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Research Progress and Frontier Orientation of Scientific and Technological Innovation in China Based on CiteSpace Visualising Bibliometrics

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Abstract

Innovation is an inexhaustible driving force for the development of a country and a nation. It is also one of the main engines of economic growth. It has become a general consensus that scientific and technological innovation is the driving force and leader of development, which has attracted great attention from the government and scholars in all dimensions of social governance. The overall trend of scientific and technological (referred as S & T) innovation research in China has been increasing year by year. The purpose of this study is to comprehensively text-mine and evaluate all S & T innovation articles published in academic journals from 2010 to 2021, systematically review the progress of S & T innovation research in China, and discuss the future development direction of S & T innovation. In China's S & T innovation, we must build a research pattern that simultaneously tackles key core technologies and advances basic application-oriented technologies from the perspectives of comprehensive research, top-level design and high-level promotion.

Keywords

Scientific and Technological Innovation, Research Progress, Frontier Orientation, Trend

1. Introduction

Global scientific and technological innovation has entered a period of unprecedented activity since the beginning of the 21st century. A new round of S & T

revolution and industrial transformation is reshaping the global innovation landscape, and the global economy faces new opportunities and growth points. Innovation has become a key theme of regional economies (Ion & Cristina, 2014), the internal driver of scientific and technological progress, and an important way for a country to catch up and improve international competitiveness. It is a viable strategic option for increasing productivity and performance and for fostering a sustainable economic growth, especially in the current context, in which even the more developed countries took a big hit from the global economic crisis (Doloreux & Gomez, 2017). Innovation, whether it is managerial or technological, is without a doubt a source for competitiveness, which in turn creates a series of advantages for its "holder", giving him an advantageous edge in regards to the competitors. The Chinese government is now embarking on a "new era" of development, promoting the quality of growth aims first and foremost at reaching the technological frontier through innovation, containing digital economy, new energies and networks (Aglietta & Guo, 2019). In the post-COVID-19 era, the complex diversity of the world's economic and social development and the macro context of global economic integration have made global innovation more urgent and necessary. In 2021, the Central Economic Work Conference of the Chinese government proposed the implementation of a three-year action plan for the reform of the science and technology system and the formulation of a ten-year plan for the implementation of basic research. Innovation-driven development has become China's national strategy, and innovation has become the new era's main driver of social development. The World Intellectual Property Organization (WIPO) has released the report of the Global Innovation Index (GII) for 2022, in which China is ranked 11th overall, up one place from 2021. In comparison with Switzerland, Sweden, the UK, the US and other developed countries, there is still a large gap in China's innovation development, which is mainly reflected in weak innovation capacity, insufficient interaction among innovation agents, low efficiency of resource allocation, difficult breakthroughs in key and core areas, and low conversion rate of research results (Shen & Li, 2023). If China wants to make new breakthroughs, it must keep up with the pace of the times, readjust its layout and seek new growth points and driving forces for development in the face of a new round of scientific and technological revolution. Aiming at high-quality innovation and development, we should improve innovation quality, possess key generic technologies, accelerate the transformation from low-cost advantages to high-quality innovation advantages, strive for independent and controllable key core technologies, and provide inexhaustible driving force for sustainable economic development (Yu et al., 2023).

Nowadays, the literature on S & T innovation is abundant. Domestic research pays more attention to the application research compared with foreign innovation research. Firstly, institutional research focuses on the construction of the demand-oriented S & T innovation system (Zhao & Chen, 2023) and the study of the mechanism of technological innovation (Li et al., 2020). Secondly, policy

researches adopt the policy evaluation framework of Swedish scholar Vedung E. (Vedung, 1997), construct the evaluation framework and evaluation index system of scientific and technological innovation policy (Yan et al., 2021), design and application of innovation index (Dai et al., 2022), evaluation and quantitative research of S & T innovation policy development (Zhang, 2019; Zhang & Ma, 2017). Thirdly, institutional research on S & T innovation is carried out, according to this research, China's technology innovation gained a large space for development and achieved remarkable results under government's multi-faceted support (Zhang, 2021). The government should strike a balance in the allocation of attention to S & T innovation and actively promote the development of the knowledge society (Zhu & Yuan, 2023).

In brief, current research on scientific and technological innovation does not dig much into the content of the research itself, and there is a slight lack of application type, and the applicability of trend analysis and corresponding policy research is not sufficient. Policy text mining is underutilized in past studies. The keyword co-occurrence, clustering and topic recognition of research content are completed by computer algorithms, relying on text mining technology to explicitly process the implicit knowledge and information in research texts.

2. Data Sources and Research Methods

Officially published scientific papers in the natural sciences reflect the latest theory and frontier of scientific and technological innovation, which is an important reflection of a country's S & T innovation capacity. What determines the speed and direction of a country's technological learning (or the amount and composition of its transformative activities) are its institutions, its incentive structure and its learning capacity, and these factors can be systematically identified in the published scientific literature. CiteSpace taken in this study is a software for tracking and analysing the latest international research, which is quite user-friendly. This software is based on bibliometrics and takes the bibliometric system and bibliometric characteristics as the object of study. Citespace can describe and predict the development of specific research fields, as well as quantitatively measure the contour distribution, relationship and clustering between studies. Using statistical analysis, CiteSpace literature measurement tool and literature research method, this study summarizes the status quo and characteristics of China's S & T innovation research from annual literature publication number, keyword co-occurrence and emergence, keyword strategy map and timeline, and predicts research trend and frontier orientation.

From specific operational dimension, this study collects Chinese S & T innovation literature data from CSSCI database. The data that support the findings of this study are openly available in public resources. In the research, the retrieval period was set from 2010 to 2021. Due to a certain amount of lag in the Chinese CSSCI database, the year 2021 has been set as the date of the most recent literature in the literature analysis. With "science and technology innovation", "science

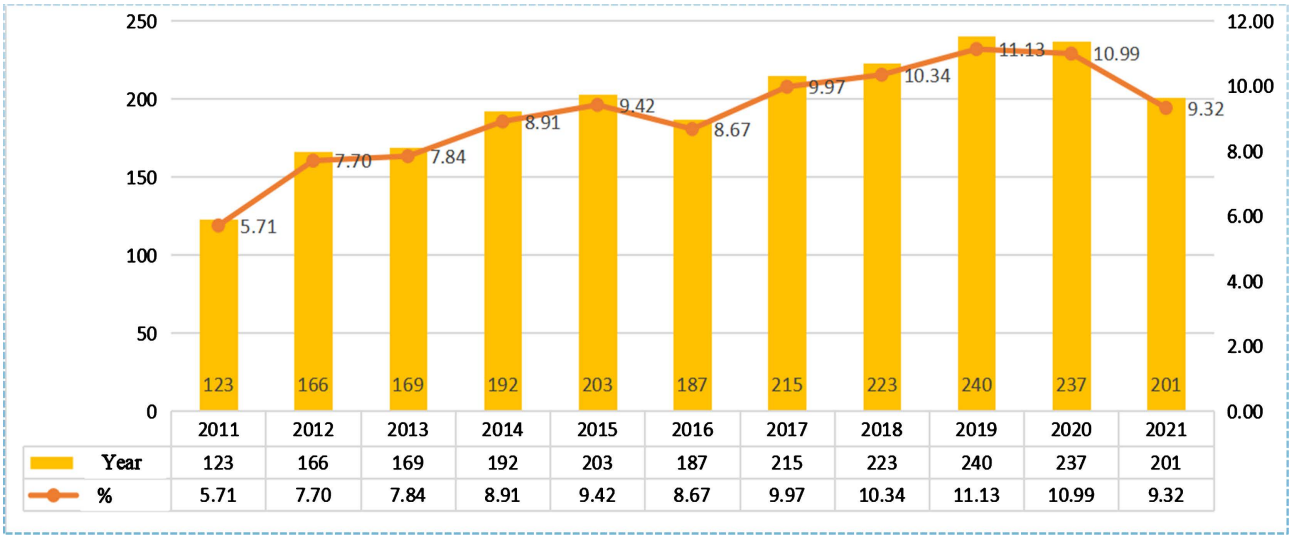
and technology" and "innovation" as titles, a total of 2156 valid literatures were retrieved, and no duplicate literatures were found after using CiteSpace software to de-duplicate literatures. The running time of the software was set to "2011-2021", Top N = 50, the pruning mode was Pathfinder, whole network pruning, systematic data were obtained and analyzed after the run.

3. Overview of Scientific and Technological Innovation Research

3.1. Trend of Publication Volume

The development status of the field of S & T innovation and the future research trend can be reflected in the change in the number of published documents. Figure 1 shows the number of papers that have been published in this field of research over the last 10 years. From 2011 to 2021, a total of 2156 papers on S & T innovation were published, showing an overall stable growth trend. In 2011, there were only 123 papers, indicating a nascent stage of related research, possibly related to limited research methods and a lack of high-quality related literature during this period. Afterwards, with the enrichment of research methods and content, as well as the increase of attention to social and economic development, the number of published papers gradually increased to more than 200 in 2015. In 2016, there was a slight decline in the number of published papers, and then the number of published papers continued to increase, with the annual number of published papers stabilizing at more than 200. This phase can be considered as the stable period for the field to develop. From 2021 onwards, the number of published papers will reach 201, which indicates that the heat of the related research will not decrease, and the number of published papers is expected to increase further.

Chinese experts have always maintained a high level of enthusiasm for S & T innovation research, as measured by the total number of S & T innovation



	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Year	123	166	169	192	203	187	215	223	240	237	201
%	5.71	7.70	7.84	8.91	9.42	8.67	9.97	10.34	11.13	10.99	9.32

Figure 1. Trend chart of publication volume.

research publications. The strategic position of S & T innovation can be seen from the above.

3.2. Keyword Co-Occurrence

The high-frequency keywords are an important node in the priority allocation of the attention of the experts and scholars in the field of research. The research on high-frequency keywords can well explain the research hotspots in this field in a certain period of time. In this study, 341 keywords were found following the keywords in the literature, which formed 434 lines. The co-occurrence map of the hot keywords in the literature is shown in Figure 2. In Figure 2, the size of the text represents the frequency of occurrence of the keywords, the lines between the nodes represent the connections made at different times, and the thickness of the lines represents the intensity of the keyword occurrence.

It can be seen that the "scientific and technological innovation" is the largest node, followed by the "innovation mechanism" and the "reform of the scientific and technological system". Higher degree of nodes means higher degree centrality of nodes and more important nodes in network. From the degree centrality index, which represents the importance of nodes (see Table 1), "sc" scientific and technological innovation", "innovation mechanism" and "innovation-driven development" are strongly correlated with other hot keywords, indicating that relevant research focuses on these keywords. More recently, "scientific and technical self-sufficiency", "dynamic mechanism", "new development stage", "new national system", "opening up to the outside world", etc. are expected to become the new direction of scientific and technical innovation research in the future.

The intermediate centrality of keywords is an important indicator to judge the research focus of this research field, and also an important basis to judge the focus of scholars. From the intermediary centrality index, which represents the promotion of nodes (see Table 2), the communication between "science and technology finance", "science and technology innovation" and "transformation

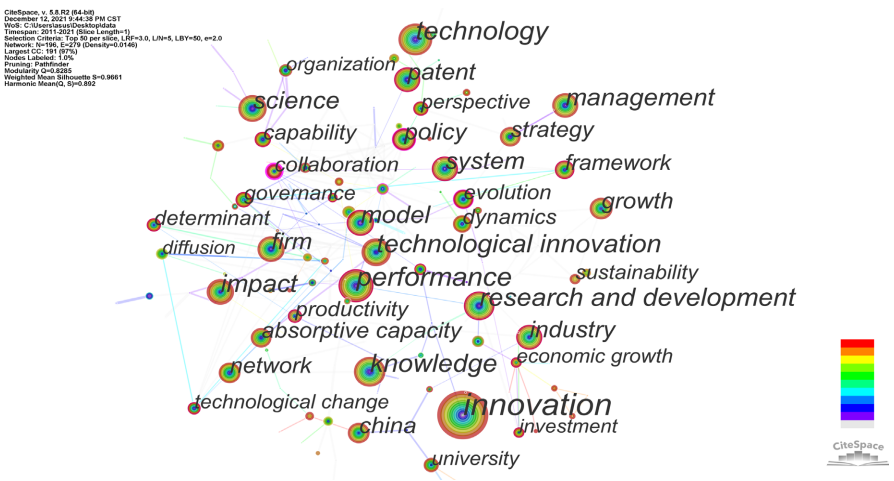


Figure 2. Key words co-occurrence map.

Table 1. Top 10 keywords with the highest frequency (sorted by degree of centrality).

Serial number	Key words	Frequency	Degree centrality
1	S & T innovation	1685	61
2	mechanism of innovation	172	13
3	innovation-driven development	14	11
4	industrial structure	12	10
5	synergetic development	22	9
6	innovative country	13	9
7	S & T finance	44	8
8	innovation-driven development strategy	32	8
9	innovation performance	16	8
10	research input	8	8

Table 2. Top 10 Keywords Centrality (sorted by intermediate centrality).

Serial number	Key words	Frequency	Intermediation centrality
1	S & T finance	44	0.76
2	S & T innovation	1685	0.72
3	transformation and upgrading	7	0.38
4	innovation-driven development strategy	32	0.37
5	mediating effects	5	0.35
6	Finance development	19	0.34
7	innovation performance	16	0.33
8	industrial structure	12	0.33
9	innovation-driven development	14	0.3
10	synergetic development	22	0.29

and upgrading" and other hot keywords is strong, which shows that relevant research is carried out by using these keywords. We also find that keywords like "transformation and enhancement" and "mediation" have a higher centrality of mediation, indicating that they are often in communication with other keywords, thus positively influencing the cross-citation relationship of the literature.

3.3. Keyword Clustering

A Research Hotspot is the focus of scholars in a particular academic field, and also embodies the main issues discussed in that field over a given period. As an important part of academic papers, keywords condense the essence of the paper and are often used for the study and discussion of hot issues in a particular field.

On this basis, the CiteSpace software is used in this paper for the cluster analysis of the co-occurrence of keywords in order to directly reflect the research hotspots of scientific and technological innovation. The presented view of the keyword clustering is shown in Figure 3, where the coloured blocks represent the clustering regions.

Node N = 341, number of links E = 434, network density = 0.0075. The size of the module value Q is associated with the node density. The larger the value of Q, the better the clustering effect becomes. It can be used for scientific analysis of clustering. The homogeneity of the cluster can be measured by the size of the average contour value S. The larger the value of S, the higher the homogeneity of the network, which indicates that the cluster has a high degree of reliability. As shown in Figure 3, Q = 0.8451, indicating that the network structure has a good clustering effect. With S = 0.9719, the homogeneity was high and the different clusters were well divided. Ten clusters are presented, led by "scientific and technological innovation", "high-quality development" and "modern finance". The average years of the top five clusters are from 2015 to 2017, which is an indication of the gradual maturation of relevant research during this period. Scientific and technological innovation, which occurred in 2015 and contains 64 keywords, is the largest cluster among them. The main keywords include scientific and technological innovation, reform of the scientific and technological system, innovation mechanism, and so on. Through the integration of the top five clusters, it can be seen that the main research topics in the field of science and technology innovation are the promotion of high-quality development through science and technology innovation, science and technology financing, and the joint upgrading of key industries of science and technology innovation.

The most important key words for the clustering are shown in Table 3. In

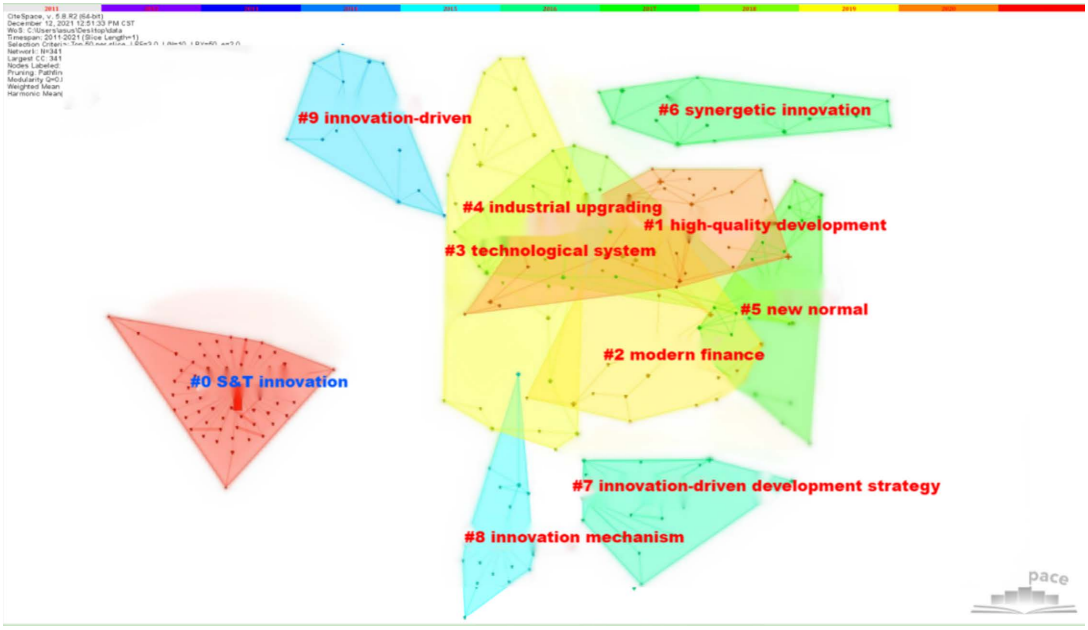


Figure 3. Keywords clustering map.

Table 3. Main keywords of clustering.

Serial	clusting	Key words	year	number
1	S & T innovation (change)	S & T innovation (265.08, 1.0E−4); S & Tsystem reform (61.24, 1.0E−4); innovation mechanism (46.89, 1.0E−4)	2015	64
2	high-quality development	High−quality development (35.58, 1.0E−4); industry structure (20.56, 1.0E−4); coupling harmonious degree (17.66, 1.0E−4); economic growth (17.61, 1.0E−4); regional economy (16.69, 1.0E−4)	2016	30
3	modern finance	modern finance (33.62, 1.0E−4); synergetic development (29.74, 1.0E−4); New era (27.99, 1.0E−4);	2016	29
4	S & T system	S & T system (29.92, 1.0E−4); independent innovation (21.43, 1.0E−4); international S & T cooperation (17.71, 1.0E−4); S & T Powerhouse (17.65, 1.0E−4); intellectual property (13.11, 0.001)	2015	25
5	industrial upgrading	industrial upgrading (31.81, 1.0E−4); the optimization of industrial structure (25.86, 1.0E−4); Industry Structure Upgrade (24.91, 1.0E−4); threshold effect (20, 1.0E4); industrial structure rationality (17.45, 1.0E−4)	2017	25

2015, there were 64 occurrences of the keyword "scientific and technological innovation". This shows that scientific and technological innovation research has emerged as a major research direction during this period. High-quality development became an important initiative of the government and the country's economic and social development in 2016. This is also reflected in the field of research.

3.4. Timeline

Frontier trend analysis is mainly based on co-citation clustering and citations, and describes the transition and research nature of a particular research field by continuously citing literature clustering of a fixed group of basic literatures. The timeline map displays keyword clustering on a two-dimensional timeline, which helps researchers explore the evolution process and frontier trend of keyword clustering in S & T innovation research.

The largest cluster of S & T innovation-related literature is "scientific and technological innovation/reform", with 64 keywords and an average year of 2015, as shown in Figure 4. Of these, "scientific and technological innovation" was proposed in 2011. The keywords "crowding-out effect", "resource-based city", "cultural innovation", etc. are added as time goes by. The cluster concentrates

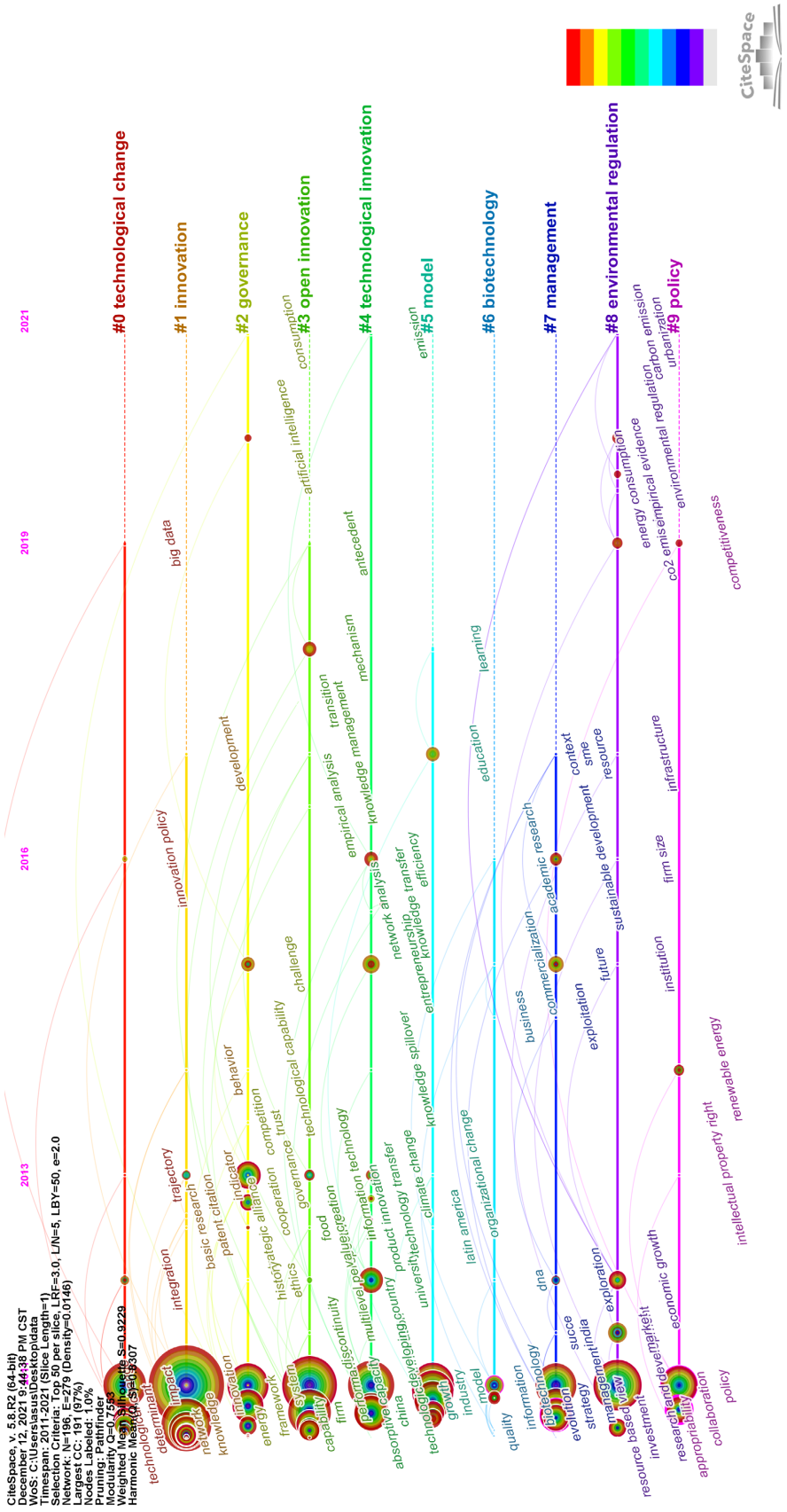


Figure 4. Timeline.

on the reform of the scientific and technological innovation system. According to the recent clustering results in the figure, it can be seen that the new keywords include "national strategy", "financial technology", "industrial agglomeration", etc., and the change and development of clustering is always centred on the mechanism of scientific and technological innovation. It should be noted that open innovation, which emerged in 2013, has brought new ideas for developing scientific and technological innovation, emphasising systematic and open innovation and cultivating innovation capability.

3.5. Keyword Emergence

For the purpose of better understanding the evolution and development trend of scientific and technological innovation, this paper collects the emerging words from the field of S & T innovation research. The results, including the year of emergence, duration and intensity of the emergent words, are shown in Table 4. Based upon these, the development trend of S & T innovation research will be predicted from three aspects: intensity, duration and time of appearance.

From the perspective of time series, "innovation mechanism", "reform of the

Table 4. Keyword emergence.

Keywords	Year	Strength	Begin	End	2011-2021
Innovation mechanism	2011	10.02	2011	2013	
S & T system reform	2011	5.56	2011	2013	
technical innovation	2011	3.41	2011	2015	
sci-tech novelty retrieval	2011	2.72	2011	2012	
policy	2011	2.51	2011	2014	
strategic emerging industry	2011	4.25	2012	2016	
innovation-driven development	2011	3.06	2014	2015	
S & T system	2011	2.74	2014	2015	
innovation-driven	2011	4.66	2015	2016	
economic growth	2011	3.21	2015	2017	
s & t evaluation	2011	2.61	2015	2016	
regional economy	2011	2.49	2015	2018	
innovation efficiency	2011	2.51	2017	2019	
substantial economy	2011	5.07	2018	2019	
fundamental research	2011	2.98	2018	2021	
High-quality development	2011	8.5	2019	2021	
Coupling coordination degree	2011	3.49	2019	2021	
S & T powerhouse	2011	3.02	2019	2021	
industry structure upgrading	2011	2.71	2019	2021	

scientific and technological system" and "technological innovation" started earliest, "high-quality development", "high-quality economic development", "coupling coordination degree" started at the latest and continued to the present, which will be a connecting point for future research. Moreover, from the point of view of the duration of emergence, "Strategic Emerging Industry", "Technological Innovation", "Small and Medium Enterprises", "New Urbanisation", and so on, had a long emergence period, which indicates a long focus of relevant research. According to the emergence strength of emerging words, the emergence strength of "innovation mechanism" (Strength = 10.02), "high-quality development" (Strength = 8.5), and "reforming the scientific and technological system" (Strength = 5.56) is very high, indicating the occurrence of great changes. In general, "high quality development" and "high quality economic development" are not only emerging with high intensity, but also close in time. This can be considered as the latest emerging research hotspot. On the whole, with the passage of time, the progress of society and the change of the external environment, the research content and the research focus of "scientific and technological innovation" are also constantly evolving, which also shows that "scientific and technological innovation" is a topic of research value from a different perspective.

4. Conclusion

Based on S & T innovation research literature data in CSSCI database from 2010 to 2021, this paper uses statistical analysis, literature measurement and literature research methods to summarise the number of S & T innovation research papers in China during this period. It also analyses the research hotspot and trend of science and technology innovation based on keyword co-occurrence and emergence, keyword time line.

At present, China has made great achievements in developing S & T and achieved fruitful research results. China's S & T innovation has achieved good results in accumulating "quantitative transformation" and is approaching the stage of "qualitative transformation", which is mainly attributed to the government's guidance and promotion of the development of scientific and technological innovation. However, there are still many "bottlenecks" in China's S & T innovation in key core technologies and advanced fields. This is due to the long-standing irrationality of China's economic structure and S & T structure, as well as the long-standing weakness of China's economic and S & T levels (Feng, 2016). To put it another way, China's overall strength and level of S & T innovation can still be improved compared with that of developed nations. The exploration of the potential of innovation resources and the improvement of S & T innovation activities are largely limited by the national innovation research.

According to existing literature, if China's S & T innovation really wants to reach the international frontier and build itself into a powerful S & T country, it needs to further strengthen relevant research in the following aspects:

1) Enhancing comprehensive basic research. The government should streng-

then the idea of demand-oriented S & T innovation management as China is in the strategic transition period to innovation-driven development. Integrated basic research is the foundation for smart, inclusive and sustainable economic growth. Integrated basic research is the foundation of smart, inclusive and sustainable economic growth, emphasizing the responsibility of scientific research and technological innovation, paying attention to the comprehensive use of interdisciplinary knowledge of sociology, politics, economics and technology, focusing on the thorough study of innovation governance and the social responsibility of S & T innovation, and guiding the development of innovation activities in the direction of social contentment.

2) Aim for international cutting-edge research. Focusing on the key core technologies of the new round of S & T revolution, China will push forward the layout of key frontier innovation fields, realize more advanced manufacturing fields to lead the international frontier, and eventually achieve the powerful driving force of S & T innovation to develop the manufacturing industry and even the national economy. S & T innovation research should be devoted to consolidating China's leading position in global innovation, focusing on artificial intelligence, advanced materials, precision medicine, genetic engineering, quantum communication, advanced manufacturing, aerospace, new energy and green environmental protection and other frontier scientific and technological innovation fields.

3) Improving the research on top-level design. In this context, China needs to strengthen the national S & T policy and ensure that basic laws and regulations formulated at national level play a leading role. It is needed to explore how to build a new type of national system where the government is decentralized, resources are pooled and problems are addressed by concerted action. Government departments should actively improve the evaluation system of S & T achievements, establish a scientific research competition mechanism, break unreasonable restrictions, and support regulatory and service reform in the S & T field.

4) Strengthening research on the ecological chain of S & T talents. The research of S & T innovation is, in the last analysis, the research of the implementation of the human subject. Enhancing the ecological chain science including nurturing, introduction and retention of talents, which are the production factors. Through preferential policies, China should strengthen the foundation of high-level scientific research talents in the country. We should speed up the multidimensional design of the Chinese science and technology talents policy from the top to the bottom, form a hierarchic, hierarchic and classified innovation talents policy system, and build a long chain management system throughout the cycle.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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