The Knowledge Landscape and Trends of University-industry Collaboration Research: An Analysis Based on the Web of Science Core Collection

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Abstract. University-industry collaboration research has shown a vigorous academic life and great potentials. This study examines the publication trends, discipline distributions, research hotspots, evaluation path, and research trends of university-industry collaboration using bibliometric methods, based on the literature included in the Web of Science Core Collection from 2012 to 2022, to depict its knowledge landscape and evolution path. The results reveal that technology transfer offices, collaborative agglomeration, managing triple helix operation, and firm innovation are prominent research hotspots in the field of university-industry collaboration. University-industry collaboration research demonstrates a stable knowledge base with multidisciplinary engagement, indicating its robust academic presence and significant potential. The evolutionary analysis identifies three distinct stages in the evolution path of university-industry collaboration research, indicating its continuous development over time. Based on this study, it is predicted that the multidisciplinary development trend of university-industry collaboration research will be further strengthened and a holistic ecosystem for university-industry collaboration is about to attract more attention. Based on this study, it is predicted that the multidisciplinary development trend of university-industry collaboration research will further strengthen, emphasizing the increasing attention on establishing a holistic ecosystem for university-industry collaboration.

Keywords: University-industry collaboration, research hotspots, evolution path, development trends, bibliometrics

1 Introduction

The interaction between university and industry (U-I) has been considered an important factor for enhancing innovation through knowledge exchange [1]. The modern meaning of university industry cooperation that has been successfully implemented in innovation management practices can be traced back to the model known as the "Terman-style" of Stanford University in the 1950s [2]. In the 19th century, universities have teaching and research as their first and second missions, followed by the emergence of the third mission in the second half of the 20th century, which involves the generation, use, application and exploitation of knowledge, with external stakeholders and society in general [3]. One significant approach to achieve the third

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mission is U-I collaboration [3]. Nevertheless, it was not until 1966 that Lincoln, an American scholar, published the first paper in the field of U-I collaboration, pioneering the research in this field [4]. U-I collaboration is considered as a new organizational model to enhance the independent innovation capabilities of nations and regions, which can realize the mutual coupling of all aspects from knowledge production to knowledge commercialization, and is a primary option to address the issue of poor connection between education, science and technology, economic and social development [5]. Given the situation that universities have gradually become the core of the knowledge production system and their role in innovation has become more important and diversified, thus governments are actively promoting the formation and development of U-I network, creating and implementing innovation policies [6, 7, 8]. The interaction between university and industry has emerged as a potential alternative to boost innovation and technological advancement, facilitating knowledge flow across all sectors [9, 10].

U-I collaboration is a relationship between two or more organizations that join forces to exchange resources and knowledge with a shared goal [11, 12]. For the industries, collaboration with universities enables access to relevant knowledge and relationships with learning networks that can generate knowledge that may not be readily accessible otherwise [13]. For universities, collaboration with businesses can help faculty members understand the technical bottlenecks in actual production, so that they can target their counterparts in technology development and promote the feasibility of their technology, and also leverage the role of universities as favorable environments for innovation and primary incubators, providing support for faculty members and students to start their own business [5]. There are already many studies that focus on content, cooperation methods, cooperation mechanisms, cooperation benefits, development obstacles, and solutions in university-industry cooperation [1, 14, 15], while research on summarizing the development path of international research on U-I collaboration and understanding the future direction of this field is still insufficient. In view of this, this study employs bibliometrics methods to systematically analyze literatures regarding U-I collaboration included in major international databases, and provides reference for in-depth exploration in this field.

The article is structured in 5 sections. Section 2 outlines the methodology with the criteria used for literature search. Section 3 presents the findings from the literature review. Section 4 discusses the findings of this study and future research trends. Finally, Section 5 presents the conclusions and limitations of this study.

2 Methodology

Bibliometrics has been widely used in various fields in recent years, providing a unique and valuable technical strategy for the study of fundamental problems [16, 17]. Based on bibliometric approaches, this study uses CiteSpace (v.6.1.R6) to evaluate and summarize the distribution pattern of existing research by measuring the number of publications, countries/regions, authors and other information in a time slice of each year. The analytical basis are topics extracted automatically from journal articles. Through the analysis of the number of publications, high-frequency keywords, keyword co-occurrence, keyword clustering, keyword emergence, and co-citation analysis, this study investigates key research

hotspots in U-I collaboration, sorts out its development evolution path, and predicts future trends. We aim to gain a more comprehensive understanding of the current status of U-I collaboration research, accurately grasp the research hotspots, and deeply understand the mechanisms of thematic evolution to enhance our ability to predict future development trends.

The Web of Science was selected as the data source for its international comparability, data availability and software adaptability. This effectively ensures the scientific accuracy of our results. This database includes international humanities and social sciences journals with significant influence, which are highly regarded academic journals, and their publications could represent the mainstream of university-industry collaboration research. 4 sub-databases of the WoS were selected as the data sources for this study, which are Science Citation Index Expanded (SCI-E), Social Sciences Citation Index (SSCI), Arts and Humanities Citation Index (A&HCI), and Emerging Sources Citation Index (ESCI). Among these sub-databases, ESCI includes new journals with great potential and regional academic impact, which can significantly broaden the search scope while maintaining the quality of publications [18].

As a part of the increase of policies emphasizing the marketing of research and the bonds between basic research and social needs, the study of U-I collaboration has emerged as a specific research field in the last three decades [19, 3]. Given this background, this study employed a “topic search” and set the search topics as "university-industry" and "university collaboration". The time interval was from 2012 to 2022, and included article and review article types. A total of 1,294 publications were retrieved, and 1093 of them were retained after manually eliminating non-academic articles, such as notices, interviews and book reviews, and irrelevant articles (retrieved in April 2023). The data were converted to UTF-8 format to be recognized by CiteSpace, and were finally de-duplicated.

3 Results

3.1 Growth trends and discipline distribution of literature

From 2012 to 2017, the overall trend of the number of papers about U-I collaboration has been increasing with fluctuations, remaining around 45 to 75 (see Figure.1). In 2018, there was a significant surge in the number of articles, which reached its peak at 166 in both 2020 and 2021. During the period of 2018-2021, U-I collaboration attracted a substantial number of researchers, leading to a steady increase in research intensity. The research gradually transitioned from an initial stage of explosive growth to a mature and stable stage. An inflection point occurred in 2022; however, research in U-I collaboration remained active, as the number of articles stayed consistently above 130.

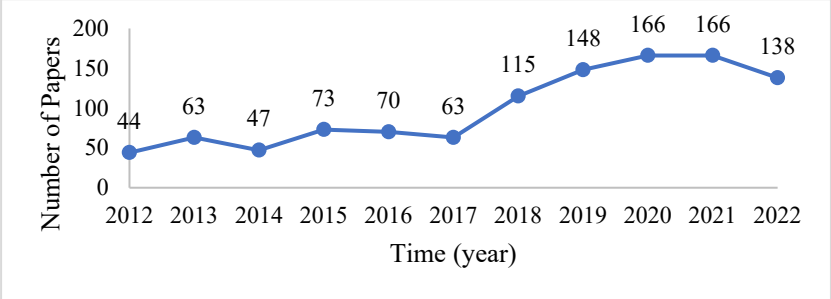

Fig. 1. Trends in literature growth of U-I collaboration research

The top ten disciplines in U-I collaboration research were identified based on the research areas covered in the sample literature (see Figure 2). Researchers from the fields of "Management", "Business", "Education & Educational Research", "Engineering Industrial", and "Information Science Library Science" conducted extensive research in the field of U-I collaboration, accounting for 33.27%, 12.12%, 9.42%, 9.17%, and 7.91% of the studies, respectively. The remaining disciplines encompassed "Environmental Studies", "Economics", "Regional Urban Planning", "Computer Science Interdisciplinary Applications" and "Environmental Sciences". From the perspective of disciplinary distribution, these intersecting disciplines validate the multifaceted nature of U-I collaboration, spanning research, industry, and management domains.

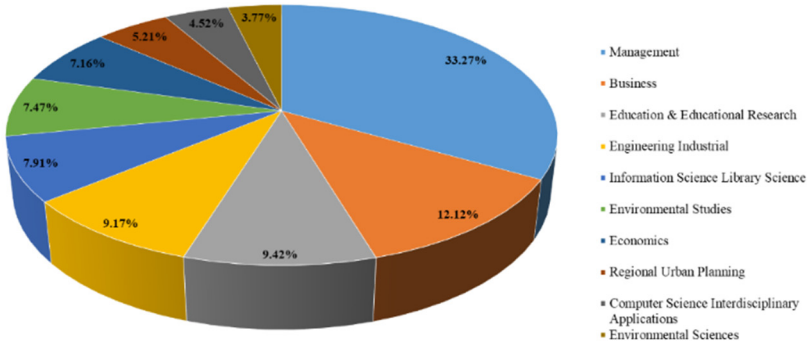

Fig. 2. Discipline distribution of U-I collaboration research

3.2 High frequency keywords and keyword co-occurrence analysis

A statistical analysis was conducted based on a sample of 1,093 articles. Due to space limitations, only the top ten high-frequency keywords are presented in this paper. The study identified the top three terms as "innovation," "performance," and "knowledge." Notably, "innovation" had a significantly higher frequency, occurring 331 times more frequently than the other keywords (see Table 1). Despite "innovation" having the highest frequency, it is "knowledge" that exhibits the highest centrality. This indicates that "knowledge" has the strongest association with other keywords, making it the most important key node during the period from 2012 to 2022.

Table 1. High-frequency keywords of U-I collaboration research

Frequency	Centrality	Keyword
331	0.01	innovation
237	0.02	performance
214	0.05	knowledge
210	0.02	university-industry collaboration
203	0.01	knowledge transfer
196	0.02	technology transfer
186	0.03	research and development
183	0.03	triple helix
146	0.02	science
143	0.03	firm

Among the top ten high-frequency keywords, only one term, "triple helix," is of theoretical nature. This theory, proposed by Henry Erzkowit, focuses on the university-industry-government relationship in the formation and implementation of innovation strategies. Erzkowit and Loet Leydesdorff pioneered triple helix innovation research in the 1990s [20]. The continued inclusion of "triple helix" among the top ten high-frequency keywords confirms its position as a mainstream research theory in the field of U-I collaboration.

While high-frequency keywords offer insights into research hotspots and trends in U-I collaboration to some extent, a linear arrangement based solely on frequency cannot comprehensively reveal their relationships. Hence, keyword co-occurrence analysis is necessary [21]. Centrality serves as a measure of keyword importance and reflects the overall network structure [22]. The size of keyword nodes and their links to other nodes visually represent centrality. Keywords that appear more frequently in the literature hold greater significance. Point centrality, intermediate centrality, and near-centrality are used to assess node centrality [23]. Figure 3 illustrates that "indicator", "model", "developing country", "open innovation", "public research", "Bayh-Dole Act", "knowledge", "cooperation", "university-industry interaction" and "strategy" rank among the top ten central keywords. These keywords dense connections with other terms, indicating their prominence and relevance to the current issues in U-I collaboration research.

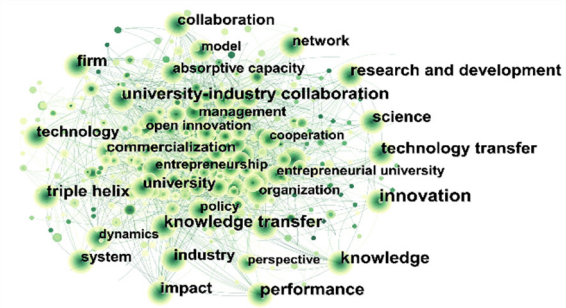

Fig. 3. Keyword co-occurrence network of U-I collaboration research

3.3 Keyword clustering analysis

Based on the clustering analysis results depicted in Figure 4, the modularity value Q is determined to be 0.3915, larger than 0.3, indicating a significant clustering structure.

Additionally, the weighted mean silhouette value is 0.7068, exceeding the thresholds of 0.7. These results indicate that the clustering structure is both significant and credible. The literature on U-I collaboration encompasses various clusters, including "technology transfer office", "collaborative agglomeration", "managing triple helix operation", "triple helix", "firm innovation", "emerging economies", "academic patent", "academic productivity", "top institution" and "university-industry collaboration" among others. “Technology transfer office” focuses on the transfer of knowledge. "Collaborative agglomeration" explores the collaborative innovation between universities and industries. "Managing triple helix operation" and "triple helix" involve theoretical research and the practical application of triple helix theory. "Firm innovation" centers around the innovation ecosystem within companies. "Emerging economies" discusses the role of open science in emerging economies. "Academic patent" and "academic productivity" emphasize university technology transfer and knowledge exchange."Top institution" pertains to the subject of technology transfer and the success rate of transformation. "University-industry collaboration" investigates the performance of organizational collaborations.

Fig. 4. Keyword clustering of U-I collaboration research

3.4 Keyword burst analysis

The top keywords in Figure 5 exhibiting the strongest citation bursts from 2021 to 2022 provide insights into the research frontiers during different periods [24, 25]. These bursts highlight emerging areas of research and increased scholarly attention. Among the identified keywords, "university industry government" demonstrates a higher citation burst. It not only appeared earliest but also had the longest duration, indicating its sustained relevance and impact over time. The keyword "university-industry linkage" displays the strongest citation burst, indicating a significant surge in research activity and attention. Its duration falls within the middle range, suggesting sustained interest and relevance during a specific period. During the specific period of 2012-2015, "South Korea" garnered attention in the field, while "US" became the focal point during 2016-2017. These countries were specifically relevant to the research landscape during those time frames. Starting from 2017, "case study" gained popularity in the field of U-I collaboration, indicating its growing significance and utilization as a research approach. In 2018, research began to incorporate students as a factor of consideration in the context of U-I collaboration, reflecting a shift or expansion in research focus.

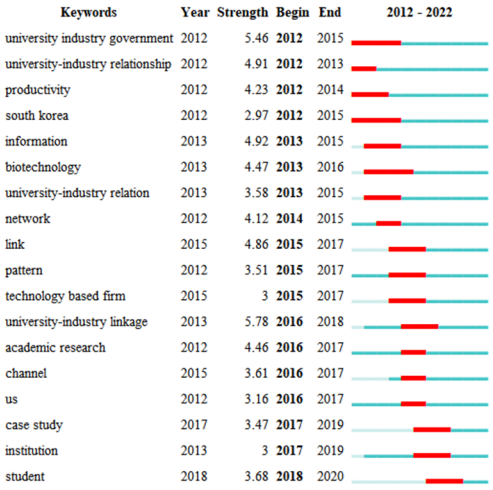

Fig. 5. Keyword bursts of U-I collaboration research

3.5 Co-citation analysis

The co-citation information of the literature was analyzed and 5 articles with high citation frequency were obtained, as shown in Figure 6. Perkmann and colleagues conducted an analysis in 2013 to examine the distinctions between academic engagement and commercialization, with a specific focus on knowledge transfer. Their study explored the involvement of researchers and institutions in U-I collaboration activities [26]. In 2015, Ankrah and AL-Tabbaa conducted a systematic review of the literature on universities-industry collaboration. Their study analyzed the formation, mechanisms, impediments, and outputs of U-I collaboration using a comprehensive procedure [9]. Esther de Wit-de Vries and her fellow researchers explored the factors that hinder or facilitate knowledge transfer in U-I collaborations. They identified knowledge differences and differences in goals resulting from diverse institutional cultures as significant barriers to knowledge transfer. Moreover, they highlighted trust, communication, the use of intermediaries, and experience as facilitators for knowledge transfer, which help overcome the identified barriers [27]. Rajalo and Vadi proposed a creative approach to explain the heterogeneity and variation of U-I collaboration at the individual level. Their aim was to reconceptualize the analysis of university-industry collaboration by developing an appropriate approach. They empirically tested this approach through multiple case-study research involving 12 cases [28]. Based on a proximity approach, Villani and their team developed a theoretical framework that elucidated how intermediary organizations can reduce cognitive, geographical, organizational, and social distance in U-I collaborations [29]. They also distinguished between Technology Transfer Offices, University Incubators, and Collaborative Research Centers, highlighting their respective differences [29].

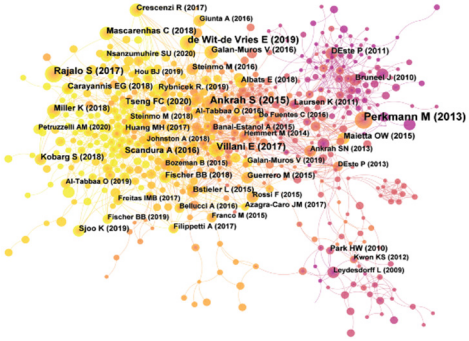

Fig. 6. Co-citation of U-I collaboration research

4 Discussion

4.1 Interdisciplinary research of U-I collaboration

Currently, the mainstream approach in U-I collaboration research is characterized by multidisciplinary participation, with Management Science emerging as the dominant field. This observation aligns with Gibbons' Knowledge Production Mode II, which emphasizes the breakdown of disciplinary barriers [30]. The extensive body of interdisciplinary research has contributed to the diversification and multi-perspectival nature of U-I collaboration, enhancing its overall breadth and depth. Apart from Management Science, researchers from Business, Education, and Engineering have significantly contributed to U-I collaboration research, collectively representing the largest proportion of published articles at approximately 64%. Nevertheless, the analysis reveals a fluctuating pattern in the number of articles published by Management Science researchers over the past five years, with an initial increase followed by a subsequent decrease. In contrast, the percentages of articles published by researchers from Business and Education have remained relatively stable. Notably, Environmental Studies & Sciences researchers accounted for a substantial proportion of 22% in published articles. When combined with Management Science researchers, their collective contribution reached 64%, establishing them as the main driving force in U-I collaboration research in 2021. In 2022, the proportion of Management Science publications declined from 44% to 32%, while the other four disciplines accounted for individual proportions ranging from 11% to 17%. This suggests that the top five disciplines engaged in U-I collaboration research have gradually achieved a state of balanced competition in terms of publication proportions between 2018 and 2022. These observations imply that future developments in U-I collaboration research are likely to exhibit a more interdisciplinary orientation.

4.2 Evolution path of U-I collaboration research

Analysis of the temporal mapping of U-I collaboration research, as depicted in Figure 7, reveals distinct evolutionary characteristics characterized by variations in the emergence time and duration of research segments and hotspots.

The first stage, spanning from 2012 to 2015, primarily focused on themes such as industry output, knowledge exchange, U-I relationship, and interaction. Researchers and enterprises were the main objects of study during this period. Subsequently, academic engagement, patent analysis, and innovation strategy became the primary topics, while objects of research turned into scientists and research institutions in this period. What is noteworthy is that the participation and interaction of governments and social capital in U-I collaboration gradually received scholars' attention. Along with the development of U-I collaboration research, topics like technology transfer, academic regulation and performance indicators have been proposed successively. Similarly, the linkage between academic community and industry remains as a hotspot and core of research.

The second phase is from 2016 to 2020, in which the research for U-I collaboration gradually matured and started to be polarized. On one hand, scholars shifted their attention beyond the association between universities and enterprises to explore how U-I collaboration contributes to the development of innovation ecosystems from a macro perspective of regional and national innovation. On the other hand, researchers began investigating micro-level factors and challenges hindering U-I collaboration, striving to establish optimized collaboration models with broader applicability through the examination of typical cases. This phase also introduced the concept of sustainability-oriented innovation in relation to U-I collaboration research.

The third phase is from 2021 to the present. This stage represents the maturation of U-I collaboration research. However, the analysis of Figure 7 indicates that since 2021, no particular prominent keyword nodes have emerged, and there is a lack of concentrated distribution of keyword nodes. This suggests that although research on U-I collaboration has witnessed enrichment based on previous studies, it has not formed a systematic research hotspot or focus. The research landscape is characterized by increased diversification and scattered interests [31].

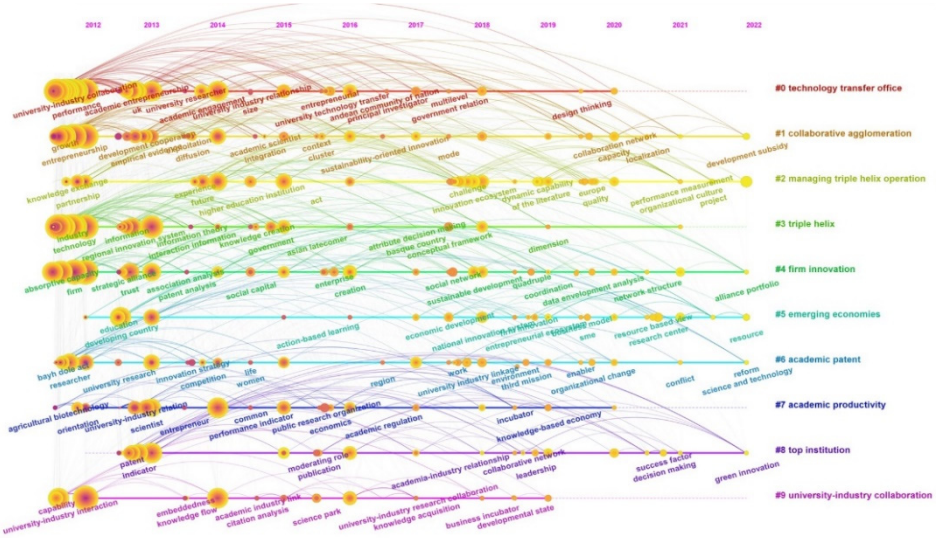

Fig. 7. Evolution path of U-I collaboration research

4.3 Holistic ecosystems of U-I collaboration

U-I collaboration holistic ecosystems takes universities and enterprises as the main carrier, and introduces various theories such as industry-university-research collaborative innovation, triple helix and even multiple helix [32]. Its ultimate purpose is to establish a spontaneous evolutionary system that promotes the transformation of innovation and scientific achievements of universities, which is an important internal factor to promote knowledge spillover from universities.

Recently, research on U-I collaboration has generally focused on vertical integration and improving university-government-enterprise interface, while less research has been conducted on academic-industrial community and U-I innovation alliance. Figure.7 shows that "collaboration network" and "innovation ecosystem" are more prominent in the second phase of research, but not enough attention has been paid to them in the third phase. Research has highlighted the benefits of collaborative knowledge-creation within university–industry consortia, yet little attention was given for a holistic approach to U-I collaboration and to the organizational design framework that is fruitful by participants [33]. Many scholars have even found that the current U-I collaboration is relatively independent in economic development, not well integrated into local industrial clusters, and the links with the upstream and downstream of the industrial chain are not strong enough [34, 35, 36].

U-I collaboration is a knowledge-sharing system that rely on a "nested network" approach [33]. Therefore, the lack of holistic ecosystems that focus on the cooperation between universities and enterprises will significantly block the interaction channels of U-I interaction and reduce the efficiency of the cooperation between them. This will lead to a low coupling between U-I collaboration development and local economic development. U-I collaboration cannot fully meet the needs of regional innovation development. Moreover, a good U-I collaboration model cannot be replicated and generate scale benefits, or it is extremely difficult to implement. As a result, it is one of the keys of future U-I collaboration research to explore how to link U-I collaboration with regional economic development, to build an academic-industrial community with universities as the source of innovation and enterprises as the intermediate place for the transformation and incubation of achievements. Establishing a closed-loop ecosystem of U-I collaboration should be attached to much more importance [21].

5 Conclusions and limitations

This study takes the research on U-I collaboration included by the Web of Science from 2012-2022 as a sample, and analyzes the trend of U-I collaboration research in the last decade in terms of literature publication trends, discipline distributions, research hotspots, evaluation path, research trends and other characteristics. Based on the aforementioned results and discussion, the main conclusions of this study are as follows:

(1) In the past decade, U-I collaboration research has experienced the research trend of "steady development-rapid growth-retracement" and has now matured. The distribution of disciplines is multidisciplinary, with Management Science occupying a major position, whereas, according to the research trends in the past five years, it can be predicted that the trend of multi-polarization in this field will be further strengthened.

(2) The most frequent keywords in U-I collaboration research are innovation, performance and knowledge. The mainstream research theory in this study area is triple helix. Hotspot topics included technology transfer office, collaborative agglomeration, managing triple helix operation, etc., and their average duration is about 1.9 years.

(3) U-I collaboration research has distinctive evolutionary features and its evolutionary path has gone through three stages. The first stage focuses on researchers and enterprises themselves, and the scope of research includes industry output, knowledge exchange, and the association between universities and industry. The second stage shows the polarization of research. On the macro level, U-I collaboration research with the purpose of promoting regional innovation and national economy appears; on the micro level, a lot of research with the purpose of solving obstacles to university industry cooperation and proposing optimization measures appears. In the third stage, the research system has matured and the it tends to be diversified.

(4) It is found that the research on U-I collaboration is more focused on vertical integration and improving university-government-industry collaboration, and less on academic-industrial community. In the future, researchers should explore more about how to establish a closed-loop ecosystem of academic-industrial collaboration.

The results of this study are limited since its analysis database only included the Web of Science and the time window of literature merely covered from 2012 to 2022, which is not long enough to show the whole research history of U-I collaboration. Results could provide more significant information with long time windows regarding regional investigations, so future research should enlarge time windows of data and conduct research regarding certain areas.

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