 5. The frequency distribution of publication.

C. AUTHORS OF PUBLICATIONS

Individuals in university-industry collaborative innovation have attracted increasing attention. Therefore, to obtain an accurate and reliable research summary in this field, the most critical task is to evaluate the publication situation of the relevant authors and to identify and focus on the most productive and influential authors. Lotka revealed a pattern between the distribution of authors and number of publications [50]. FIGURE 5 shows the distribution of the 366 authors according to their publication. 87.2% of the authors published an individual study involving university-industry collaborative innovation, and 10% wrote two papers, compared to only 0.4% of the authors who wrote 5 papers in this research field.

TABLE 3 reveals the top 10 authors and average citations in individual-level research on university-industry collaborative innovation. FIGURE 6 shows their productivity over time, with the volume of the sphere proportional to the number of each year, and the depth of color of the sphere proportional to the number of citations per year [51]. Perkmann and Tartari were the most prolific, both publishing 5 articles with an average citation of 175.60 and 71.80 respectively, indicating that they were highly productive and influential authors in this field. Perkmann M. published his first paper on individual research in 2008 and has been working on this topic for a long time. However, research of Tartari V. is relatively concentrated, and 5 high-quality papers were published within three years. D'Este P., Boardman P. C., and Salter A. published 4 papers each, and it is worth noting that D'Este P. has focused on individual research since 2007, with a high average citation of 369.5.

To determine the authors' specific interests of individuals in university-industry collaborative innovation, we drew a

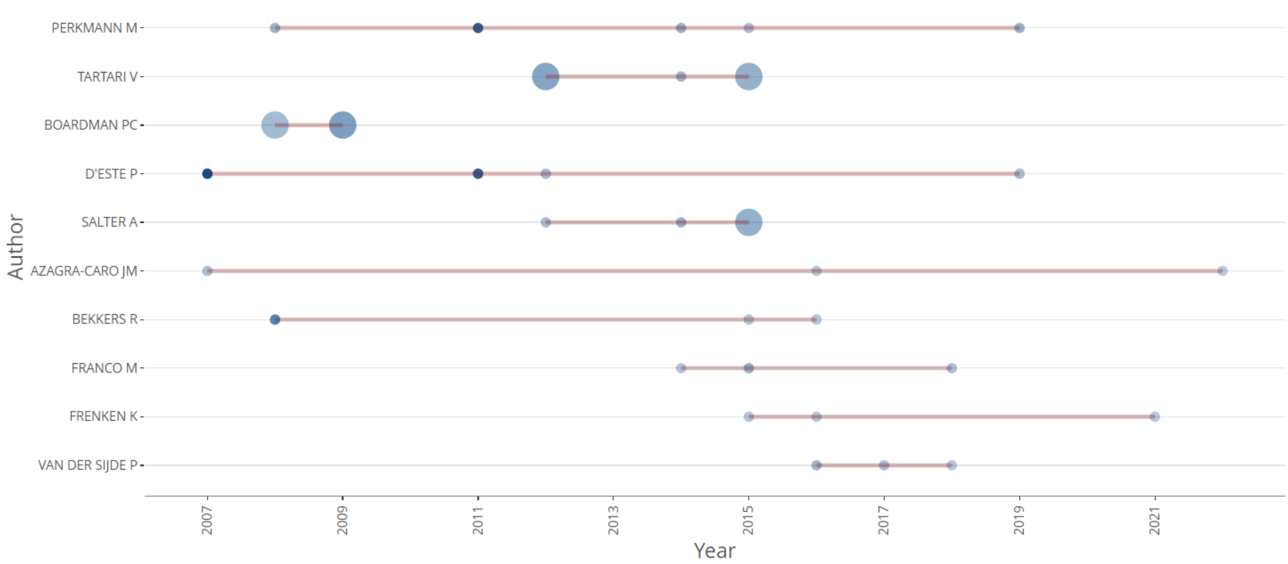

FIGURE 6. Top 10 authors' productivity over time.

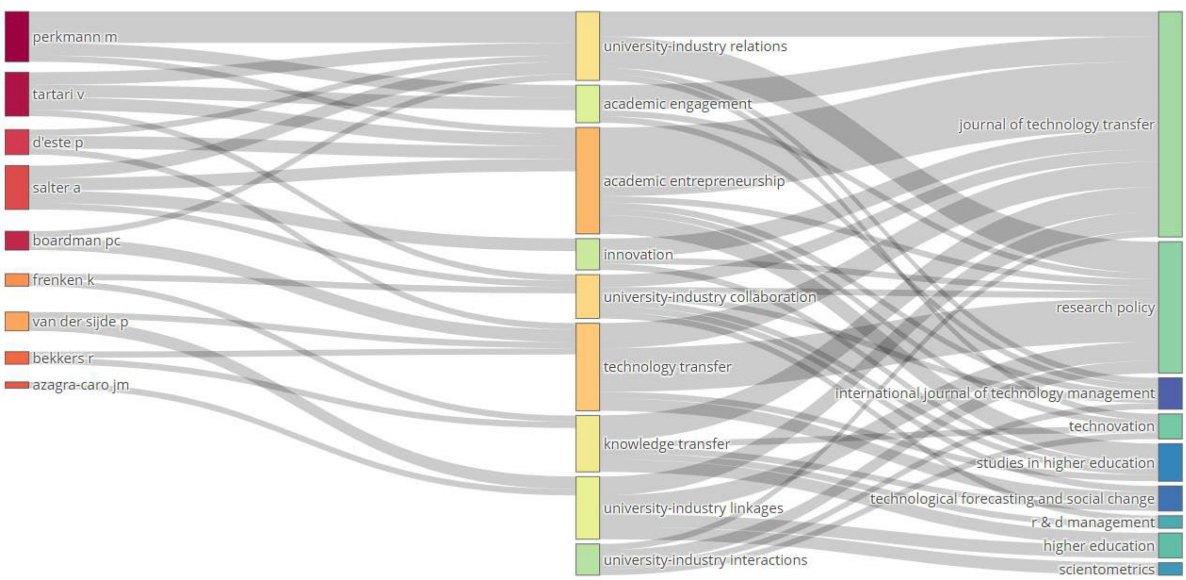

FIGURE 7. Sankey diagram representing authors' interest of research.

Sankey diagram to establish linkages among authors, keywords, and journals of publication. In FIGURE 7, the authors are listed on the left, the keywords the author focuses on are listed in the middle, and the journal of publication is listed on the right. Thus, we can map and infer the authors' research interests and fields from these linkages. It can be found that Perkmann mainly focuses on science-based organizations and entrepreneurship, with special interest on the interface between the world of academic science and industry, as well as the behavior of academic engagement that can bridge both worlds [2], [52], with the keywords "university-industry relationship", "academic engagement", "academic entrepreneurship". Tartari V. is also interested in "university-industry relations" and "university-industry collaborations". Specifically, her research discusses the production process of scientific knowledge in academia, the transfer process of scientific knowledge to industry and society, and the influencing factors and mechanisms involved in these processes [37]. The research of D'Este P. focuses on the interaction between academic scientists and industry, and its impact on academic and commercial performance. For example, using large-scale survey data of scientists to explore the diverse channels of

TABLE 3. Top 10 productive authors.

Author	Publications	Average Citations
Perkmann M.	5	175.60
Tartari V.	5	71.80
D'Este P.	4	369.50
Boardman P. C.	4	85.75
Salter A.	4	63.50
Azagra-Caro J. M.	3	26.33
Bekkers R.	3	157.67
Franco M.	3	45.67
Frenken K.	3	9.67

university-industry collaboration, and to analyze the motivations and factors behind individual collaborative innovation [2], [30], mainly using "academic entrepreneurship" and "knowledge transfer" as keywords.

According to Price's law [53], Equation (1), which measures the minimum number of publications by core authors in a research field, is as follows:

$$m = 0.749 \times N_{max} \tag{1}$$

where m is the minimum number of publications for the core authors, and N_{max} is the number of publications for the most published authors. The results show that the authors who published 2 or more articles were the core authors in this research field, with a total of 47 people. The number of papers published by core authors accounted for 26.3% of all authors' publications, indicating that the core author cluster in this research field has begun to take shape but still needs to be developed. FIGURE 8 further explores the research collaboration of the core authors and shows the collaborative networks among them. The nodes are proportional to the number of linkages between the authors, and the thickness of the linkages is proportional to the collaborative relationship between the authors. The network has a total of 24 clusters, and the largest one has 6 elements, consisting of outstanding authors such as Perkmann M., Tartari V., D'Este P. and Salter A., who have contributed a total of 11 papers, indicating that collaborative research between these core authors can significantly promote the knowledge advancement of research on university-industry collaborative innovation of individuals.

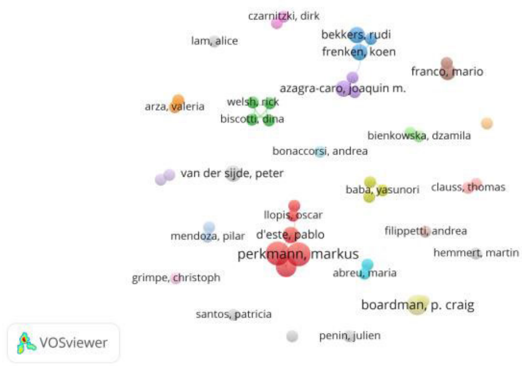

FIGURE 8. Collaborative network visualization of core authors.

TABLE 4. Top 10 productive institutions.

Institution	Country	Publications
Katholieke University Leuven	Belgium	7
Universitat Politècnica de València	Spain	7
Copenhagen Business School	Denmark	6
Imperial College London	United Kingdom	6
Leiden University	Netherlands	5
Georgia Institute of Technology	USA	4
Lund University	Sweden	4
University of Beira Interior	Portugal	4
University of Utrecht	Netherlands	4
University of Sussex	United Kingdom	3

D. INSTITUTION AND COUNTRY DISTRIBUTION

Institutions and countries are important variables in bibliometric analysis that reflect the research intensity and knowledge contribution of different institutions or regions. Analyzing the publication and citation of papers from different institutions or countries contributes to the assessment of their academic performance and collaborative networks. If multiple authors from the same institution or country contributed to an article, that institution or country was counted once. During the period 2000-2022, a total of 248 institutions published relevant scientific papers. Considering that 91.94% of the institutions published only 1-2 papers, we listed the top 10 institutions with publications, as shown in TABLE 4. 9 of these universities are from European countries, with Katholieke University Leuven and Universitat Politècnica de València publishing 7 papers, Copenhagen Business School and Imperial College London publishing 6 papers, and Leiden University publishing 5.

At the country level, it can be found that 166 papers in this study were distributed in 37 countries, with TABLE 5 showing the top 10 countries with the highest number of publications. In terms of the number of publications, the United States published far more papers than other countries, ranking first with 35 papers and an average of 55.54 citations per publication. The UK ranks second with 25 publications, with an average citation of 129.64, followed by the Netherlands with 21 papers, with an average citation of 48.90.

A country cooperation network diagram was generated by constraining the minimum number of publications in a country to 2. As shown in the donut chart in FIGURE 9, 25 of the 37 countries reached the threshold. The nodes in the figure represent the country and the size of the nodes is proportional to the number of publications. The line between two countries represents their cooperation, and the thickness

TABLE 5. Top 10 productive countries.

Country	Publications	Average Citations
USA	35	55.54
United Kingdom	25	129.64
Netherlands	21	48.90
Italy	20	61.20
Spain	16	62.06
Germany	13	31.00
China	12	8.67
Sweden	12	29.83
France	9	38.00
Belgium	7	85.86

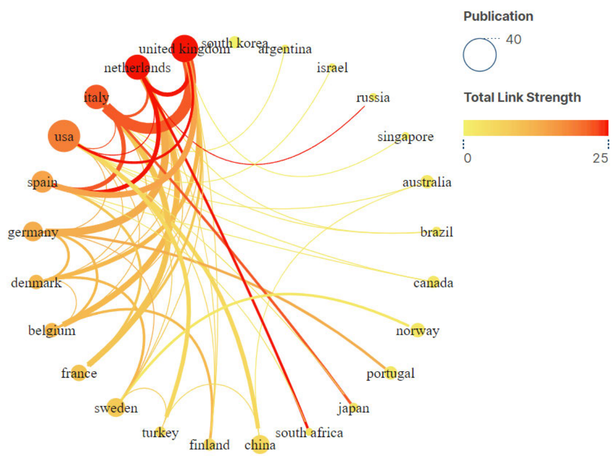

FIGURE 9. Collaborative network of countries.

of the line is proportional to the strength of cooperation between countries. Although the United States has the largest number of publications, its partners are scattered, and the intensity of cooperation is relatively low, radiating to many countries such as the United Kingdom, Germany, China, and Canada. The UK, the Netherlands, and Italy have more concentrated cooperation networks, with total cooperation intensities of 25, 25, and 22, respectively. These countries are highly interconnected and closely cooperative, and have more cooperation with other countries at the same time.

To gain insight into which countries and regions are actively engaged in individual research in the field of university-industry collaborative innovation, we created an overlay visualization of the national collaboration network and color-mapped the nodes by the average publication year of research in different countries. As shown in FIGURE 10, it can be found that research in this field began in 2012 on average, suggesting that the academic potential and research value of individual research were not valued in the decade when they were first proposed. The United States was the first country to pay attention to university-industry collaborative innovation at the individual level. Since the passage of the Bayh-Dole Act in the 1980s, the relationship between American universities and industry has changed significantly [11]. As federal funding for academic research declined, universities shifted to private sector for research funding and support. In addition, they were more aware of the commercial potential of academic research. As a result, academic scientists and faculty members were actively encouraged to leave the ivory tower to participate in patenting, licensing, and commercialization, and the number of university-industry partnerships increased dramatically [54]. In the context of the rapid development of university-industry collaborative innovation, changes in the working patterns of academic scientists related to industry and their consequences have also attracted much attention and research. As the second academic revolution swept across Europe, the relationship between science and industry was re-recognized. Governments actively formulated policies to guide academic scientists in collaboration and technology transfer across organizational borders and introduced some new supporting infrastructure to enhance innovation systems (such as technology transfer offices and business incubators) [55]. Scholars from European countries, such as Belgium, Italy, the United Kingdom, and France became more interested in this topic and generated new insights. The countries that started research first were developed countries due to their many prestigious research-intensive universities and strong industry sectors with large multinationals, laying the foundation for collaborative innovation systems and individual engagement [56]. In the last five years, a third wave of academic knowledge transfer has emerged in emerging economies in Asia, Eastern Europe and South America. For example, the Chinese government regarded collaborative innovation as an important means to realize a leap in industrial technology and promote the reform of the national innovation system to enhance independent innovation [57]. Brazil introduced a landmark innovation law to regulate university-industry collaboration and encourage academia to take the lead in supporting collaborative innovation [42], [58]. As a result, an increasing number of developing countries have joined the research and discussion in this field.

E. REVELANT ARTICLES

The 166 individual-level studies on university-industry collaborative innovation selected in this study received 8828 citations in various publications. A total of 108 papers were cited at least 10 times, accounting for 65.06%, indicating that most of these papers were recognized by scholars. TABLE 6 presents the top 10 cited papers, accounting for 40.19% of the total citations, proving their authority and influence in this field. The article published by D'Este and Patel in 2007 received significantly high citations of 842 [30]. It not only divided the diverse channels of faculty members to engage in collaborative innovation into five groups: meeting and conference, consultancy and contract research, creation

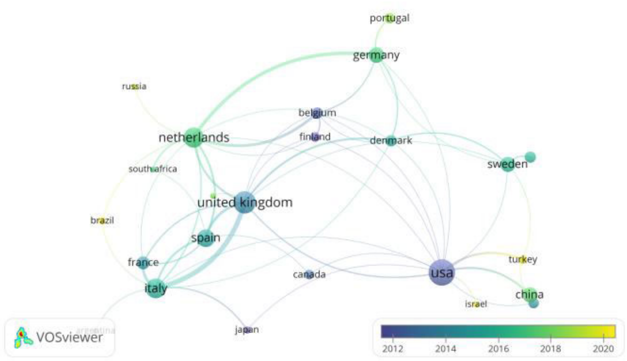

FIGURE 10. Overlay visualization of countries.

of physical facilities, training, and joint research. Factors that influence the type and frequency of interactions were also analyzed, and the key roles of individual characteristics (including previous experience of research collaboration, discipline, age, and academic status) were highlighted in comparison with the characteristics of departments and universities. Their findings provide important insights into the consensus on patterns of university-industry interaction among faculty members and point to potential directions for research on individuals and their characteristics. Also involving D'Este, the article collaborating with Perkmann received 542 citations [2]. The Authors further investigated the drivers of faculty members' involvement in formal or informal collaboration and identified four main motivations: commercialization, learning, access to funding, and access to in-kind resources. They argued that engagement in diversified modes of interaction is driven by various motivations, with commercialization being the least important motivation for collaborative innovation, while research-related motivations dominate, prompting a rethink of research and policy on academic entrepreneurship and incentives. Gulbrandsen and Smeby's article, which explored the relationship between industry funding and scientific performance, came third with 453 citations [59]. They found that industry funding is significantly associated with higher publication productivity and greater collaboration among university professors. Academic entrepreneurship has not caused significant harm, and in some cases, has boosted scientific creativity, thus answering the intense debate about the optimism and pessimism of research commercialization.

TABLE 7 lists the top 10 of the 6,510 references cited in the 166 publications identified in this study. Several highly cited articles mentioned above have been cited in references. 5 of these papers are not studies at the individual level and discuss the knowledge spillover effect brought about by collaborative innovation and its relationship with science and innovation from the macro perspective of universities or departments [60], [61], [62]. In addition, an individual-level literature review focuses on the individual categories of university academic scientists and systematically reviews the personal, organizational, and institutional antecedents and consequences of their academic engagement [1]. It can be found that research on university-industry collaborative innovation of individuals is a further development on the basis of macro research, while most research focuses on faculty members, and there is still a gap in the theory and practice of other roles and their behaviors.

F. KEYWORDS ANALYSIS

Keywords are the highly concentrated content of a literature. We can quickly locate research hotspots in this field and predict its future research development by exploring the relationship between research themes in a field through keyword analysis [63]. To obtain accurate results, irrelevant keywords were manually removed and the minimum occurrence of keywords was set to 10 as a threshold. The network visualization was constructed based on 34 keywords that met the threshold of a total of 799 keywords, as shown in FIGURE 11.

In network visualization, the combination of nodes and labels forms an element and the size of the node is proportional to the frequency of the keywords. The linkage between the two nodes implies the co-occurrence of two keywords. "Innovation", "science", "technology-transfer" and "knowledge" are the largest and most frequent nodes, indicating that they are the most important keywords of individual-level research in university-industry collaborative innovation. In this network, the color of a node represents the different clusters to which it belongs, and the distance between different clusters represents the correlation between them. Specifically, if the distance between two clusters is short, a close correlation between them can be determined and vice versa. The network visualization shown in FIGURE 11 has four main clusters: blue, green, red, and yellow.

The blue cluster includes keywords such as "innovation", "performance", "industry", "enterprise" and "research and development", which focuses on the relationship between individual activities and industrial development in university-industry collaborative innovation. The direct contribution of academia to corporations is often characterized by informal connections and relationships that are essentially based on individual knowledge spillovers [52]. Firms provide ample space for the learning and reorganization of knowledge through various forms of interactive connections with faculty members, which contributes to the generation of unique technologies with commercialization potential [64]. The acquisition of extensive expertise and networks also actively promotes R&D productivity, which in turn leads to the development of new products [14]. Although it has been suggested that firms can only obtain short-term returns from collaborative innovation, rather than more uncertain but long-term returns [65], different types of academic scientists, such as Pasteur or Bohr scientists [66] and academic star scientists [67], also have different effects on the improvement of firm innovation output. Overall, collaborations with academic scientists facilitate the transfer of tacit and complex

TABLE 6. Top 10 cited articles.

Author(s)	Title	Year	Total Citations	Average Citations
D'Este and Patel	University-industry linkages in the UK: What are the factors underlying the variety of interactions with industry?	2007	842	49.53
D'Este and Perkmann	Why do academics engage with industry? The entrepreneurial university and individual motivations.	2011	542	41.69
Gulbrandsen and Smeby	Industry funding and university professors' research performance.	2005	453	23.84
Bekkers and Freitas	Analysing knowledge transfer channels between universities and industry: To what degree do sectors also matter?	2008	446	27.88
Balconi et al.	Networks of inventors and the role of academia: an exploration of Italian patent data.	2004	315	15.75
Abreu and Grinevich	The nature of academic entrepreneurship in the UK: Widening the focus on entrepreneurial activities.	2013	246	22.36
Van Looy et al.	Publication and patent behavior of academic researchers: Conflicting, reinforcing or merely co-existing?	2006	189	10.5
Lam	From 'Ivory Tower Traditionalists' to 'Entrepreneurial Scientists'? Academic Scientists in Fuzzy University-Industry Boundaries.	2010	177	12.64
Ankrah et al.	Asking both university and industry actors about their engagement in knowledge transfer: What single-group studies of motives omit.	2013	170	15.45
Boardman	Government centrality to university-industry interactions: University research centers and the industry involvement of academic researchers.	2009	168	11.2

TABLE 7. Top 10 cited references.

Author(s)	Title	Year	Total Citations
D'Este and Patel	University-industry linkages in the UK: What are the factors underlying the variety of interactions with industry?	2007	62
Perkmann et al.	Academic engagement and commercialization: A review of the literature on university – industry relations.	2013	53
Cohen et al,	Links and impacts: The influence of public research on industrial R&D.	2002	43
D'Este and Perkmann	Why do academics engage with industry? The entrepreneurial university and individual motivations.	2011	43
Etzkowitz and Leydesdorff	The dynamics of innovation: from National Systems and "Mode 2" to a Triple Helix of university-industry-government relations.	2000	38
Gulbrandsen and Smeby	Industry funding and university professors' research performance.	2005	38
Agrawal and Henderson	Putting patents in context: Exploring knowledge transfer from MIT	2002	34
Bekkers and Freitas	Analyzing knowledge transfer channels between universities and industry: To what degree do sectors also matter?	2008	31
Meyer-Krahmer	Science-based technologies: university-industry interactions in four fields.	1998	31
Partha and David	Toward a new economics of science.	1994	30

knowledge, driving a wide range of enterprise innovations, including management, services, and business processes, not just products [68].

The red cluster includes the high-frequency keywords ''science'', ''technology transfer'', ''knowledge transfer'', ''cooperation'' and ''impact'', which refer to the modes, channels, and influencing factors of individual interactions between universities and industry in collaborative innovation. Empirical evidence shows that in the process of collaborative innovation, knowledge flows through multiple channels, including patents, licensing, R&D programs, conferences, consulting, training, personnel mobility, joint publications, and spin-offs [31]. The interactive channels for collaborative innovation can be divided into several categories. Relevant criteria to distinguish these channels include the formality of the agreement, the length of the agreement, the degree of interaction, the direction of knowledge flow, the potential for the application of the achievements, and the benefits obtained [69]. By focusing on individuals in both industry and academia, it was found that in the context of their considerable autonomy in determining research agendas and cooperative partners, differences in channels and propensity of engagement in collaborative innovation are more determined by the characteristics of the individuals involved in the process [31]. Factors such as gender, age, country, education level, and title of academic scientists have been extensively discussed [10], [70], and further studies have also included individual experiences (such as overseas education experience, work, or cooperation experience outside the ivory tower) [46], [71], research activities (such as research productivity, academic impact, and research orientation) [45], [72], [73], and the relationship between different types of university-industry collaboration.

The green cluster focuses on the academic entrepreneurship, attitudes and barriers of individual faculty member collaborative innovation through high-frequency keywords including "knowledge", "entrepreneurship", "scientist" and "academic participation". Different components of an innovation system have disparate institutional logic. Merton defined the norms specific to the university and academic profession: communality, universalism, disinterestedness, and organized skepticism. Faculty members engage in research and teaching objectively, autonomously, and freely, sharing knowledge openly through collegial work, not seeking personal advantage, but advancing science for the public good [74]. As the driving effect of scientific research in economic and social development became more prominent, policy emphasis underwent a subtle shift to break down boundaries between organizations. Since the enactment of the Bay-Dole Act, academic entrepreneurship has received increasing interest from scholars and practitioners. Encouraged by the university, entrepreneurship spread among faculty and students who began to engage widely with the public and influence practices [75]. Motivations such as obtaining funding and equipment, learning external knowledge, improving reputation and recognition, and fulfilling social missions have driven academic scientists to open the door to collaborative innovation [70], [76]. However, there are transaction barriers (lack of commercialization experience, time and energy issues, weak financial and policy support, lack of management procedures, etc.) and orientation barriers (institutional logics, role transformation, diverging orientation and practices, intellectual property conflicts, etc.) in the process of university-industry collaboration, which damage the efforts and propensity of faculty members [37], [39], [77]. Recent empirical studies have found that peer effects, network capabilities, trust, and collaborative experience contribute to improved attitudes and perceptions of academic engagement among university faculty [37], [78], [79], [80]. Therefore, more attention must be paid to the role of these factors in collaborative innovation.

The yellow cluster focuses on the relationship between collaborative innovation and individual scientific production, including high-frequency keywords such as "technology", "patent", "intellectual property", "academic research", and "productivity". However, the conclusions regarding this topic remain controversial. Several authors have indicated their concern that increased interaction with industry would interfere with the research autonomy of faculty members and reduce the quality of scientific output [81], [82]. A strong commercial orientation may undermine the commitment of academic scientists to publish papers and contribute to public science. Industry involvement may also delay or even suppress scientific publication and dissemination, endangering the consensus and practice of "knowledge sharing" and "open science." The closer the connection with the industry, the more likely it is to influence the selection of research projects, leading to the inclination of basic research to applications, thereby damaging research quality and leading to a substitution effect between patents and publications [83]. On the other hand, academics that contribute to technology transfer maintain that collaboration with industry complements their own academic research, obtains funding and equipment for projects, and provides new research ideas [84]. Ideas from the industry can also expand traditional research agendas, benefiting researchers' overall scientific performance [85]. Researchers who engage in university-industry collaborations are more productive, publish more papers, and receive more citations than their peers. Further studies have found that the impact of collaborative innovation on scientific production depends on the type and intensity of collaborative activity [86]. Linkages with industry sectors may improve research achievements, but a high degree of cooperation may damage research value, reduce research time, and cause attention problems, thereby harming research outputs, which may be a non-linear relationship [87], [88].

Based on the network visualization, an overlay visualization of keywords containing time information was constructed. The color of a node in this network indicates the average publication year of all the articles with that keyword. Keywords closer to 2013 are shown in dark blue, whereas those closer to 2022 are shown in yellow. FIGURE 12 shows that the keywords "technology" and "university-industry relations" have the earliest average publication years. Research on university-industry collaborative innovation of individuals began with a discussion of the cross-organizational cooperation relationship and its impact on academic norms and scientific creativity [28], [55]. With the improvement of innovation system, the scope of research has gradually broadened, and scholars have paid more attention to "knowledge transfer", "innovation" and "performance" in collaborative innovation. In addition, the average publication years of "researcher" and "academic engagement" are 2018 and 2019, respectively, suggesting that focusing on academic scientists' academic engagement behavior is an emerging research topic that needs further exploration.

By constructing keyword density visualization, the depth of research on university-industry collaborative innovation of individuals can be observed in FIGURE 13, with colors ranging from blue to green, yellow, and red. The color of the area is closer to red if the number of nodes near it is larger and the weight of the nodes is higher. Conversely, if the node is sparser and less influential, its color is closer to blue. Through density visualization, we can quickly realize that the topics of innovation, performance, knowledge, and technology transfer are currently widely discussed in research on individuals.

IV. THEMATIC EVOLUTION AND FUTURE DIRECTIONS

Understanding the evolution of themes will contribute to clarifying the research context and identifying future research directions. As shown in FIGURE 14, the visualization shows the sizes of various information streams related to the main topics and the evolution of the topics over time. It shows that in the past ten years, ten research themes such as "productivity", "policy" and "management" in this field have evolved from the past six research themes. It can be found

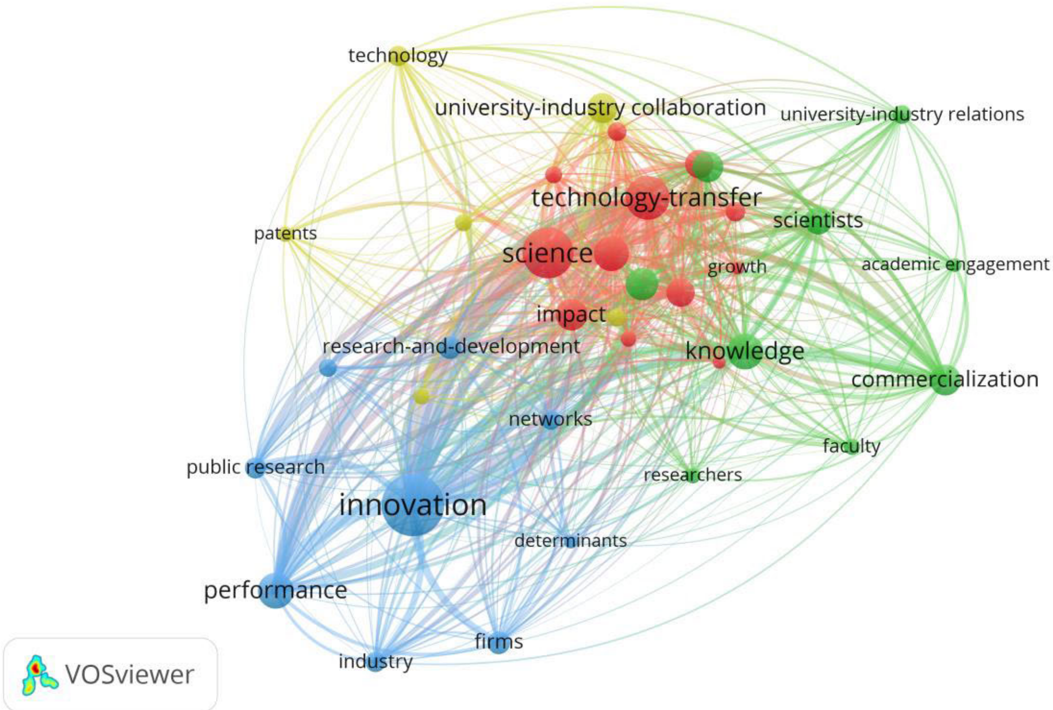

FIGURE 11. Network visualization of keyword co-occurrence.

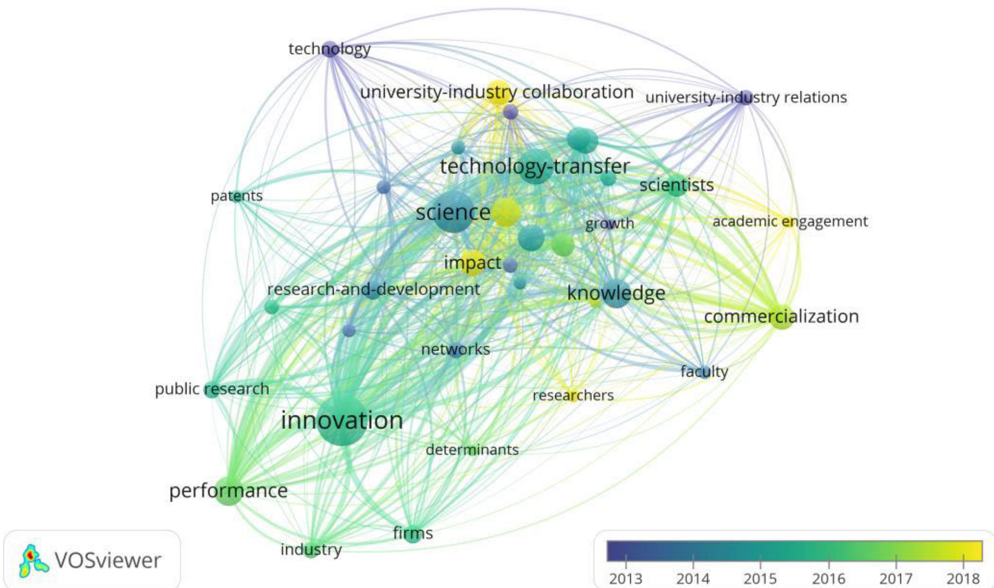

FIGURE 12. Overlay visualization of keyword co-occurrence.

that with the deepening of individual university-industry collaborative innovation practices, scholars who pay attention to the relatively broad theme of "science" have begun to focus on practical needs and research issues, and have refined the theme into "policy", "management", "productivity", etc. The emphasis on "knowledge" has also expanded to focus on themes "innovation" and "economy". "Trust" and "education" are still important themes in research of individual interactions and relationships. In addition, the focus on "dynamics" in university-industry collaborative innovation has gradually evolved into thinking about the specific behavior of "engagement".

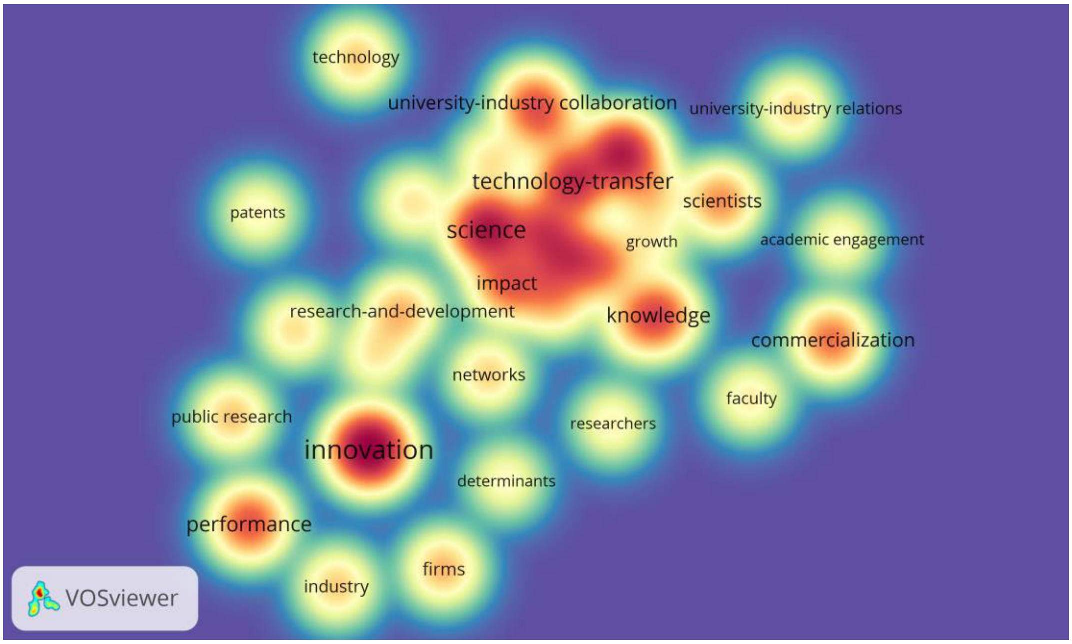

FIGURE 13. Density visualization of keyword co-occurrence.

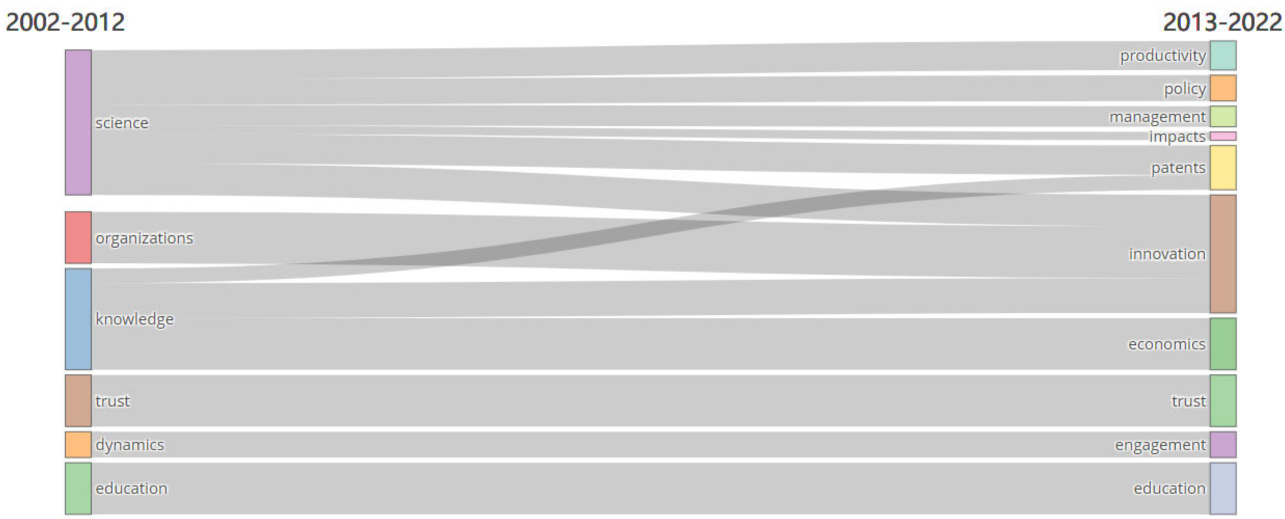

FIGURE 14. Thematic evolution.

Based on the dynamics of research themes and keyword analysis, as well as a systematic literature review, this study proposes the following possible future research directions:

(1) University-industry collaborative innovation is a multi-subject interaction process across organizational borders. Academic scientists are the elemental actors of cooperative interactions and knowledge dissemination. Collaborative innovation behavior and influencing factors are the focus of most studies [10]. However, scholars have seldom discussed the characteristics and behaviors of other individuals in university-industry collaborative innovation, such as students, firm employees, and members of intermediary agencies. Given the differences in the characteristics, backgrounds, and motivations of academia, industry, and other partners in university-industry collaboration [66], the mechanisms for managing their partnerships are likely to differ substantially in nature. The effectiveness of different types of collaborative innovation mechanisms and channels depends on the motivation and characteristics of participating individuals. For example, research has found that students who have been trained in academic entrepreneurship and commercialization have achieved significant entrepreneurial outcomes and have better quality and growth potential than faculty members in the same field. In some cases, faculty

members are better suited to licensing or conducting collaborative research with enterprises than to being initiators of new ventures [89]. Therefore, identifying the functions and roles of different individuals and their characteristics in diverse collaborative innovation channels may be an interesting potential direction. Enhancing the consensus in this field can help optimize supporting policies and management mechanisms of universities, maintain sustainable university-industry partnerships, and increase the feasibility of knowledge transfer.

(2) The innovation and education systems of emerging economies differ from those of developed countries. Different countries also have various barriers, incentive structures, and policies aimed at promoting collaborative innovation between universities and industry [90]. Late-developing countries often have weak innovation systems and a lack of internal resources for independent development. Owing to the low potential of innovation and technology transfer, and relatively far from the technological frontier, collaborative innovation in the emerging innovation system is more involved in product improvement and the commercialization of services [42]. In addition, it may be accompanied by stronger political factors and relationship characteristics [91]. This may lead to non-traditional collaborative innovation channels and models. For example, in China, the government launched the Science & Technology Expert Secondment Program, which aims to dispatch faculty members from universities to work on the frontline of enterprises for a year to improve business innovation [92]. In addition, student workstations in enterprises have been established to combine talent training and technological innovation to compensate for the lack of innovation ability and funds. These activities may bring unique knowledge and experiences to individuals, thereby affecting their propensity for engagement. Therefore, the exploration of individual collaborative innovation behavior in emerging economies is not only an interesting supplement to the existing individual-level research, but also conducive to exploring new forms of collaborative innovation and helping national and regional governments enhance the collaborative innovation system.

(3) At the individual level, scholars have generally recognized the importance of academic scientists' individual characteristics in university-industry collaborative innovation and have explored the impact of gender, age, academic status, research type, and academic productivity [1]. Currently, the role of a scientist's biological and academic age in broad individual characteristics remains unclear. Previous research suggests that older academic scientists are good at using the knowledge and networks accumulated in their early careers to cooperate with the industry. However, some studies have also found that young scientists undergoing the transformation of entrepreneurial universities are more actively involved in the industry [10]. Therefore, it is necessary to further explore the types of collaborative innovation and the academic life cycle effect. In addition, non-academic work and cooperative experience are conducive to the sustainability of collaborative innovation [37], [72], but the discussion is mostly limited to a static perspective, and the mechanism of the experience effect is still unclear. This requires further understanding of individual collaborative innovation activities and their psychological foundations, and exploring the dynamic process of entry, exit, and persistence of university-industry collaboration, to accurately capture the evolution of experience effects and the propensity of engagement.

V. CONCLUSION

With the rapid development of university-industry collaborative innovation and expansion of relevant practices and interests, the fundamental role of individuals has been increasingly acknowledged. This study is based on bibliometric analysis, using the Bibliometrix R-package and VOSviewer software to analyze research on university-industry collaborative innovation of individuals published in the Web of Science database from 2000 to 2022. Journal, authors, institutions, countries, articles, keywords, and other information were extracted for citation, co-citation, co-authorship, co-occurrence, content analysis, and visualization to determine the current situation of this field, analyze research hotspots, evolution characteristics, and future directions. The main conclusions are as follows:

(1) The number of studies published on university-industry collaborative innovation of individuals showed an overall upward trend, peaking and stabilizing after 2019. Research Policy, Journal of Technology Transfer, and Technovation are the core journals that should be focused on in this field. Perkmann M. and Tartari V. are the most outstanding researchers in the research of individuals in university-industry collaborative innovation, followed by D'Este P., Boardman P. and Salter A. (2) Several universities in Europe, such as Katholieke University Leuven and Universitat Politècnica de València, are the most important institutions. In terms of countries, the USA is the most frequently published country, followed by the United Kingdom, the Netherlands and Italy. The USA was the first to conduct research in this field and formed a relatively extensive cooperation network. Western European countries followed closely with closer cooperation. Recently, emerging economies, such as China and Brazil, have also contributed to this topic. (3) Through the analysis of article citations and keyword co-occurrence, it was found that the research mainly focused on the relationship between individual collaborative innovation behavior and industrial development, and the modes, channels, and influencing factors of individual interaction, academic entrepreneurship of faculty members, and the relationship between collaborative innovation and scientific production. (4) Future research potential and development direction of research on university-industry collaborative innovation of individuals may need to explore the sophisticated mechanism of individual characteristics of academic scientists in collaboration, such as age and relevant experience, and break through the limitations of faculty to enrich the understanding of other individual objects, such as students or employees. In addition, it is necessary to

strengthen the exploration of diversified individual activities of university-industry collaborative innovation in emerging economies.

This study has some limitations. First, this analysis is limited to journal articles from the Web of Science database. Although the Web of Science database is widely recognized, it may not cover all research on university-industry collaborative innovation. Therefore, other databases (such as Scopus, JSTOR, etc.) should be considered in the future to ensure that important and influential journals are covered. Second, we referred to the keywords in the existing literature to retrieve articles related to research on university-industry collaborative innovation of individuals, which provides a certain theoretical basis for our retrieval strategy. However, new concepts constantly created by the development of university-industry collaborative innovation may cause some research to be neglected. Finally, only English articles were selected for the analysis in our study, and non-English articles should be considered in future research.

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