

Research Hotspots and Cutting-Edge Discussions on Digital Innovation Ecosystems

Ziyi Yu, Zheng He*, Tao Zeng

School of Management, Xi'an Polytechnic University, Xi'an, 710048, China

*Corresponding author: Zheng He, heehzheng_128877@163.com

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Abstract: In the context of the digital transformation of the global economy, the digital innovation ecosystem has become the core engine driving economic growth and social progress. Based on CiteSpace knowledge mapping and bibliometrics, this paper systematically compiles the research hotspots and cutting-edge trends in this field, and reveals its theoretical evolution and practical development. It is found that the research themes of digital innovation ecosystem focus on technological innovation and value creation, ecosystem evolution mechanism, path selection and sustainable development. Platform enterprises, as the core architects, promote complementary innovation and optimal allocation of resources through the formulation of technical standards and governance rules, and promote the sustainable development of the ecosystem. However, system evolution faces challenges such as technology path dependence, increasing digital divide, and environmental resource pressure. Future research should deepen the enabling mechanisms of digital technologies, strengthen the study of dynamic evolution mechanisms, expand cross-cultural and cross-regional comparative studies, and focus on its synergistic evolution with sustainable development.

Keywords: Digital Transformation; Innovation Ecosystem; CiteSpace; Bibliometrics

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Introduction

With the worldwide transformation of economic patterns towards digitization, innovative digital ecosystems have gradually become a key driving force for the economic uplift and social development of all countries. As the world's second-largest economy, China has attached great importance to digitalization in recent years, incorporating it into its strategic planning at the national level. Especially in 2021, the relevant departments issued a series of guiding documents such as the "14th Five-Year Plan for the Development of the Digital Economy", which provides policy protection and directional guidance for the orderly development of the digital economy. These policies are committed to promoting the deep integration of digital technology and the real economy by optimizing the digital innovation environment, strengthening the construction of digital infrastructure, and promoting the market allocation of data elements^[1]. The rapid development of digital technology is reshaping the allocation of innovation resources and injecting new vitality into the science and technology innovation ecology^[2]. This innovation model breaks through the limitations of traditional theories, and through the deep integration of information technology, products and services, it not only changes the product form and service mode, but also the wave of digital transformation is reshaping the economy and society in many dimensions. On the demand side, consumers'

purchasing behaviors and preferences have significantly changed; on the supply side, enterprises have adjusted their operation modes to adapt to the new environment; and on the market level, the competitive situation of the industry has also shown different characteristics from the past^[3]. At the same time, the evolution path and organization of technological innovation are undergoing profound changes, mainly due to the continuous penetration and integration of the new generation of digital technologies. Collaboration among enterprises and between enterprises and other organizations has become increasingly close, and partners, funds, resources, suppliers, R&D transformation and customers and other elements have formed a wider and deeper network^[4]. This technology-driven innovation model not only expands the theoretical boundaries of the traditional innovation ecosystem, but also gives it a new connotation^[5]. Therefore, in-depth investigation of the operation mechanism of digital innovation ecosystem and its symbiotic evolution path is of great significance for both theoretical research and practical development.

In recent years, with the in-depth promotion of digital transformation, digital innovation ecosystem research has gradually become a hot topic of academic attention. This emerging research field has evolved along with the rapid development of new-generation information technologies such as artificial intelligence and big data, and its theoretical boundaries and research scope have continued to expand. International academics have carried out multi-dimensional exploration around this topic, focusing on core issues such as system composition, operation logic, development trajectory and its socio-economic effects. Meanwhile, domestic researchers have also actively engaged in this field, promoting the construction and improvement of the relevant theoretical system through diversified research perspectives and methods. For example, Lv Kun et al.^[6] constructed the analytical framework of “center-periphery” from the perspective of system elements. In terms of system hierarchy, Xu^[7] proposed a four-level model, which subdivided the system structure into kernel, core, expansion and derivation layers, which provides a new way of thinking to understand the hierarchy of innovation ecosystems. In addition, Ma^[8] used the scientometrics method to systematically trace the theoretical origin of innovation ecosystems through bibliometric analysis, and made an in-depth combing of its knowledge evolution vein, which laid an important foundation for the subsequent research; while foreign scholars paid attention to the research of digital innovation ecosystems earlier, Lopez^[9] put forward the framework of the innovation strategy under the perspective of ecosystems, which emphasized the value co-creation and ecosystem competition; Quero^[10] focused on platform ecosystems and explored the interaction mechanism of platform leaders and complementaries; Rentschler^[11] systematically sorted out the conceptual connotation, characteristics and evolution mechanism of digital innovation ecosystems; and Draschbacher^[12] constructed a theoretical model of digital innovation ecosystems’ value creation from the perspective of value co-creation. model. Although academics have made some progress in the construction of the knowledge system and development of the innovation ecosystem and its digitalization process, the theoretical foundation of the digital innovation ecosystem is still weak. Specifically, the definition of core concepts is still controversial, the research paradigm has not yet been unified, and the boundaries of disciplines are ambiguous. To a certain extent, these theoretical deficiencies have constrained the in-depth development of the field, and also provided room for exploration for subsequent research. Existing studies are mostly confined to specific fields and lack a systematic exploration of the knowledge structure and research trends of digital innovation ecosystems from a holistic perspective. This status quo highlights the urgent need to explore the research hotspots and frontiers in this field from a macro level. From a methodological point of view, the application of knowledge mapping analysis technology in China’s academic research is still in a preliminary stage of exploration, and the depth and breadth of its practice in different disciplines need to be further expanded. As an advanced scientometric tool, CiteSpace, with its powerful data processing and visualization functions, can effectively reveal the development of a specific research theme, clearly show the key nodes and cutting-edge trends in the evolution of disciplines, provide powerful technical support for researchers to grasp the development trend of the field, and provide strong methodological support for the study of digital innovation ecosystem^[13]. This knowledge graph-based analysis method not only helps to clarify the research lineage, but also provides scientific guidance for the future research direction.

Based on the comprehensive examination of existing theoretical research and practical progress, this study adopts a mixed research method, combining bibliometric analysis with knowledge mapping technology. The research data comes from the internationally renowned Web of Science database and the domestic authoritative China Knowledge Network platform.

By systematically collecting and organizing the relevant English literature, and using CiteSpace visualization and analysis tools, the study analyzes the whole research landscape in the field of digital innovation ecosystems in a multi-dimensional way, aiming at revealing the trajectory of the development and the hotspots of research in this field. The study focuses on the development overview, research hotspots and evolutionary trajectory of the field, refines the core research content through systematic analysis, and prospectively explores the future research direction. This study not only helps to deepen the theoretical construction of digital innovation ecosystem, but also provides a reliable theoretical basis and practical guidance framework for subsequent research.

1.Data sources and research methodology

1.1 Data sources

The literature data source of this paper consists of two parts, domestic and foreign, and the starting date of searching is set as January 2015, and the deadline is set as January 2024. The foreign literature data comes from Web of Science database, with “Digital Innovation Ecosystem” and “Digital transformation” as the keywords. After eliminating the search results of duplicated literature and non-relevant disciplinary content, 301 foreign literatures were finally obtained; the domestic literature data came from the China Knowledge Network (CNKI) database, with the keywords “Digital Innovation Ecosystem”, “Innovation Ecosystem”, “digital transformation” as keywords, after eliminating the search results of duplicated literature and non-relevant disciplinary content, 224 effective documents were finally obtained, and the specific search method is shown in Table 1.

Table 1 Literature search methods related to digital innovation ecosystems

form	comprehensive database	Search method	Type of literature	time span	retrieval time	Search results
English Literature Search	WoS database	TS = “Digital Innovation Ecosystem”, etc.	Article	2015-2024	February 2025	Part 301
Chinese Literature Search	China Knowledge Network Database	keyword = “digital innovation ecosystem”, etc.	periodicals	2015-2024	February 2025	224 articles

1.2 Research methodology

This study adopts a quantitative research method to systematically analyze the research data through bibliometric means. Firstly, Excel and other data processing tools are used to carry out basic statistical analysis of the literature in the field, and then the CiteSpace visualization and analysis platform developed by Chen’s team is introduced to carry out in-depth mining of the literature data in the field of digital innovation ecosystems and the construction of the knowledge graph, so as to realize the visual presentation and interpretation of the research topic. The software is able to form a knowledge map with dynamic, diversified and time-sharing characteristics in time by clustering and burst analysis of keywords, authors, institutions and even citations on the basis of knowledge unit analysis, and at the same time embedding a series of artificial intelligence algorithms, such as text processing, data mining and detection, etc., to draw the interconnection between the required information.

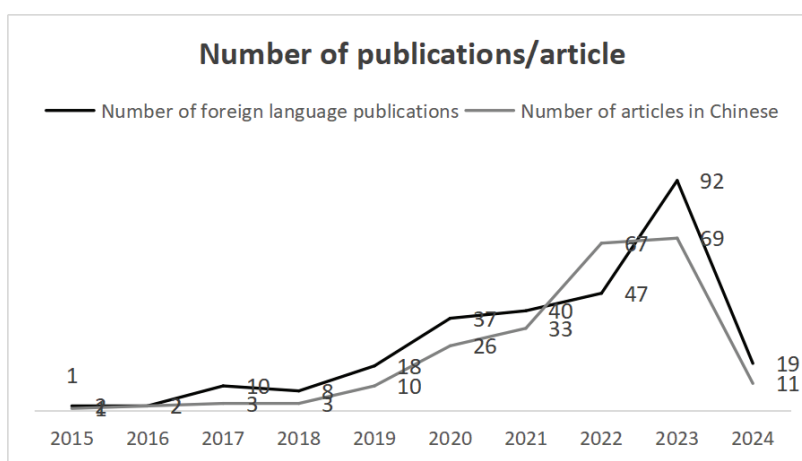
Utilizing the above tools, this paper analyzes the existing studies on digital innovation ecosystems by bibliometrics and text mining, in order to reveal the structure, characteristics and regularity of the studies on digital innovation ecosystems. Through the statistical analysis of the original research data, this study conducts a quantitative study in terms of the growth trend of the number of documents, the cross-disciplinary characteristics and the distribution pattern of journals. This analytical process helps to grasp the overall development profile and disciplinary distribution characteristics of this research topic. Finally, we analyze the co-occurrence of keywords and draw a more ideal keyword clustering time view and keyword clustering information table by appropriately adjusting the parameter settings, so as to systematically summarize the main research hotspots emerging from the digital innovation ecosystem as well as the evolution trend of the research hotspots, in order to more comprehensively grasp the current research frontiers.

2. Visual analysis of digital innovation ecosystems

2.1 Analysis of the volume of publications

Since 2015, the literature on digital innovation ecosystem research at home and abroad has continued to grow every year (see Figure 1). Taking 2021 as the time point, the amount of English literature issued has seen a sustained and substantial growth, much higher than that of Chinese literature, and with the development and progress of the research direction, the amount of Chinese literature issued has begun to fall back and stabilize. From the point of view of foreign research: the number of articles issued during the period of 2016-2019 is developing steadily, and the number of articles issued from 2021 to the present is developing rapidly. From the viewpoint of domestic research: from the perspective of the time dimension, the output of research results in this field presents obvious stage characteristics. The research data show that the number of literature maintains a stable growth trend between 2018 and 2020, while significant fluctuations occur after 2022. It is worth noting that after reaching the historical peak in 2024, the annual literature output gradually leveled off, indicating that the research field may have entered a relatively mature stage of development. The point at which the number of domestic publications reaches the peak of the phase shows that domestic research is closely related to the policies introduced at the national level.

Figure 1 Annual Distribution of Digital Innovation Ecosystem Literature at Home and Abroad, 2015-2024



2.2 Analysis of disciplines and journals

According to the statistics, the domestic literature on digital innovation ecosystem is scattered and published in 132 journals, and overall, the distribution of journals is relatively wide. The top 10 journals have published 77 papers related to digital innovation ecosystems (see Table 2), 34.37% of the academic papers related to digital innovation ecosystems are published in 1.3% of the journals, indicating that the main journals carrying articles about digital innovation ecosystems in China are relatively concentrated.

Table 2 Names of domestic source publications

rankings	Name of source publication	record (in sports etc)
1	Scientific and technological progress and responses	15
2	scientific research	14
3	Science and Technology Management Research	9
4	research management	8
5	China Science and Technology Forum	6
6	Industrial Technology and Economics	6
7	techno-economic	5
8	Technical Economics and Management Studies	5
9	Science and Science and Technology Management	5
10	soft sciences	4

In terms of discipline distribution, the main journals carrying articles in the field of digital innovation ecosystem in China are mostly concentrated in the disciplines of enterprise economy, industrial economy, macroeconomic management and sustainable development, economic system reform, scientific research management and so on. In foreign countries (see Table 3), the distribution of journals of digital innovation ecosystem research literature presents similar to that in China, with the top 10 journals in terms of publication volume publishing a total of 206 articles, accounting for 68.43% of the total number of articles published in foreign language literature, which is a more concentrated distribution.

Table 3 Names of foreign source publications

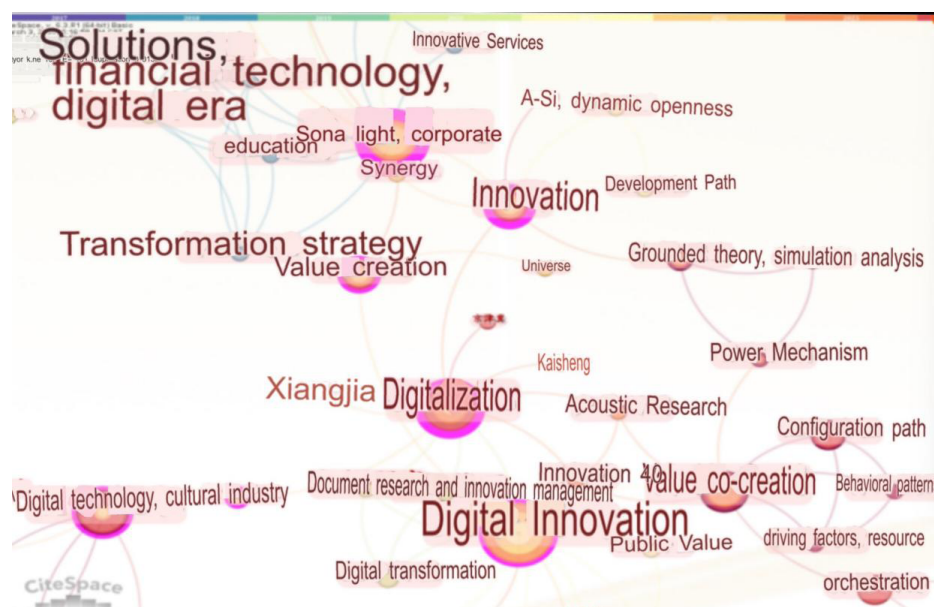
rankings	Name of source publication	record (in sports etc)
1	TECHNOVATION	34
2	SUSTAINABILITY	33
3	MIS QUARTERLY	28
4	IEEE ACCESS	24
5	JOURNAL OF ENGINEERING AND TECHNOLOGY MANAGEMENT	17
6	COMPUTERS & INDUSTRIAL ENGINEERING	17
7	JOURNAL OF STRATEGIC INFORMATION SYSTEMS	14
8	IEEE TRANSACTIONS ON ENGINEERING MANAGEMENT	13
9	HELIYON	13
10	EUROPEAN JOURNAL OF INFORMATION SYSTEMS	13

3. Research Hot Spots and Research Trends

3.1 Keyword co-linear analysis

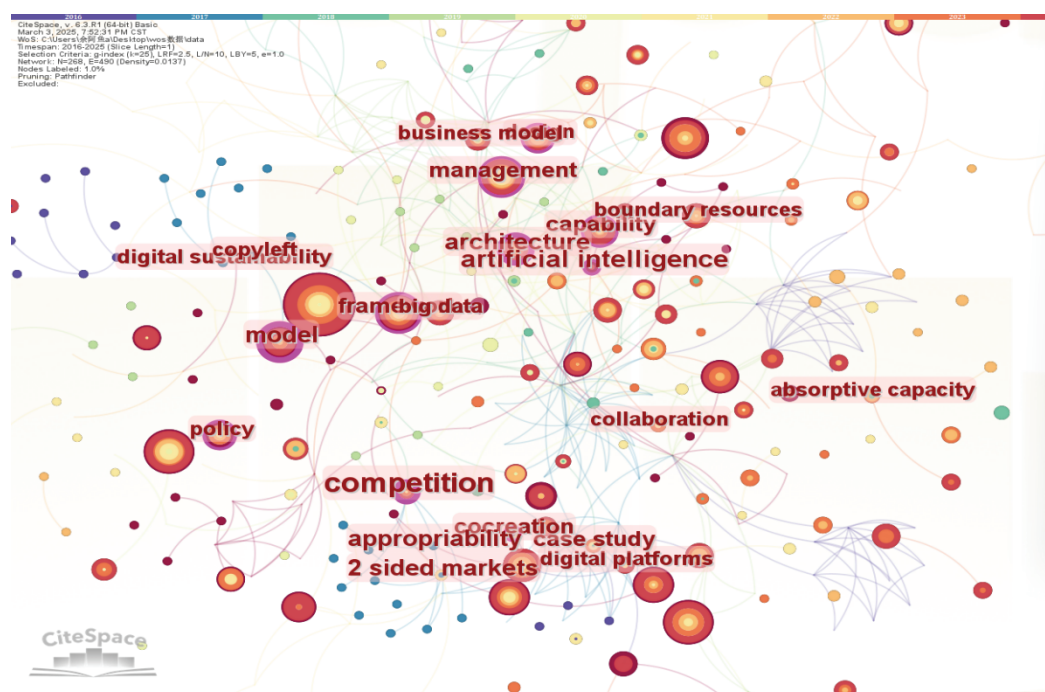
In view of the current theoretical research foundation and the development trend of the discipline, this study adopts CiteSpace, a knowledge visualization tool, and bibliometrics to systematically research the relevant English-language literature included in CNKI and WoS databases. By integrating and analyzing the academic resources of the two databases, the study focuses on the overall development of the field of digital innovation ecosystems, the distribution of core issues and the evolution path of the discipline, and then summarizes the key research themes in the field and analyzes the predictive trend of the future development of the field. The establishment of this research path is not only conducive to the improvement of the theoretical system of digital innovation ecosystems, but also provides a systematic academic reference and practical guidance for the subsequent exploration of this field.

Fig. 2 Knowledge map of keyword co-occurrence in domestic digital innovation ecosystems



This study adopts the knowledge graph analysis method to carry out a metrological study of related literature worldwide with the help of CiteSpace visualization tool. Through in-depth mining of massive literature data, keyword co-occurrence network analysis was conducted systematically, and a knowledge map reflecting the research hotspots of digital innovation ecosystem was drawn. The results of this visualization analysis clearly show the distribution of research topics and their intrinsic connection, which provides an important reference for grasping the development dynamics of the discipline. The research data show that the graph generated by the WoS database contains 198 keyword nodes, forming 873 associated lines, with a network density of 0.0448 (shown in Figure 3). The size of the nodes in the graph is positively correlated with the frequency of keyword occurrence, and the node color gradually changes from the center to the periphery, reflecting the temporal distribution characteristics of the research topic - the darker the color of the periphery, the more relevant research is concentrated in the recent past. This visualization result contrasts with the analysis results of CNKI domestic database, which intuitively demonstrates the hotspot distribution and evolution trend of international research.

Fig. 3 Knowledge map of keyword co-occurrence in foreign digital innovation ecosystems



Through the above comparative analysis, it is found that domestic scholars pay more attention to the keywords of ecosystem, digitization, value deduction, digital technology, etc., while the keywords of competition, model, artificial intelligence, information technology, etc., are widely paid attention to and discussed by foreign scholars. The study shows that although there are significant differences in the research focus of domestic and foreign academics in the field of digital innovation ecosystem, the core issues are centered on the two basic dimensions of “digital innovation” and “ecosystem”. Specifically, domestic research focuses more on the practical application of the theory, while international academics tend to explore the key technological elements that support digital innovation ecosystems. This difference in research orientation reflects the diversity of research perspectives in different academic contexts, as well as the richness and multidimensionality of research content in this field.

3.2 Keyword clustering analysis

Keyword clustering analysis is an effective method to reveal the knowledge structure and developmental lineage of the research field. In this study, the LLR algorithm in CiteSpace software is used to cluster the literature data, and the distribution characteristics of the research topics are presented through visual mapping. The clustering effect is mainly evaluated based on two quantitative indexes: module value (Q value) and profile value (S value). When the Q-value exceeds 0.3, it indicates that the clustering structure is statistically significant; the S-value is greater than 0.5 means that the clustering results are reasonable, and if it exceeds 0.7, it indicates that the clustering credibility is high. This method can help researchers

The keyword clustering time series mapping of the literature on supply chain digital transformation from China Knowledge and WOS databases are shown in Figures 4 and 5.

v6.1.R0 (64-bit) Basic
 Strategy: t1: 0.02 w: 0.32 z: 0.15
 PNF: 0.00000000
 Selection Criteria: p-value (q=0.95), LRF=0.0, L/N=10, LRF=0.5, w=1.0
 Software: 3/1/2022 10:07:17 (Density=0.9448)
 Largest CC: 108 (94%)
 Modularity: 0.974
 Pruning: None
 Modularity Q=0.98
 Weighted Mean Silhouette S=0.9126
 Harmonic Mean Q, S=0.9427

#0 digital transformation
 #1 smart contracts
 #2 sustainable supply chain management
 #3 uncertainty
 #4 digital servitization strategies
 #5 supply chain integration
 #6 digital technologies
 #7 dig data analytics
 #8 sustainable development

CiteSpace
 v6.1.R0 (64-bit) Basic
 Strategy: t1: 0.02 w: 0.32 z: 0.15
 PNF: 0.00000000
 Selection Criteria: p-value (q=0.95), LRF=0.0, L/N=10, LRF=0.5, w=1.0
 Software: 3/1/2022 10:07:17 (Density=0.9448)
 Largest CC: 108 (94%)
 Modularity: 0.974
 Pruning: None
 Modularity Q=0.98
 Weighted Mean Silhouette S=0.9126
 Harmonic Mean Q, S=0.9427

CiteSpace v. 5.8.R1 (64-bit) Basic
 March 3, 2026, 8:42:29 PM CST
 Modularity Q=0.9826 Weighted Mean Silhouette S=0.9826
 Weighted Mean Q=0.9826 Weighted Mean Silhouette S=0.9826
 Selection Criteria: g-index (k=20), LRF=2.5, M=10, LB=10, LB=10, e=1.0
 Network: W=0.9826, S=0.9826 (MeanQ=0.9826)
 Largest CC: 253 (84%)
 Nodes Labeled: 1.0%

Pruning: None
 Modularity Q=0.9826
 Weighted Mean Silhouette S=0.9826
 Harmonic Mean(Q, S)=0.9826
 Excluded: 2016

2017 2018 2019 2020 2021 2022 2023 2024 2025

#0 digital servitiz...
 #1 basic condition
 #2 digital transfor...
 #3 platform feature
 #4 o2o citizen part...
 #5 models-an explor...
 #6 digital ecosyste...
 #7 conceptual frame...
 #8 new venture
 #9 empowering 6g co...
 #10 organizational c...

From Figure 4, Chinese literature research mainly emerged in 2018, and before 2018, research on digital innovation ecosystem aspects in China is still in a blank stage. Domestic literature mainly focuses on the content of five themes, including

digital economy (#0), ecosystem (#1), value co-creation (#2), digital innovation (#3), digital technology (#4), and complements (#5). Among them, Digital Economy (#0) has been the hotspot of domestic scholars' research from 2018-2025, the application of Digital Innovation (#3) in supply chain has been deeply concerned by scholars since 2019, and Ecosystem (#1) and Value Co-creation (#2) have been gradually incorporated into scholars' research in 2019 2020, respectively.

From Figure 5, English literature research has been covered since 2016. Its keywords have been classified into 10 categories: digital servitization (#0), basic condition (#1), digital transformation (#2), platform feature (#3), o2o citizen partment (#4), and so on. Among them, basic condition (#1), platform feature (#3) have been concerned by foreign scholars from 2012-2022, digital servitization (#0), digital transformation (#2), o2o citizen partment (#4) have entered the research scope of scholars from 2017, and have been focused on by foreign scholars. digital servitization (#0), basic condition (#1), digital transformation (#2), and new venture (#8) have received more attention from foreign scholars in the recent years have received more attention from foreign scholars and become the research hotspot in recent years.

The keyword clustering information of digital innovation ecosystems in China Knowledge Network and WoS database literature is shown in Table 4 and Table 5, respectively.

Table 4 Keyword clustering information of literature in digital innovation ecosystems

China Knowledge Network database

serial number	Size	S-value	particular year	LLR clustering keywords (partial)
#0	32	0.996	2020	Digital economy, digitization, application scenarios, cloud services, paperless, digital middleware
#1	13	0.869	2021	Ecosystems, continuous improvement, sustainable procurement, Green New Deal, strategic transformation
#2	11	0.932	2021	Value co-creation, manufacturing, whole industry chain, value chain, innovation chain, double cycle
#3	9	0.972	2020	Digital Innovation, Blockchain, Cloud Computing, Artificial Intelligence, Internet of Things, Big Data
#4	7	0.993	2021	Digital technology, cloud manufacturing, real-time monitoring, online monitoring, smart factory, intelligence
#5	6	0.968	2020	Complementarities, industrial economy, diffusion of innovations, level of modernization, synergistic operations

Table 5 Keyword clustering information for the digital innovation ecosystem WoS database literature

serial number	Size	S-value	particular year	LLR clustering categories
#0	31	0.753	2019	digital servitization
#1	29	0.760	2018	basic condition
#2	27	0.643	2018	digital transformation
#3	22	0.768	2021	platform feature
#4	20	0.989	2021	o2o citizen partment
#5	18	0.808	2021	Models-an explorer
#6	12	0.986	2018	digital ecosystem
#7	10	0.950	2016	Conceptual framework
#8	10	0.875	2017	New venture
#9	7	0.915	2021	Empowering 6g condition
#10	6	0.672	2017	Organization

Data analysis shows (see Tables 4 and 5) that the average contour value S of all subclusters exceeds 0.5, indicating that the results of cluster analysis are reliable and representative. By comparing the clustering characteristics of the Chinese and English literature, it can be found that despite the differences in the research perspectives of domestic and international scholars on digital innovation ecosystems, they all focus on the core topic of digital transformation and technological innovation in the context of the digital economy. The research data further reveal that the international research in this field started earlier, while the domestic related research is mainly concentrated after 2018, and the research hotspots show an obvious chronological evolution characteristic.

4. Analysis of research frameworks for digital innovation ecosystems

4.1 Connotation of digital innovation ecosystem and related theoretical foundations

Digital innovation ecosystem refers to a dynamic evolutionary system driven by digital technology and jointly constructed by multiple subjects (enterprises, universities, research institutions, governments, users, etc.) through open collaboration, resource sharing, value co-creation, etc., aiming at realizing digital technological innovation, application, and diffusion, and ultimately promoting high-quality economic and social development^[14]. In the theoretical exploration of digital innovation ecosystem, scholars have put forward insightful views from different perspectives. Some researchers have focused on exploring the technology-driven factors, such as Ren Rongrong, who pointed out that the emerging information technology represented by cloud computing and big data constitutes the core driving force of the system development, which promotes the in-depth fusion and innovative application of technologies^[15]. At the same time, Regel and other scholars draw on the theory of ecology to regard digital innovation as a complex system with the participation of multiple subjects, focusing on analyzing the synergistic mechanism and evolutionary law among the participating elements^[16]. From the perspective of research scope, the field has formed a relatively complete research framework, and foreign scholars represented by Camila mainly focus on the core issues such as the basic theory of the system, structural characteristics, development laws and governance strategies^[17]. Domestic scholars, Shi Jianning, focus more on the construction path, policy support, and case studies of digital innovation ecosystems in the Chinese context^[18]. To summarize, scholars' research on digital innovation ecosystem covers many aspects such as system concept, development and evolution law, and role mechanism, which lays a solid foundation for subsequent research.

4.2 Analysis of research themes in digital innovation ecosystems

Systematically exploring the core issues of digital innovation ecosystem not only helps to grasp the current research dynamics, but also provides a basis for predicting the future development direction. Based on the results of keyword co-occurrence analysis, combined with the literature review, it is found that the research in this field mainly focuses on the following dimensions: the reasons and evolution mechanism of digital innovation ecosystems, the evolution strategy and path selection of digital innovation ecosystems, and the evolution results of digital innovation ecosystems.

4.2.1 Evolutionary mechanisms of digital innovation ecosystems

The dynamic development of the digital innovation ecosystem is mainly due to the continuous promotion of technological innovation. The disruptive technology clusters represented by cloud computing, artificial intelligence, etc. have continuously broken through the existing technological boundaries, and injected a strong impetus for the evolution of the system through technological integration and collaborative innovation. The iterative upgrading of these emerging technologies not only solves the many limitations under the traditional technological framework, but also opens up new development space and application scenarios for digital innovation^[19]. At the same time, the constant changes and upgrading of user needs also drive the continuous evolution of the digital innovation ecosystem. For example, Huy^[20] pointed out in his study of the development of China's e-commerce platform that it has driven the transformation of e-commerce platforms from pure commodity trading platforms to comprehensive service platforms, which in turn has led to the evolution of the entire e-commerce ecosystem. Jointly promoting digital technology innovation, application and proliferation^[21]. Pham^[22] stated that when studying the autonomous driving ecosystem, he found that close cooperation between automobile manufacturers, technology companies, universities and research institutes, government departments and other subjects is a key factor in promoting the rapid development and commercial application of autonomous driving technology. Shen^[23] believes that the

interaction between the subjects within the system will spontaneously form a certain order and structure, and emerge new functions and characteristics. Wang^[24] believes that in studying the open source software ecosystem, it is found that the self-organizing mechanism of the open source community and the active participation of community members promote the rapid development and innovation of open source software. In summary, the evolution of the digital innovation ecosystem is a complex and dynamic process that is the result of a variety of factors such as technology, demand, subject, environment, and system. Future research can further focus on the power mechanism, path selection, governance model and other issues of digital innovation ecosystem evolution to provide theoretical support and practical guidance for building a healthy and sustainable digital innovation ecosystem.

4.2.2 Evolution Strategy and Path Selection of Digital Innovation Ecosystems

The evolution of the digital innovation ecosystem requires multiple subjects to collaboratively develop and implement effective strategies to cope with the complex and changing environment and challenges. Scholars at home and abroad have proposed a variety of evolution strategies from different perspectives. First, strengthening the breakthrough of core technology and consolidating the foundation of digital innovation, core technology is the root of the development of digital innovation ecosystem^[25]. For example, Li^[26] pointed out in her research on the development of the chip industry that strengthening the independent research and development of core technology is the key to breaking the monopoly of foreign technology and building a safe and controllable chip industry ecosystem. The government should encourage the construction of an open, shared, and collaborative digital innovation platform to promote the efficient flow and allocation of innovative resources such as data, technology, and talent. For example, Sun^[27] pointed out in his research on the development of industrial Internet platform that building an open and collaborative industrial Internet platform can promote the digital transformation and intelligent upgrading of manufacturing enterprises. The government should encourage enterprises to actively participate in international standardization and technical cooperation, integrate into the global digital innovation network, and enhance the international competitiveness of China's digital innovation ecosystem. For example, Lago^[28] pointed out in his study of open source software ecosystems that active participation in the international open source community can enhance the international influence of China's open source software ecosystem.

The path selection of digital innovation ecosystem is a complex and dynamic process, which needs to be considered comprehensively according to its own resource endowment, development stage, external environment and other factors. Oriented by the breakthrough of core technology, it can build a digital technology innovation highland with international competitiveness by increasing R&D investment, introducing high-end talents, and strengthening the cooperation between industries, universities and research institutes. For example, Zhou^[29] pointed out in his study of the development experience of Silicon Valley in the United States that the success of Silicon Valley is due to its strong scientific and technological innovation capability and active entrepreneurial atmosphere, which provides useful reference for the construction of China's digital innovation ecosystem. Guided by market demand, we cultivate and grow the digital industry through the development of digital products and services that satisfy users' needs, forming a virtuous cycle of market ecology. For example, when studying the development of China's e-commerce platform, Rong^[30] pointed out that the success of e-commerce platforms such as Alibaba is due to its keen market insight and strong user base, which provides important insights for the construction of China's digital innovation ecosystem. With the goal of ecological construction, a symbiotic and co-prosperous digital innovation ecosystem is formed by creating a favorable innovation ecosystem, attracting and cultivating diversified innovation subjects. For example, Huang Shan pointed out in his study of open source software ecosystems that the self-organizing mechanism of open source communities and the active participation of community members are the key to the success of open source software ecosystems^[31].

The benign development of the digital innovation ecosystem relies on the collaborative participation and continuous investment of multiple actors. Stakeholders such as governments, enterprises and academic institutions need to form a synergy to promote the innovative breakthroughs and practical applications of digital technologies through the formulation of scientific development strategies, so as to promote the transformation and upgrading of the economy and society. It should be emphasized that due to the differences in the development foundation and resource endowment of each region, the

construction path of digital innovation ecosystems should be adapted to local conditions, and a development model suitable for its own characteristics should be explored in practice. Future research can further focus on the evaluation index system, influencing factors, optimization strategy and other issues of digital innovation ecosystem path selection, so as to provide theoretical support and practical guidance for the construction of digital innovation ecosystem.

4.3 Exploring the research frontiers of digital innovation ecosystems

4.3.1 Technological innovation and value creation in digital innovation ecosystems

Technological innovation and value creation in digital innovation ecosystems is a core issue of academic concern, which involves multi-subject synergy, dynamic evolution, and complex network effects. Pohlmann et al.^[32] first systematically described how digital technologies reshape the innovation process, suggesting that digital technologies not only change the way of value creation, but also redefine the boundaries and structure of innovation ecosystems. This view has been widely supported by subsequent studies, and Shen^[33] further pointed out that digital technology can break through the traditional resource limitations and realize more efficient value co-creation by providing a new “empowerment mechanism”. It is worth noting that platform enterprises play a key role in the process of technological innovation and value creation. By constructing technological architectures and governance rules, platform enterprises not only promote complementary innovation, but also create new value networks. However, the relationship between technological innovation and value creation is not linear, and Liu^[34] proposed the concept of “innovation alignment”, emphasizing that technological innovation must be matched with other elements in the ecosystem in order to realize value creation. This viewpoint was further expanded in the study of Hu et al.^[35], who found that technological innovation often triggers the reconfiguration of ecosystem structure, which in turn affects the pattern of value distribution. In recent years, Ozor^[36] pointed out that these technologies not only change the process of value creation, but also redefine the value capture mechanism.

4.3.2 Digital innovation ecosystems and sustainable development

The synergistic evolution of digital innovation ecosystems and sustainable development is the current frontier of innovation research, which centers on how to utilize digital technologies to promote multidimensional sustainable development of economy, society and environment. In recent years, scholars have explored this topic from multiple perspectives, with the most representative research directions including the enabling mechanism of digital technology for sustainable development, the green transformation path of innovation ecosystems, and ecosystem governance under the orientation of the SDGs. Özdemir et al.^[37] first systematically elaborated the key role of digital innovation ecosystems in achieving the SDGs, emphasizing that digital technology contribute to sustainable development by improving resource efficiency, promoting circular economy and supporting green innovation. This view is widely supported by subsequent studies, with Sun et al.^[38] further stating that digital innovation ecosystems provide new paths to achieve sustainable development by reducing information asymmetry, promoting knowledge sharing and optimizing resource allocation. Notably, platform companies play an important role in promoting sustainable development, Du^[39] emphasized that platform companies can significantly enhance the sustainability of ecosystems by setting green standards, promoting sustainable innovation and guiding user behavior. However, the synergy between digital innovation ecosystems and sustainable development also faces a number of challenges, with Chen et al.^[40] pointing out that the widespread use of digital technologies may bring about new environmental problems, such as increased e-waste and rising energy consumption. This view was further expanded in the study of Li et al.^[41] who found that the rapid expansion of digital innovation ecosystems may exacerbate the digital divide and affect social equity. In recent years, with the deepening of the Sustainable Development Goals (SDGs), scholars have begun to pay attention to the governance of digital innovation ecosystems, and Tonelli et al.^[42] suggest that a new governance framework needs to be constructed to balance innovation efficiency with the SDGs.

5. Conclusion

Using bibliometrics and knowledge mapping analysis methods and CiteSpace visualization tools, this study conducted a systematic examination of the research field of digital innovation ecosystem. By comparing and analyzing domestic and international literature, it reveals the theoretical development and research dynamics of the field. The study shows that academics mainly focus on the following core issues: the mechanism of technological innovation and value realization,

the law of system evolution, the choice of development mode, and the key issues of sustainability. As the core architect of the ecosystem, platform enterprises promote complementary innovation and optimal allocation of resources through the formulation of technological standards and governance rules, thereby promoting the sustainable development of the ecosystem. However, the evolution of digital innovation ecosystems also faces many challenges, such as technological path dependence, the aggravation of the digital divide, and the pressure on environmental resources, which are in urgent need of further research. In the future, we should focus our research on these points:

I. Deepen the understanding of the enabling mechanism of digital technology and explore the synergistic effect of technological innovation and institutional innovation.

The rapid iteration of digital technology is profoundly changing the organisational form and operation logic of traditional industries, and the study of its enabling mechanism needs to break through the perspective of pure technical efficiency and build an analytical framework driven by both 'technology and system'. On the one hand, technological innovation reduces information asymmetry through the flow and reconfiguration of data elements, giving rise to new industries such as platform economy and shared manufacturing, but the full release of technological potential is often limited by lagging institutional design. For example, the application of blockchain technology in supply chain finance needs to be promoted in tandem with institutional innovations such as the determination of the legal effect of smart contracts and the regulation of cross-border data flows. On the other hand, institutional innovation can provide a stable environment for technology diffusion through mechanisms such as property rights definition, standard setting and incentive compatibility. The practice of China's 'Digital Economy Promotion Regulations' and the EU's 'Digital Market Act' shows that a moderately forward-looking institutional design can guide the development of technology in an inclusive direction. Future research should focus on the match between technological characteristics and institutional flexibility, especially on how AI ethical standards can be synergised with industrial policies, and how to balance the incentives for innovation and risk prevention in the legal system. By constructing a multi-level case base and a simulation model for institutional experiments, the differential impact of different synergy models on total factor productivity can be quantitatively assessed.

II. Strengthen research on the dynamic evolution mechanism of digital innovation ecosystem, especially the interaction of multiple factors such as technology, demand, subject and environment

The non-linear evolutionary characteristics of digital innovation ecosystems require researchers to adopt complex adaptive systems theory to deconstruct the dynamic coupling relationships among the technology supply side, market demand side, multiple subject networks and institutional environment. From the technological dimension, breakthroughs in basic digital technologies (such as 5G and AI big models) will trigger chain innovations in 'technology clusters', but there is a dynamic game between the speed of technological track and the absorption capacity of the industry. Demand-side changes are manifested in the explosive growth of demand for personalised customisation and the rigidity of demand for public digital services, which force enterprises to build flexible innovation networks. At the subject interaction level, heterogeneous subjects such as platform enterprises, 'small giants' with specialised expertise and open source communities form a value network of competition and symbiosis, whose power asymmetry may lead to the risk of ecological niche locking. Environmental disturbances, such as carbon tariffs or geopolitical conflicts, can indirectly change the flow path of innovation resources through supply chain restructuring. It is recommended that a simulation model with positive and negative feedback loops be constructed using a system dynamics approach, focusing on capturing the threshold effects of key elements, such as the emergence of eco-level innovations that may be triggered when the coverage of digital infrastructure exceeds 70 per cent.

III. Expanding cross-cultural and cross-regional comparative research to analyse the development paths and governance models of digital innovation ecosystems under different institutional environments

Global digital innovation practice presents significant institutional diversity characteristics, which requires the establishment of a multidimensional analysis matrix based on a comparative political economy perspective. In free-market dominant economies, digital innovation is mainly led by tech giants and driven by venture capital and patent systems, but is prone to data monopoly and regional innovation polarisation. In the developmental country model, the government is directly involved in digital infrastructure construction through the 'Smart Nation' strategic plan, but it may inhibit the vitality of grassroots

innovation. The EU's 'digital sovereignty' strategy shows an attempt to balance normative forces (GDPR) with technological sovereignty (Gaia-X cloud programme). On the cultural dimension, high uncertainty avoidance cultures may slow down the adoption of disruptive technologies, while high individualism cultures are more likely to generate breakthrough innovations. The study suggests using qualitative comparative analysis (QCA) to identify the causal paths between institutional combinations (industrial policy intensity, data governance model, financial support system) and innovation performance, with a special focus on the BRICS countries' experience of "leapfrogging" against the backdrop of the digital divide.

IV. Focus on the synergistic evolution of digital innovation ecosystem and sustainable development, and explore the path of green transformation and governance framework.

The in-depth integration of digital technology and the 'dual-carbon' goal is giving rise to a new paradigm of 'digital green symbiosis'. At the technical level, the Industrial Internet can achieve precise optimisation of the carbon footprint of processes through device-level energy consumption monitoring, but the energy consumption of computing infrastructure constitutes a paradox of 'digital carbon emissions'. In terms of institutional innovation, it is necessary to build a three-dimensional governance toolkit that includes digital carbon accounts, green computing power certification and ESG digital disclosure standards. The case of the 'digital twin wind farm' in the Netherlands shows that digital twin technology can improve the operation and maintenance efficiency of wind turbines by 30 per cent and reduce carbon emissions by 15 per cent at the same time, but this kind of synergy requires supporting reforms of the grid scheduling system and the carbon trading market. In terms of subjective behaviours, digital platform companies need to embed carbon constraints in their algorithms for allocating arithmetic resources, while consumers rely on behavioural economics to facilitate their digital low-carbon choices. It is proposed to establish a Digital-Green Collaboration Index (DGCI) to quantitatively assess the progress of each country in the three dimensions of greening digital infrastructure, digital transformation of industries and digitally-enabled environmental governance, so as to provide a basis for the formulation of differentiated transformation policies. In the future, it will be necessary to focus on breaking through key technological bottlenecks, such as carbon tracking of the entire life cycle of digital products and distributed energy management of edge computing nodes.

The research in this paper not only provides new perspectives for the theoretical study of digital innovation ecosystems, but also provides useful references for policy making and ecosystem governance in practice. With the continuous development of the digital economy, the digital innovation ecosystem will play an increasingly important role globally, and future research should continue to focus on its dynamic evolution and sustainable development to cope with the complex and changing economic and social environment.

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Conflict of Interests

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