Research Hotspots and Evolution Paths Analysis of Coordinated Development Between Scientific and Technological Innovation and Economy Based on CiteSpace

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ABSTRACT

This study is based on 308 pieces of research literature on coordinated development between scientific and technological innovation and economy included in the WOS kernel database from 1992 to 2022. Using CiteSpace visualization software, visual analysis is conducted from the publishing research institutions and teams, as well as keywords. The research hotspots and evolution context of the coordinated development between scientific and technological innovation and economy are systematically sorted out, revealing research progress in the field. Research has shown that: The number of published papers in this field showed a trend of "maintaining stability smoothly-increasing slowly in fluctuations-increasing sharply in fluctuations"; the year 2015 was a turning point in the field's sharp increase in academic attention received; a small number of core cooperative teams were formed among scholars in the field and stable cooperative groups weren't formed among research institutions; the research hotspots in this field mainly focused on the evaluation research of coordinated development between scientific and technological innovation and economy, research on environmental issues and national policies in the context of economic development and technological progress, and research on coordinated development between scientific and technological innovation and economy in the process of urbanization; keywords such as "energy efficiency", "co2 emissions", "carbon neutrality", and "sustainability" frequently appeared in the study of evolution paths graphs. In the future, scholars in this field should be guided by the concept of ecological civilization and continuously deepen and expand the above hot research topics.

Keywords: *Scientific and technological innovation, Economic development, Coordinated development, Knowledge graph.*

1. INTRODUCTION

The report of the 20th CPC National Congress pointed out that the development of socialism with Chinese characteristics in the new era should adhere to the important strategic support of technology and talent, adhere to innovation-driven high-quality economic development, and accelerate the implementation of national major scientific and technological innovation projects with strategic foresight and overall significance, in order to achieve the key goal of high level self-reliance in scientific and technological innovation. Throughout the more than 70 years of China's economic takeoff, scientific and technological innovation, as an important means of supporting the country to gain competitive advantages in the international market, has been included in the national key strategic development direction since the reform and opening up. Affected by major global crises, the current global economic situation is not optimistic. Exploring the profound significance of research on coordinated development between scientific and technological innovation and economy under emerging international challenges has important guiding significance. Therefore, this paper uses the WOS kernel database as the literature retrieval platform and utilizes CiteSpace visualization software to conduct visual analysis of coordinated

development between international scientific and technological innovation and economy.

2. RESEARCH METHODS AND DATA RESOURCES

CiteSpace is a visualization software developed based on scientometrics analysis. It mainly reveals the track of research hotspots and future key prospects in the discipline field through citation analysis and co-occurrence analysis [1]. Based on CiteSpace and through text mining, this study drew knowledge graphs of key information such as authors, research institutions, and keywords in the field[2], visualizing research hotspots and trends in WOS coordinated development between scientific and technological innovation and economy from 1992 to 2022. In the WOS kernel database, SSCI and SCI journal literature searches were conducted with "theme=technological innovation" and "theme=economic development" and "theme=coordination", and 308 pieces of English literature were obtained. After deleting irrelevant literature and conference solicitation articles, the retrieved literature was imported into CiteSpace 6.1R6 to complete data preparation. In CiteSpace 6.1R6 visualization software, it first set the time slice to 1 year and sequentially drew the author cooperation network graph and institutional cooperation network graph. Next, it set the time slice to 6 years and sequentially drew a keyword co-occurrence network graph, keyword clustering graph, and keyword timeline graph to reveal the research progress in the field of WOS coordinated development between scientific and technological innovation concept and economy.

3. BIBLIOMETRIC ANALYSIS

Based on the literature data processed by CiteSpace, an analysis of the bibliometric characteristics of the field carried out in terms of the number of articles issued, authors and institutions of articles issued.

3.1 Time Distribution of Number of Published Papers

The fluctuation of number of published papers is closely related to changes in field policies. By analyzing the time distribution of number of published papers, the time nodes of academic attention to research in this field can be determined, revealing the future trend of academic research in the field. From 1992 to 2022, the overall number of published papers of research on coordinated economic development between international scientific and technological innovation and economy in the WOS kernel database showed a trend of "maintaining stability smoothly-increasing slowly in fluctuations-increasing sharply in fluctuations" (see "Figure 1").

According to "Figure 1", from 1992 to 2014, the average annual number of published papers in this field was 3, which was in its infancy; from 2015 to 2019, this field gradually gained widespread attention from the academic community, with an average annual number of published papers of 18, which was in a growing period; from 2020 to 2022, research in this field became a hot research topic in the academic community, with a rapid increase in the number of published papers, and the average annual number of published papers increased exponentially compared to the previous stage, reaching 48. Although the number of published papers in 2020 and 2022 occasionally declined, it still remained above the average. Overall, the future research prospects in this field are promising and the development potential is enormous.

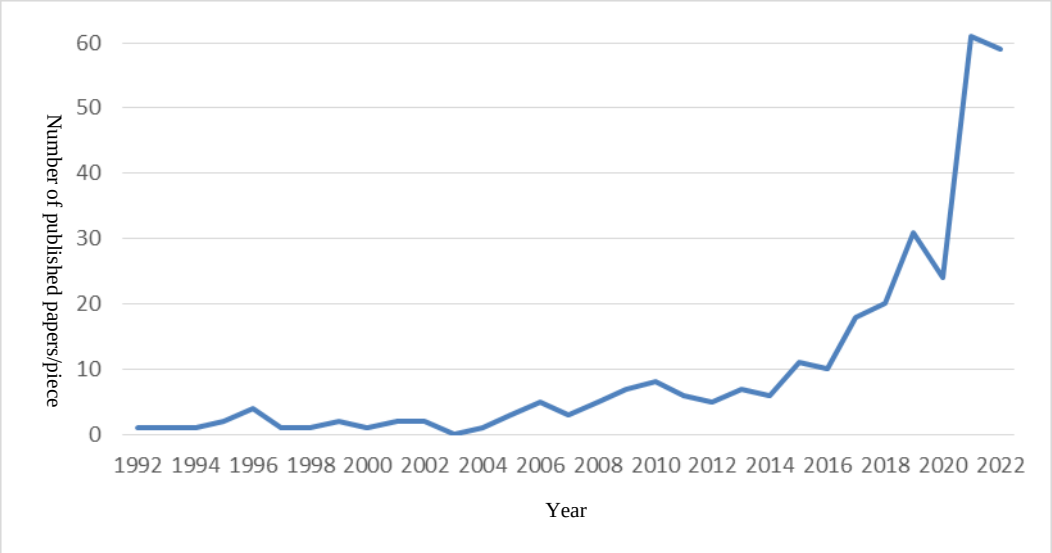

Figure 1 Number of kernel database published papers in the research field of WOS coordinated development between scientific and technological innovation and economy.

3.2 Analysis of Authors' Cooperation

By analyzing the number of published papers and earliest publication time of authors, a core author group composed of high-yield authors and leading figures in the field can be identified. The size of the nodes in the figure is directly proportional to the frequency of the authors' published papers, and the connections between the nodes reflect the cooperative relationship between the authors. The thicker the connections, the closer the cooperation.[3] Based on the visualization graph of cooperative networks, it can be seen that relatively stable core research teams have been formed in the field of coordinated development between scientific and technological innovation and economy. The distribution of authors in this research field of WOS exhibits a close clustering feature, with Xia Jun's team, which has the most number of published papers and scholars involved, as the core, and also includes the following cooperative teams with fewer scholars: Lin Boqiang-Ma Ruiyang, Zhang Xuyao-Lu Chunping, Antikainen R-Saikku L, Chang Hao-Liu Ying, Jin Xue-Yin Kedong, Zheng Ziyang-Wang Litao-Zhu Yingminghe, and Chave H-Soto E-Garza A (see "Figure 2"). According to the Price law [4], $m = 0.749\sqrt{n_{\max}}$ can be used to define the core authors in the field, where, m, according to calculation, is the lower limit of the number of published papers by the core authors in the field, and n represents the maximum number of published papers by the scholars in the field. By substituting the data into the calculation, the minimum number of published papers by the core authors in the research field of WOS coordinated development between scientific and technological innovation and economy should be 2.

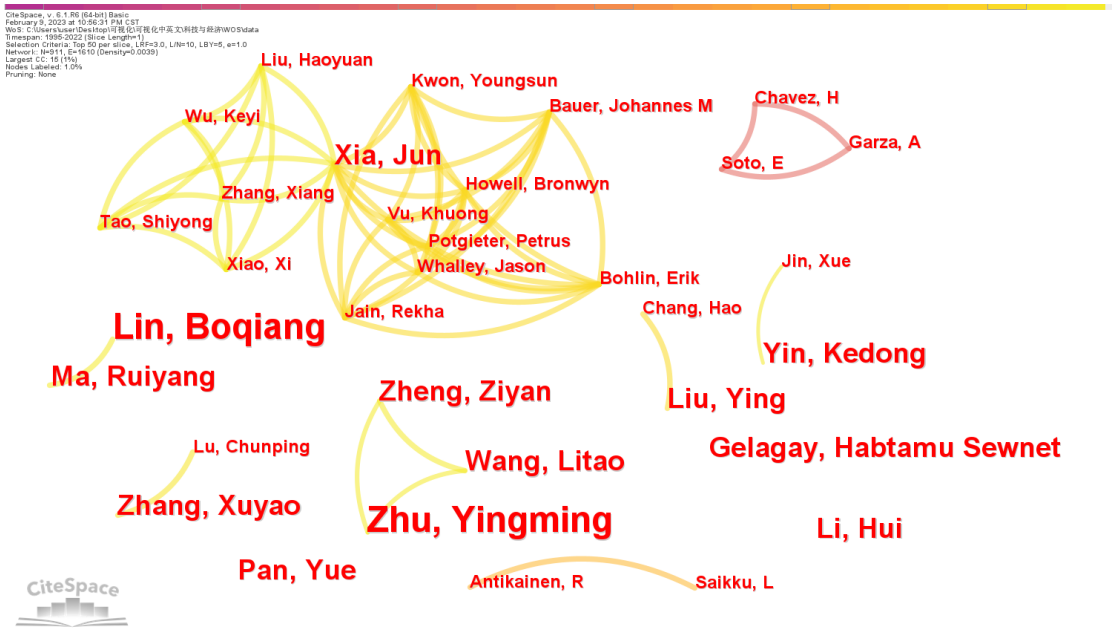

Figure 2 Network graph of author cooperation in the research field of WOS coordinated development between scientific and technological innovation and economy.

Based on the minimum number of published papers standard for core authors in the research field of WOS coordinated development between scientific and technological innovation and economy, a table of the top 10 core author groups of number of published papers in the field can be obtained by sorting out the literature (see "Table 1"). The Price law [4] states that the total number of published papers of the field core authors should reach 50% or more of the total number of published papers in the field. According to calculations, the total number of published papers published by the WOS core author groups is 28, accounting for 90% of the total number of published papers in the field, which fails to meet the 50% standard, indicating that a stable core author group has not yet formed in this research field, and that in the future, it is urgent to strengthen academic communication and cooperation among scholars to enhance the influence of the field.

Table 1. Core author group

WOS core authors	Number of published papers
Zhu, Yingming	3
Lin, Boqiang	3
Liu, Ying	2
Li, Hui	2
Gelagay, Habtamu Sewnet	2
Wang, Litao	2
Xia, Jun	2
Polterovich, Victor M	2
Zhang, Xuyao	2
Ma, Ruiyang	2

3.3 Analysis of Cooperation Among Institutions

In terms of research on coordinated development between scientific and technological innovation and economy, from a regional perspective, most of the top 10 universities and research institutions of number of published papers on WOS are located in China and Russia, of which Beijing and Nanjing are the main regions in China, mainly including: Chinese Acad Sci (Chinese Academy of Social Sciences), Russian Academy of Sciences, Wuhan Univ Technol (Wuhan University of Science and Technology), North China Elect Power Univ (North China Electric Power University), Ocean Univ China (Ocean University of China), Xiamen Univ (Xiamen University), Nanjing Univ Sci & Technol (Nanjing University of Science and Technology), Beijing Univ Posts & Telecommun (Beijing University of Posts and Telecommunications), Nanjing Univ (Nanjing University), and Nanjing Univ Aeronaut & Astronaut (Nanjing University of Aeronautics and Astronautics). At the same time, with the Chinese Academy of Social Sciences as the center, a small number of research groups with intensive cooperation have been formed (see "Figure 3").

Figure 3 Network graph of institution cooperation in the research field of WOS coordinated development between scientific and technological innovation and economy.

4. ANALYSIS OF RESEARCH HOTSPOTS

Based on a grasp of the field's bibliometric characteristics, the research on topical issues in the field is carried out from two main aspects: keyword co-occurrence network analysis and keyword clustering analysis.

4.1 Keyword Co-occurrence Network

Analyzing the co-occurrence network graph of keywords can clarify the potential connections between important keywords in different stages of the research field. The thickness and font size of node rings are directly proportional to the frequency of the keyword's occurrence, the thickness of the connection is directly proportional to the frequency of keywords co-occurring in the same literature, and the color of the connection corresponds to the year range above the graph.[5] It then uses CiteSpace to draw a WOS keyword co-occurrence network graph, as shown in "Figure 6". A total of 221 nodes and 554 connections are generated, with a network density of 0.025. It can be seen from "Figure 6" that the hot keywords on WOS in the field research from 1992 to 2021 are "technological innovation, sustainable development, economic development, policy, energy consumption, and co2 emission".

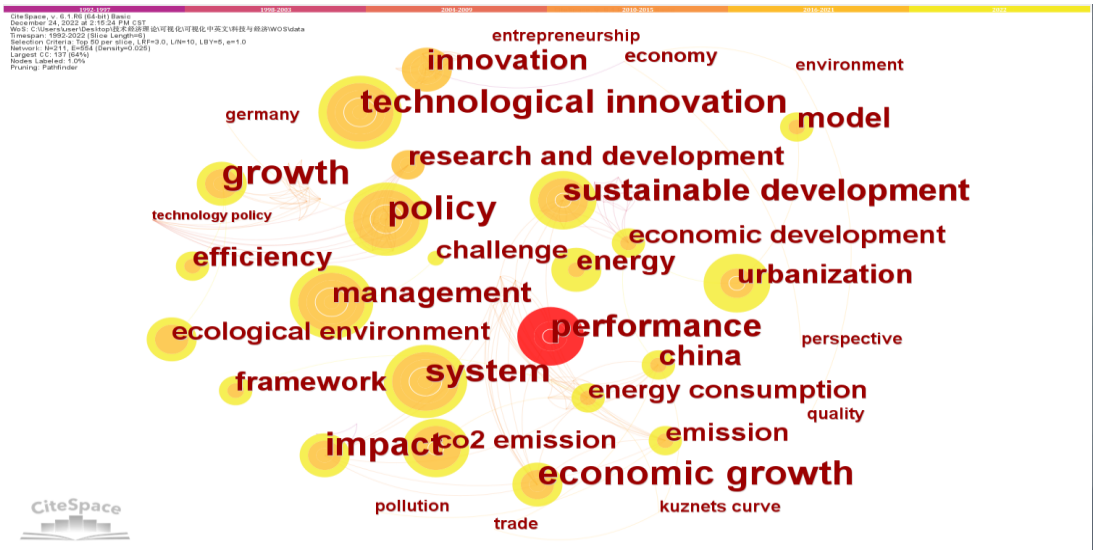

Figure 4 Keyword co-occurrence graph in the research field of WOS coordinated development between scientific and technological innovation and economy.

High-frequency keywords reveal the key directions of research in the field. Subsequently, these keywords are sorted out according to their frequency of occurrence, obtaining the top 20 keywords with frequency rankings, as shown in "Table 2". The important keywords on WOS include: economic growth, policy, technological innovation, system, performance, sustainable development, model, energy efficiency, research and development, framework, system, urbanization, co2 emission, etc.

Table 2. Important keywords table in the research field of WOS coordinated development between scientific and technological innovation and economy

Ranking	Major keywords on WOS	Frequency
1	growth	20
2	economic growth	19
3	policy	19
4	impact	17
5	technological innovation	17
6	system	16
7	performance	14
8	sustainable development	13
9	management	12
10	china	12
11	innovation	11
12	model	11
13	energy	10
14	efficiency	10
15	research and development	9
16	framework	9
17	urbanization	9
18	emission	8
19	co2 emission	8
20	challenge	8

Based on the systematic analysis of literature, it can be seen that in the research field of WOS coordinated development between scientific and technological innovation and economy, hot topics such as comprehensive evaluation research of coordinated development, research on environmental issues and national policies in the context of economic development and technological progress, and research on coordinated development between scientific and technological innovation and economy in the process of urbanization have received much attention.

4.1.1 The Evaluation Research of Coordinated Development Between Scientific and Technological Innovation and Economy

In recent years, scholars in the field have mostly studied the relationship between high-tech innovation and economic development based on quantitative analysis methods. For example, Junarsin Eddy et al. [6] used the Indonesian region as an example to study the impact of new fintech companies on regional economic development. The results show that there is a delayed effect of local financial technology in promoting economic development and there are certain limitations in scientific and technological innovation in the financial sector; Yuan Xumei et al. [7] learned from their research on the coordinated development of high-tech industrial technological innovation and regional economy that there are differences in innovation efficiency at different stages of high-tech industrial technological innovation. The coupling and coordination degree of high-tech industrial technological innovation and regional economic development in 24 provinces and cities in China has increased year by year, but there is a large spatial heterogeneity; Han Jianyu et al. [8] explored the impact of scientific and technological innovation on high-quality economic development in the Yangtze River Delta region based on an innovation-driven development strategy, combining a two-way fixed effect model, spatial Dubin model, panel threshold model, and regulatory effect model. The results indicate that there is a spatial spillover effect in scientific and technological innovation, and the scale of higher education can deepen the significant positive effect of scientific and technological innovation on high-quality economic development.

4.1.2 Research on Environmental Issues

In recent years, scholars in the field have mostly explored the two-way optimization relationship between scientific and technological innovation and economic development from the perspective of green innovation. For example, Wu Mingran et al. [9] studied the coordination relationship between China's scientific and technological innovation, environmental regulation, and economic development based on the theory of system synergy. The results show that the trend of China's economic development being driven by innovation and constrained by ecology is becoming increasingly evident, and it is urgent to establish a modern development system based on green technology; Lin Boqiang et al. [10] proposed that green technology innovation is an important means of balancing economic growth and environmental protection. They studied the impact of green technology innovation on carbon emissions in 246 prefecture-level cities in China from 2006 to 2017. The results indicate that green scientific and technological innovation can reduce carbon emissions by promoting the upgrading of industrial structure, and this promotion effect is more evident in cities with high level of human capital; Lv Shuang et al. [11] studied how scientific and technological innovation (STI) promotes economic optimization and development to achieve sustainable ecological goals based on the coupling of STI. The results indicate that the STI development model is influenced by both Chinese and foreign dual cycles.

4.1.3 Research on National Policies

Scholars in the field have shifted their research on national policies from how to promote technological progress and economic development to a sustainable ecological environment. Moshe Justman et al. [12] clarified the key role of scientific and technological innovation in obtaining competitive advantages, proposed a conceptual framework for technological infrastructure policies, and concluded that government policies have a strong catalytic effect on innovation in the process of optimizing economic development through technological progress by comparing traditional industries with high-tech industries; Allen et al. [13] focused on blockchain technology and revealed the necessity of institutional innovation for low-cost, borderless innovation technology. Considering transaction costs and institutional choices, they established a dynamic institutional innovation

model and pointed out its importance for global open innovation and sustainable economic development; Costantini et al. [14] studied how the strong correlation between socio-economic and technological innovation affects the implementation of public policies based on the gravity equation model, and the results show that policy disharmony is not conducive to the dissemination and development of environmentally friendly technologies.

4.1.4 Research on Urbanization Development

Urbanization, as an inevitable trend of economic development, occupies an important position in the research of coordinated development between scientific and technological innovation and economy. Many scholars have explored the relationship between scientific and technological innovation and sustainable development under the process of urbanization from different perspectives. Dong Liyuan et al. [15] used the Guanzhong region as an example to construct a new urbanization and ecological environment quality evaluation index system. Research has shown that technological innovation that breaks regional restrictions is of great significance for promoting urbanization and ecological sustainable development; Li Jintao et al. [16] explored the spatiotemporal differences and impact mechanisms of regional ecological well-being in the process of urbanization development by combining a coupling coordination model and a geographical weighted regression model. The results show that the innovation of environmental management technology and the formulation of environmental law are conducive to the construction of Yellow River Delta Ecological Economic Zone; Luo Xiang et al. [17] constructed a comprehensive evaluation index system for urban land development intensity and urban resilience, and studied key issues of urbanization. The results indicate that scientific and technological innovation and green industry upgrading have a significant impact on the coupling degree between urban land development intensity and urban resilience.

4.2 Keyword Clustering Analysis

It is based on the keyword co-occurrence network graph and uses Citespace to perform clustering analysis of retrieved literature, resulting in a WOS keyword clustering graph (see "Figure 5"). The clustering module value and the average silhouette value determine the clustering effect. A clustering module value greater than 0.3 indicates that the clustering structure is significant and the boundaries are clear. An average silhouette value greater than 0.5 indicates that the clustering result is reasonable and a value greater than 0.7 indicates that the clustering result is convincing.[18] From "Figure 5", it can be seen that the clustering module value of the WOS keyword clustering graph is 0.8688, and the average silhouette value is 0.9173, indicating that the clustering structure is significant and the results are reasonable. The smaller the clustering number label, the more keywords the clustering contains. According to "Figure 5", the research hot keywords in the field of WOS coordinated development between scientific and technological innovation and economy can be divided into 7 clusters, mainly including: "#0 sustainable development", "#1 tobit model", "#2 transition policy", "#3 economic development", "#4 economy", "#5 research and development", and "# zero-waste".

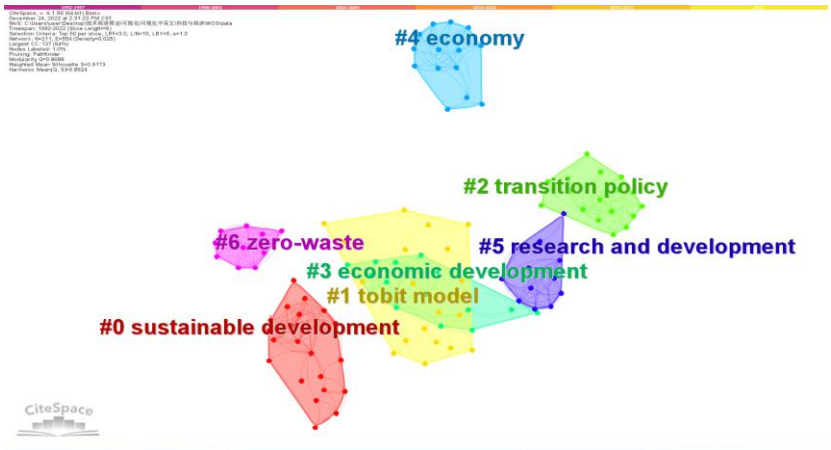

Figure 5 Keyword clustering graph in the research field of WOS coordinated development between scientific and technological innovation and economy.

By combining high-frequency keyword table and clustering graph, it can be concluded that the research hotspots of WOS coordinated development between scientific and technological innovation and economy are focused on the coupling and coordination relationship between scientific and technological innovation and economic development, the establishment of coordination models, ecological benefits, technology benefits and economic benefits, etc.

5. ANALYSIS OF THE EVOLUTION PATH OF RESEARCH

Based on the keyword co-occurrence graph and keyword clustering analysis, the temporal evolution trend of hot keywords in the field of WOS scientific and technological innovation research can be deeply explored. By utilizing the "Timeline" function in CiteSpace software, it obtains a timeline graph of keywords in the research field of WOS coordinated development between scientific and technological innovation and economy (see "Figure 6").

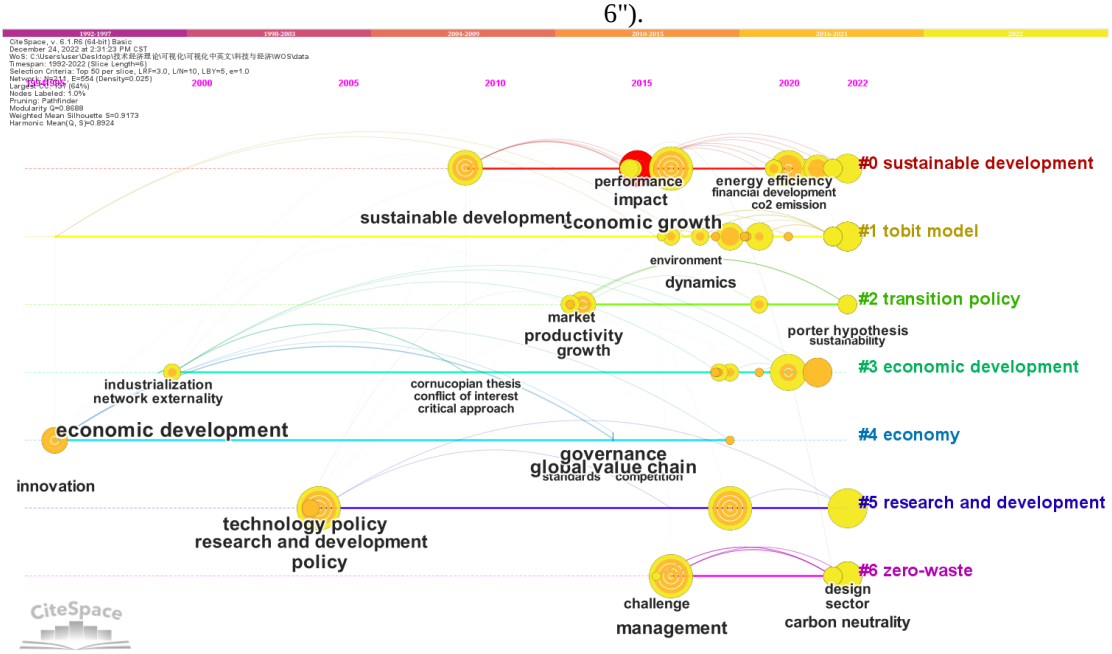

Figure 6 Keyword timeline graph in the research field of WOS coordinated development between scientific and technological innovation and economy.

According to "Figure 6", the research hotspots in the field of WOS coordinated development between scientific and technological innovation and economy can be divided into 3 stages:

- The embryonic stage (1992-2005): The hot keywords in this stage were "industrialization", "network externality", "economic development", "innovation", "technology policy", etc. From this, it can be seen that research in this stage focused on two major aspects: economic development and science and technology policies. PRYBYLA [19] proposed that technological innovation is the main indicator for measuring economic development modernization, and technological progress in the information field is a key attribute of modernization advancement; Chataway [20] took the socially unstable Central and Eastern European countries as an example to study how countries with unstable economic and political environments improve their level of technological innovation, exploring the resistance to technological innovation change from the perspectives of introducing market mechanisms, policy system changes, and economic incentive policies; Moshe Justman et al. [12] proposed that national technological innovation capabilities are increasingly becoming an important source of international competitive advantage, and requested the government to introduce new technological policies to improve technological infrastructure (TIP). By studying the role models of traditional and advanced TIPs in the economy, it is concluded that institutional innovation and

economic liberalization are equally important. At this stage, scholars mainly focused on the impact of science and technology policies on the establishment of the national science and technology system and the modernization of the national economy.

- The growth stage (2006-2015): The hot keywords in this stage were "sustainable development", "productivity", "environment", "global value chain", "conflict of interest", etc. From this, it can be seen that research in this stage focused on maintaining economic growth while adhering to the global sustainable development strategy. Cai Dongsong [21] found through empirical research that energy market innovation determined by the regional characteristics of the secondary industry can have a permanent impact on other economic sectors. The reality of energy efficiency and economic development not being coordinated requires governments and enterprises to actively adjust industrial structure and technological innovation to achieve coordinated and sustainable development of the economy and environment; Costantini et al. [14] used a gravity equation model to study the different impacts of environmental policies on economic systems in industrialized countries. The results indicate that if there is a lack of strong coordination between different energy and environmental policies, it will inhibit the development and dissemination of eco-friendly energy technologies; Wang Kailiang et al. [22] found that controlling urban carbon emissions is crucial for establishing a low-carbon ecological development model. The research results show that adopting the digital urban management model to solve the problem of urban information isolated island is the key path to the sustainable development of urban economy. At this stage, scholars mainly focused on the contradiction between rapid economic development and ecological environment protection, and sought technological innovation paths to alleviate the environmental pressure brought about by economic development.
- The development stage (2017-2022): The hot keywords in this stage were "energy efficiency", "financial development", "co2 emission", "porter hypothesis", "sustainability", "carbon neutrality", etc. From this, it can be seen that the research in this stage focused on energy efficiency, carbon emissions, environmental regulations, and other aspects with environmental protection concepts as the core. Pan Yue et al. [23], taking 30 provinces and regions in China as examples, calculated the efficiency of tourism carbon emissions from 2007 to 2017 based on the data envelopment analysis model of super efficiency measurement (SBM-DEA), and explored the coupling and coordination degree of tourism carbon emissions, economic development and regional innovation and the key factors affecting the coupling and coordination relationship; Zhu Ruiming et al. [24] estimated the carbon emission efficiency of China's energy intensive industries using a three-stage data envelopment analysis model, taking 31 provinces and regions of China as examples. They combined spatial autocorrelation analysis and regression models to deeply explore the spatiotemporal evolution trend and key influencing factors of carbon emission efficiency in energy intensive industries, providing specific guidance for the formulation of national energy technology innovation policies; Wang Jingyi et al. [25] used the Yangtze River Basin in China as an example to measure industrial carbon emission efficiency using stochastic frontier analysis method. The research results indicate that innovation in industrial low-carbon technology is a powerful means to increase industrial added value and achieve green and sustainable industrial development. At this stage, scholars mainly focused on the coordination relationship among energy efficiency, green technology innovation, and high-quality economic development.

Overall, the research hotspot in the field of WOS coordinated development between scientific and technological innovation and economy has shifted from the applicability of technological policies and economic development to the coupling and coordination research with ecological civilization as the core guiding ideology, among which the coupling relationship of coordinated development between scientific and technological innovation and economy is mainly focused on energy efficiency, carbon emissions, and green technology innovation.

6. CONCLUSION

In response to the research on international coordinated development between international scientific and technological innovation and economy, using CiteSpace visualization software, a scientometrics analysis of 308 pieces of English literature indexed in the WOS kernel database from 1992 to 2022 is conducted. After the bibliometric characteristics and distribution of research hotspots in this research field are systematically sorted out, the following conclusions are drawn: ① From the perspective of number of published papers, the overall number of published papers in this field showed a trend of "maintaining stability smoothly-increasing slowly in fluctuations-increasing sharply in fluctuations"; ② From the perspective of the authors and research institutions, a small number of core cooperative teams were formed among scholars in the field and stable cooperative groups weren't formed among research institutions; ③ From the perspective of hot keywords table and clustering, research on comprehensive evaluation of coordinated development, environmental issues and national policies in the context of economic development and technological progress, and research on coordinated development between scientific and technological innovation and economy in the process of urbanization attracted the attention of scholars in the field; ④ From the perspective of research evolution paths, "energy efficiency", "co2 emissions", "carbon neutrality", "sustainability" and so on were hot keywords in the current field of research. The focus of future international research in this field should be on deepening the coupling and coordination research with the concept of ecological civilization as the core guiding ideology. By systematically sorting out the evolution context of research hotspots in the field, it can promote the academic community to further expand the research on coordinated development between scientific and technological innovation and economy.

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