ISSN 2409-2665
Journal of Logistics, Informatics and Service Science
Vol. 12 (2025) No. 7, pp. 38-55
DOI:10.33168/JLISS.2025.0703

How Do Government Subsidies Empower Corporate Green Innovation? A Visual Knowledge Map Analysis Based on CiteSpace

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Abstract. Against the backdrop of global "dual carbon" goals, government subsidies, as a core policy tool to incentivize corporate green innovation, have consistently been a focal point of academic attention regarding their mechanisms and effects. To systematically reveal the knowledge structure, research hotspots, and evolutionary trends in this field, this study utilized CiteSpace software to conduct a visual knowledge map analysis based on 325 core documents from the Web of Science Core Collection database. The study found that: knowledge output in this field exhibits a high degree of "China-centricity," forming a mature knowledge system primarily centered on "government subsidies - green innovation - performance impact"; research hotspots have deepened from macro-level policy design and effect evaluation to micro-level theoretical mechanisms such as corporate innovation strategies, commercialization pathways, and information asymmetry; the research frontier clearly shows a dynamic evolutionary trajectory from early exploration of basic concepts to current concerns about emerging drivers like digital transformation and the systematic integration of sustainable development. By panoramically depicting the knowledge map of this field, this study provides references and insights for subsequent theoretical deepening and policy optimization.

Keywords: Government Subsidies, Green Innovation, CiteSpace, Knowledge Map, Bibliometric Analysis

1. Introduction

Against the backdrop of global climate change and environmental pollution becoming contemporary global crises (Marazziti et al., 2021), promoting green transformation and sustainable development has become a universal consensus in the international community. Green innovation is widely regarded as a key path to address climate change and achieve sustainable development (Silvestre & Tirca, 2019). It not only reduces pollutant emissions through technological advancements but also drives the economy towards a low-carbon, efficient model (Shen & Zhang, 2023). As the world's largest developing country, China faces dual pressures from economic development and environmental protection. In this context, the "dual carbon" goals have set a clear direction for enterprises' green transformation, and green innovation has become crucial for achieving both economic and environmental benefits (Guo et al., 2021). In this transformation process, the green development of heavily polluting industries, characterized by "high pollution, high energy consumption, and high resource dependence" (Lin et al., 2021), is an important path to achieve the national "dual carbon" goals. However, enterprises generally face multiple obstacles when practicing green innovation. Firstly, green innovation requires higher cost investment than traditional innovation, and its results face the risk of being imitated and copied by other enterprises in market applications, which weakens enterprises' enthusiasm for innovation (Roper & Tapinos, 2016; Wang et al., 2022). Furthermore, due to the lack of strict pricing mechanisms for pollutant emissions, enterprises lack the motivation to proactively engage in green innovation (Wu et al., 2022). In a context where market mechanisms alone are insufficient to drive enterprises to make necessary transformations, government policy intervention becomes particularly important. Government subsidies, as a key policy tool, can effectively incentivize enterprises to increase R&D investment by alleviating their financial pressure and reducing innovation costs (Liu et al., 2022), thereby significantly promoting green innovation (Huang et al., 2019). Therefore, an in-depth exploration of how government subsidies influence and empower enterprises' green innovation activities holds significant theoretical and practical implications.

Traditional literature reviews, when summarizing the current state of a field, often rely on researchers' subjective experience, making it difficult to comprehensively and objectively reveal the complex internal structures and dynamic evolutionary trends of the knowledge domain. To overcome this limitation, this study will employ the method of Scientometrics, utilizing the visualization analysis software CiteSpace, to conduct a quantitative bibliometric analysis of the field of "government subsidies and corporate green innovation." This method can transform massive amounts of literature data into intuitive knowledge network maps through mathematical algorithms and visualization techniques, thereby clearly identifying the knowledge base (cited literature and authors), research hotspots (high-frequency keywords), and frontier dynamics (burst terms) within the field (Chen, 2006).

Therefore, this study aims to utilize CiteSpace software to systematically reveal the knowledge structure, research hotspots, and evolutionary frontiers in the field of "government subsidies and corporate green innovation" by creating a scientific knowledge map. To achieve this objective, the remainder of this paper is organized as follows: Section 2 provides a review of the relevant literature. Section 3 elaborates on the research design, data sources, and analytical methods. Section 4 presents and discusses the detailed results of the knowledge map analysis. Finally, Section 5 concludes the paper by summarizing its findings and outlining the theoretical contributions, practical implications, and directions for future research.

2. Literature Review

2.1.Incentive and Inhibitory Effects of Government Subsidies on Corporate Green Innovation

The academic community has not yet reached a unified conclusion on whether government subsidies can effectively promote corporate green innovation, with two opposing views: "incentive effect" and "inhibitory effect." Scholars who support the incentive effect argue that green innovation activities lead to market failure due to their inherent "double externalities," thereby suppressing enterprises' willingness to invest (Rennings, 2000). The "incentive theory" view advocates that government subsidies, as a key policy tool, can effectively supplement enterprise R&D funds and share innovation risks (Czarnitzki & Licht, 2006; Bai et al., 2019), thereby significantly encouraging enterprises to increase their investment in green innovation. A large number of empirical studies have also confirmed that government subsidies have played a significant role in promoting enterprises' green technology innovation (Huang et al., 2019; Du et al., 2023). However, another group of scholars has put forward the view of "inhibitory effect" or "crowding-out effect" (Clausen, 2009). They believe that government subsidies may distort market mechanisms and induce rent-seeking behavior and resource misallocation by enterprises (Beason & Weinstein, 1996). Subsidy funds may "crowd out" enterprises' original R&D investment, leading to enterprises' dependence on policies, which in turn reduces their intrinsic motivation for independent innovation. Empirical studies have also found that, in some cases, government subsidies have a negative impact on enterprises' technological inventions or innovation efficiency (Chen et al., 2020). Beyond the internal focus, other studies highlight the crucial role of external collaboration, demonstrating that supply chain collaboration significantly enhances green innovation performance in Chinese logistics firms, with policy effectiveness varying based on whether a firm is state-owned or private (Ou et al., 2025).

2.2.Mechanism of Government Subsidies on Corporate Green Innovation

To explain the complexity and contradictory nature of the effects of government subsidies, subsequent research has moved beyond direct causal relationships to delve into the mediating and moderating mechanisms involved. Among these mechanisms, environmental information disclosure (EID) is considered a key mediating variable. After receiving government subsidies, companies often face stronger social scrutiny, which incentivizes them to improve the quality and transparency of their environmental information disclosure (Clarkson et al., 2008). High-quality environmental information disclosure can reduce information asymmetry, thereby promoting more substantive green innovation activities by strengthening accountability and stakeholder pressure. Furthermore, the ultimate effect of subsidy policies is also moderated by a series of internal and external factors. Externally, the intensity of environmental regulation (ER) is an important boundary condition. Strict environmental regulations increase companies' compliance costs and transformation pressure, forcing them to invest subsidy funds more effectively into substantive green innovations that address fundamental environmental problems, thereby strengthening the positive effects of subsidies (Tang et al., 2020). Using provincial data from China, Ding et al. (2025) empirically found that green finance significantly promotes industrial structure transformation, primarily through the dual pathways of enhancing green technology innovation and constraining carbon emissions. Internally, managers' environmental concern (MEC) plays a crucial moderating role. Managers with strong environmental awareness are more inclined to prioritize the long-term sustainable development of their companies, and thus they will utilize subsidy resources more rationally, directing them towards high-quality substantive green innovation projects (Song et al., 2021), rather than strategic innovations merely aimed at short-term compliance or speculative purposes. Furthermore, other research reveals that a firm's perception of science and technology policies significantly drives sustainable innovation performance through the mediating pathways of innovation investment and organizational incentives, with the effectiveness of these

internal mechanisms being moderated by innovation leadership (Zou et al., 2025).

2.3.Institutional Theory and Principal-Agent Theory

The understanding of the relationship between government subsidies and corporate green innovation is primarily built upon two major theoretical foundations: institutional theory and principal-agent theory. Institutional Theory posits that organizational behavior and decisions are deeply influenced by the external institutional environment, and that the pursuit of legitimacy is a fundamental prerequisite for an enterprise's survival and development (Scott, 2005; DiMaggio & Powell, 1983). Within this framework, government subsidy policies and environmental regulations together constitute key institutional pressures that guide and constrain corporate behavior. To obtain government resources and social recognition, companies align their green innovation strategies with external institutional expectations, thereby demonstrating compliance (Chen et al., 2018). On the other hand, Principal-Agent Theory provides profound insights into the issue of subsidy efficiency (Braun & Guston, 2003). This theory views the government as the "principal" and the subsidized enterprise as the "agent" (Jensen & Meckling, 1976). Due to misaligned objectives (the government seeks to maximize social and environmental benefits, while corporate managers may pursue personal or short-term interests) and the existence of information asymmetry, agents may engage in opportunistic behavior, such as using subsidy funds for non-core innovation areas, leading to "moral hazard" and resource misallocation, thereby weakening policy effectiveness. Therefore, monitoring mechanisms such as environmental information disclosure and environmental regulation are crucial for mitigating agency problems and ensuring that subsidy funds are effectively used to achieve the principal's (i.e., the government's) green development goals. Complementing these policy and governance frameworks, recent studies emphasize the role of technological drivers, showing that intelligent manufacturing—the deep integration of digital and advanced manufacturing technologies—significantly improves corporate environmental performance by fostering green innovation and enhancing green supply chain collaboration, with its effectiveness amplified by top management's environmental awareness (Wu et al., 2025). Shifting the focus to market-facing strategies, other research finds that destigmatization and green marketing efforts enhance a firm's dynamic competitive advantage, a relationship mediated by green corporate social responsibility and strengthened by the firm's dynamic absorptive capacity (Cheng & Chen, 2025). Focusing on internal enablers, studies also show that leadership and digital transformation competency significantly improve green business performance in SMEs, with business innovation acting as a crucial mediator that translates these capabilities into sustainable outcomes (Khanh & Cuong, 2025). Focusing specifically on logistics, research in Indonesia's courier industry shows that green technology and green transportation improve green supply chain performance, an effect that is significantly mediated by the supply chain's agility in adapting to change (Syafrianita et al., 2025).

3. Research Methodology: A Bibliometric and Knowledge Map Analysis Based on CiteSpace

To construct a high-quality, highly relevant literature database, this study selected the Web of Science (WoS) Core Collection as the data source, given its high-quality literature and complete citation data, making it an ideal choice for scientific knowledge mapping analysis. Literature retrieval followed the principle of combining comprehensiveness and precision, constructed through modular keywords. The retrieval time span was set from 2005 to 2025, the document type was limited to "Article," and the language was limited to "English." The specific retrieval logic is as follows:

First, a "government subsidies" theme module (independent variable) was constructed, including TS=("government subsid*" OR "public subsid*" OR "state aid" OR "government grant*" OR "public funding"); second, a "green innovation" theme module (dependent variable) was constructed, including TS=("green innovation" OR "eco-innovation" OR "eco innovation" OR "environmental

innovation" OR "green technolog*" OR "clean technolog*"); finally, a combined search was performed using Boolean logic (("government subsidies" module) AND ("green innovation" module)). After deduplication and screening, a total of 325 English documents highly relevant to the theme of this study were ultimately selected as the data sample for this visualization analysis.

This study aims to use CiteSpace software to map the knowledge landscape of research on "government subsidies empowering corporate green innovation" globally from 2005 to 2025. Specific objectives include:

Identifying research hotspots and core themes: Through keyword co-occurrence and cluster analysis, to ascertain the main research content and structure in this field.

Exploring the knowledge base and academic schools: Through document and author co-citation analysis, to identify foundational literature, authoritative scholars, and major academic communities in this field.

Reveal research frontiers and evolutionary trends: Through keyword burst analysis, track the dynamic changes of hot topics in the field and predict future research directions.

4. Findings and Discussion

4.1.Keyword Co-occurrence

Keyword co-occurrence analysis is a core method that reveals the main research hotspots and their interrelationships within a discipline by statistically analyzing the frequency of keywords appearing together in literature. In a knowledge graph, high-frequency keywords usually represent the core research themes and hot topics in that field over a period, while keywords with high centrality often play the role of "bridges" or "hubs" connecting different research themes, which is crucial for understanding the knowledge structure of the entire field.

The keyword co-occurrence network map generated this time (see Figure 1) contains a total of 312 nodes (N=312) and 772 links (E=772), with a network density of 0.0159. The network forms a largest connected component comprising 309 nodes (accounting for 99%), indicating that the core concepts in this research field are closely related and have formed a highly aggregated and coherent knowledge network.

Judging from the size of the nodes in the figure, "government subsidy," "green innovation," "performance," "impact," and "research and development" are the most frequently occurring keywords, forming the absolute core of research in this field. This clearly reveals the mainstream paradigm of current research, which focuses on exploring the "impact" and "performance" of "government subsidy" as a policy tool on corporate "green innovation" activities, with "research and development" being a key implementation path.

From the perspective of node centrality, keywords such as "performance," "research and development," "china," "management," and "investment" show distinct purple outer rings, indicating their high centrality (betweenness centrality). This suggests that these keywords are key hubs connecting different research sub-themes. For example, "performance" not only connects subsidy policies with innovation outcomes but also links to other management and strategic themes, serving as a core node for measuring policy effectiveness. It is worth noting that "china" also exhibits high centrality, further confirming that China is not only a high-frequency research subject in this field but also a critical context and bridge connecting different theoretical and empirical studies. These hub words collectively outline the structural skeleton of research in this field, which revolves around management and investment decisions, through R&D activities, in the important context of China, ultimately achieving and measuring the performance of green innovation.

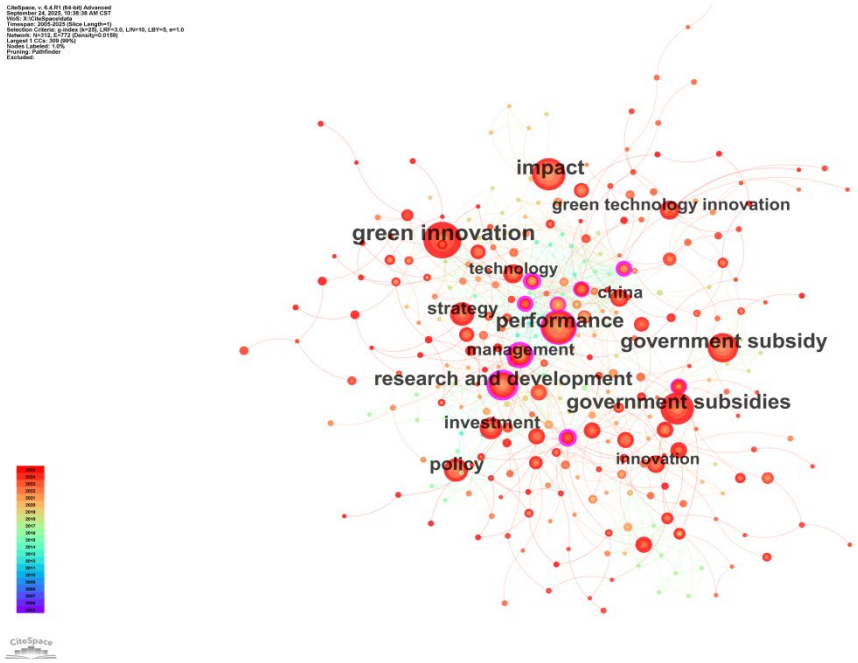

Fig.1: Keyword co-occurrence network

According to Table 1, in terms of frequency (Count), the top five keywords are green innovation (93 times), performance (74 times), impact (72 times), government subsidies (72 times), and government subsidy (70 times). This clearly indicates that the research themes in this field are highly concentrated, forming a knowledge system with "government subsidies" as the core driving factor, "green innovation" as the research object, and the exploration of its "impact" and "performance" as the main goals. In addition, terms such as research and development, policy, and investment are also among the top, further illustrating that the research content closely revolves around the core logical chain of how subsidy policies influence enterprises' R&D and investment decisions, ultimately affecting innovation performance.

Analyzing from the dimensions of Centrality and Year, we can gain insight into the evolutionary trend of the knowledge structure in this field. Environmental innovation (0.39) and management (0.38) rank high in centrality, far exceeding other keywords, indicating that they are key hubs connecting different research themes and play an important "bridge" role in the knowledge structure of the field. In terms of time, terms such as performance (2013) and research and development (2013) appeared earlier, representing foundational issues in this field. Keywords such as competition (2019), coordination (2020), and green technology innovation (2022) appeared later, reflecting that the research frontier in this field is deepening and developing from macro-level performance impact assessment towards more micro, specific enterprise competitive dynamics, policy coordination mechanisms, and specific technological innovation paths.

Table 1: Top 20 High-Frequency Keywords in Research Fields

No.	Count	Centrality	Year	Keywords
1	93	0.06	2014	green innovation
2	74	0.13	2013	performance
3	72	0.00	2018	impact
4	72	0.04	2016	government subsidies
5	70	0.03	2017	government subsidy

6	61	0.22	2013	research and development
7	42	0.08	2013	policy
8	39	0.00	2019	investment
9	35	0.03	2014	strategy
10	32	0.38	2013	management
11	29	0.04	2022	green technology innovation
12	29	0.03	2016	china
13	27	0.03	2018	innovation
14	27	0.01	2018	technology
15	23	0.08	2020	coordination
16	22	0.05	2017	firms
17	22	0.09	2019	competition
18	21	0.39	2013	environmental innovation
19	20	0.12	2013	determinants
20	20	0.06	2018	environmental regulation

4.2.Keyword Clustering

Keyword cluster analysis can organize hot words in a co-occurrence network into meaningful "thematic groups," thereby revealing the research structure and core issues in the field at a deeper level. This study uses the LLR (Log-Likelihood Ratio) algorithm to cluster the keyword network and interprets the 13 largest clusters (#0 to #12). According to the CiteSpace results (see Figure 2), the modularity Q value of the network generated by this analysis is 0.6896, which is much greater than the critical value of 0.3, indicating a very significant community structure in this research field. The weighted average silhouette S value is 0.8568, which is much higher than the high homogeneity standard of 0.7, indicating that the clustering results of this network division are of extremely high quality, with strong internal homogeneity, and reliable results.

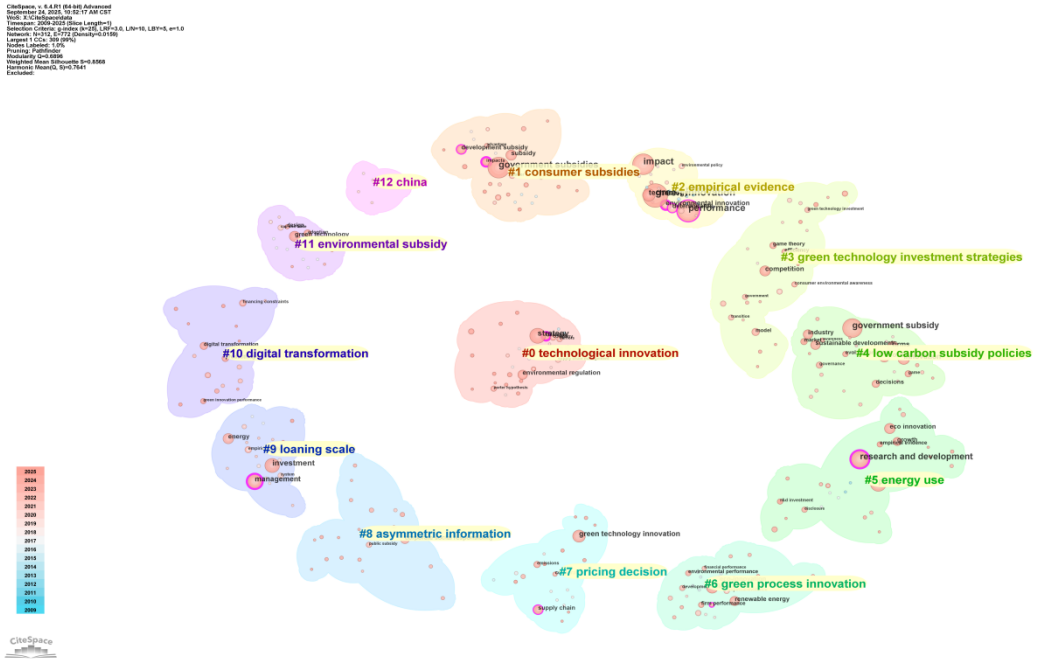

Fig.2: Research Hotspot Clustering Map

Table 2: Research Hotspot Cluster Analysis Table

Cluster ID (#)	Size	S	LLR Label	Core Keywords	Interpretation & Refined Label
#0	32	0.844	technological innovation	technological innovation, strategy, environmental regulation	Technological Innovation Strategies under Environmental Regulation
#1	31	0.784	consumer subsidies	consumer subsidies, government subsidies, impact, development subsidy	Types and Effects of Consumer Subsidies
#2	30	0.822	empirical evidence	empirical evidence, impact, innovation performance	Empirical Studies on Subsidy Impact on Innovation Performance
#3	30	0.792	green technology investment strategies	green technology investment strategies, game theory, competition	Competitive Strategies for Corporate Green Investment
#4	29	0.852	low carbon subsidy policies	low carbon subsidy policies, government subsidy, industry, sustainable development	Low-Carbon Subsidy Policies and Sustainable Development
#5	27	0.839	energy use	energy use, research and development, eco-innovation	R&D in Energy Efficiency and Eco-Innovation
#6	26	0.935	green process innovation	green process innovation, environmental performance, renewable energy	Green Process Innovation and Environmental Performance
#7	22	0.954	pricing decision	pricing decision, green technology innovation, supply chain	Commercialization of Green Technology: Pricing and Supply Chain
#8	21	0.825	asymmetric information	asymmetric information, green subsidy	Theoretical Perspective: Asymmetric Information Problem
#9	21	0.904	loaning scale	loaning scale, investment, management	Financial Mechanisms: Loaning Scale and Investment Management
#10	18	0.816	digital transformation	digital transformation, financing constraints, green innovation performance	Emerging Driver: Digital Transformation
#11	17	0.965	environmental subsidy	environmental subsidy, design, pollution	Subsidy Design for Pollution Control
#12	5	0.991	china	china	Geographical Focus: The Research Context of China

Keyword clustering analysis can organize hot words in co-occurrence networks into meaningful "thematic groups," thereby revealing the research structure and core issues in the field at a deeper level.

First, macro-level policies and effect evaluation are the cornerstones of research in this field. Cluster #2 (Empirical Studies on Subsidy Impact on Innovation Performance), Cluster #4 (Low-Carbon Subsidy Policies and Sustainable Development), and Cluster #11 (Subsidy Design for Pollution Control) collectively form the core main line of research, which revolves around how governments design subsidy policies for low-carbon development and pollution control, and empirically test their innovation performance.

Second, micro-level corporate strategies and innovation pathways are the practical focal points of research. Cluster #0 (Technological Innovation Strategies under Environmental Regulation) and Cluster

#3 (Competitive Strategies for Corporate Green Investment) reveal that researchers are highly concerned with enterprises' strategic choices for technological innovation under environmental regulations and market competition pressures. At the same time, the research content has delved into specific types of innovation, such as Cluster #6 (Green Process Innovation and Environmental Performance) and Cluster #5 (R&D in Energy Efficiency and Eco-Innovation), as well as the commercialization aspects of innovation, such as Cluster #7 (Commercialization of Green Technology: Pricing and Supply Chain).This indicatesthat research has deepened from "whether to innovate" to the specific pathways of "how to innovate" and "how to commercialize innovation."

Third, deep-seated theories and financial mechanisms provide theoretical support and implementation guarantees for this field. The emergence of Cluster #8 (Theoretical Perspective: Asymmetric Information Problem) indicates that academia has explored the issue of information asymmetry between government and enterprises from theoretical perspectives such as principal-agent theory, which is the theoretical foundation for subsidy policy design. Cluster #9 (Financial Mechanisms: Loaning Scale and Investment Management) focuses on supporting financial mechanisms beyond direct subsidies, such as credit support and investment management, which are important guarantees for the realization of green innovation.

Finally, emerging drivers and research contexts point to the frontiers and focal points of this field. Cluster #10 (Emerging Driver: Digital Transformation) is a significant research frontier, indicating that digital transformation is being regarded as an emerging and important driver for empowering corporate green innovation. For example, through an empirical study of the tourism industry, Khanh, Khoa, and Cuong (2025) found that digital transformation promotes sustainable growth, and this effect is significantly mediated by innovative change. In fact, quantitatively assessing the sustainability of digital innovations has become a frontier topic within sustainable finance. For example, Martynas Rajunčius and Algita Miečinskienė (2024) proposed a quantitative framework, the Payment Sustainability Index (PSI), to measure the sustainability of financial payment innovations by integrating ESG, social equity, and financial inclusion factors. This further confirms the trend of deep integration between digitalization and sustainable development goals. The independent existence of Cluster #12 (Geographical Focus: The Research Context of China) strongly demonstrates that China is the most core geographical context and source of cases for research in this field, with a large number of empirical studies focusing on China's policy practices and corporate behavior.

4.3.Keyword Burst Detection

Keyword burst analysis (Citation Bursts) identifies keywords with a significant increase in citation frequency over a specific period, representing the research frontiers and emerging hot topics in that field during that time. Figure 3 displays the 12 keywords with the highest burst strength. By analyzing their start and end times, we can outline the dynamic evolution path of research frontiers in the field of government subsidies and corporate green innovation.

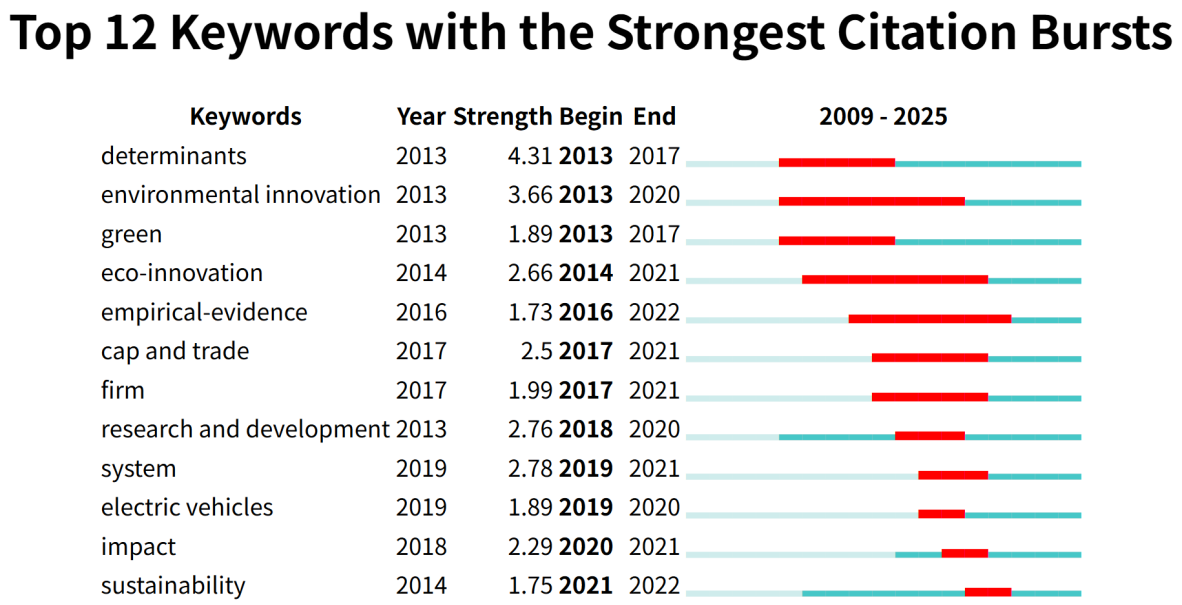

Fig.3: Keyword Bursts

The evolution of research frontiers can be broadly divided into three stages:

Phase 1: Foundational Concepts and Theoretical Exploration (approximately 2013-2017). In the early stages of research, burst keywords primarily focused on defining core concepts and exploring basic theories in the field. "determinants" was the keyword with the highest burst strength (4.31) and earliest appearance in this map, bursting from 2013-2017, indicating that the core task of early research was to identify and explore key factors influencing green innovation. Almost simultaneously, fundamental concepts such as "environmental innovation," "eco-innovation," and "green" appeared concentrically, suggesting that academia at this stage was dedicated to constructing and enriching the core vocabulary system and theoretical framework of the field. "research and development" (R&D), as a key path connecting policy and innovation, also became a research frontier during this period, with its burst continuing until 2018.

Phase 2: Empirical Testing and Exploration of Diversified Policy Instruments (approximately 2016-2021). With the consolidation of theoretical foundations, research frontiers began to shift towards empirical testing of theories and attention to more policy instruments. "empirical evidence" began to burst in 2016 and continued until 2022, marking the entry of the field into a research paradigm dominated by data-driven and empirical analysis. Concurrently, "cap and trade" became a burst keyword between 2017 and 2021, indicating that researchers' perspectives expanded from single government direct subsidies to market-based environmental regulatory tools, and began to explore the combined effects of different policy instruments. "firm" also became a burst keyword in 2017, reflecting a further focus of research perspectives on the micro-level of enterprises.

Phase 3: Deepening Impact Mechanisms and Sustainable Development Integration (approximately 2018-present). The emergence of "impact" from 2018 onwards indicates that research is no longer satisfied with simple correlation analysis but delves deeper into the specific impact pathways and mechanisms of subsidy policies. The emergence of "system" and "sustainability" signifies a further elevation of research perspectives, as scholars begin to consider government subsidies and green innovation within a broader systemic framework and sustainable development goals. "Electric vehicles" briefly emerged in 2019, reflecting a shift in research frontiers towards specific high-tech green industries, using concrete cases to deepen the understanding of general theories.

4.4.Timeline View

The timeline view, building upon cluster analysis, adds a temporal dimension, clearly illustrating the emergence, development, and continuation of various research topics (clusters), and revealing the inheritance and evolutionary relationships between them. Figure 4 displays the timeline distribution of 13 major clusters between 2009 and 2025, from which the lifecycle and developmental trajectory of research topics in this field can be interpreted.

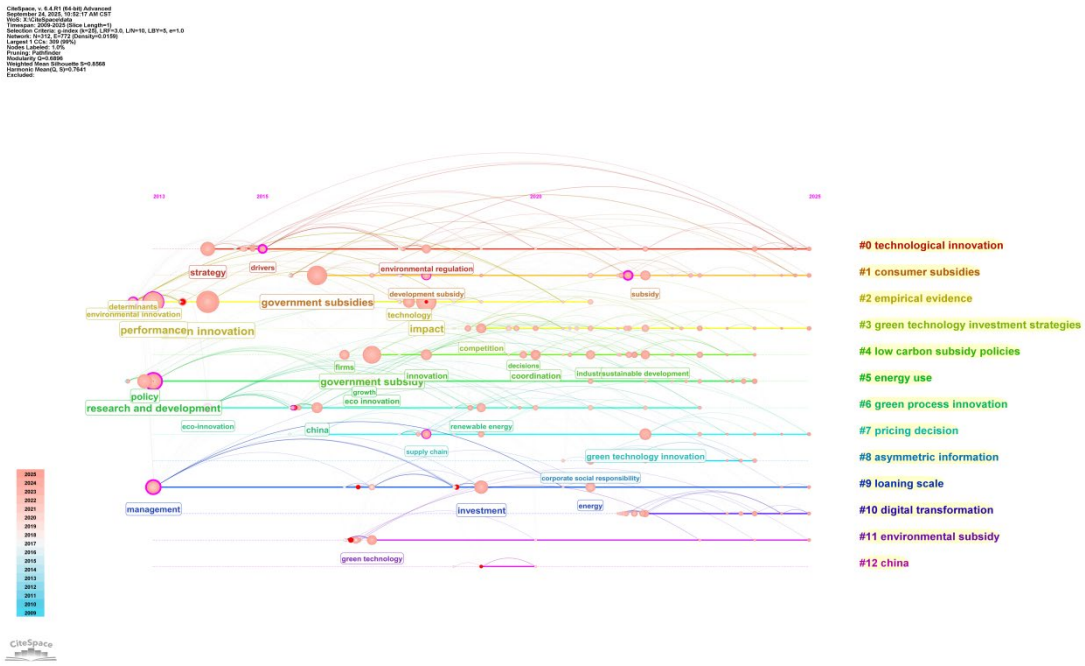

Fig.4: Timeline view

Some foundational research themes demonstrate strong vitality and continuity. For example, the timelines for Cluster #0 (technological innovation) and Cluster #2 (empirical evidence) span a very long period, extending from the early stages of research to the present. This indicates that "technological innovation" as a core issue, and the use of "empirical" methods for verification, have run through the entire development process of this research field, serving as its enduring cornerstone. Similarly, the timeline for Cluster #4 (low carbon subsidy policies) is also relatively long-lasting, reflecting that against the backdrop of "dual carbon" goals, low-carbon subsidy policies have consistently been a focus of academic attention.

Research topics show an evolutionary trend from macro to micro, and from theory to practice. In the early stages of research (approximately 2013-2017), nodes in cluster #0 (technological innovation), cluster #1 (consumer subsidies), and cluster #2 (empirical evidence) were denser, with research primarily focusing on the macro impact of subsidies on innovation and effect evaluation. Over time, research hotspots gradually deepened. For example, cluster #3 (green technology investment strategies) and cluster #7 (pricing decision) became active after approximately 2018, indicating a shift in research perspective towards more micro-level corporate investment strategies and technology commercialization issues. Cluster #8 (asymmetric information) and cluster #9 (loaning scale) also reflect a shift in research from descriptive phenomena to deeper theoretical mechanisms (information asymmetry) and financial practices (credit support).

In recent years, new interdisciplinary research frontiers have emerged, with a clear trend of theme integration. Cluster #10 (digital transformation) is a very young cluster, with its nodes primarily appearing after 2020, clearly revealing that "digital transformation" is an emerging research frontier empowering green innovation in recent years, representing the future direction of development. Furthermore, the connections between clusters in the figure show a close knowledge inheritance relationship between different themes. For example, keywords in the early cluster #0 (such as

environmental regulation) are connected to later cluster #3, cluster #4, etc., indicating that early research on technological innovation laid the foundation for subsequent more specific investment strategies and low-carbon policy research.

4.5.Author Collaboration Network Analysis

A co-authorship network analysis of 325 papers was conducted, and the results are shown in Figure 5 and Table 3. The author collaboration network in this field generally exhibits characteristics of "overall loose, locally tight." From the global network in Figure 6, the nodes are relatively dispersed, and a large-scale, cross-institutional, tightly collaborative network has not yet formed. Most scholars exist in the form of independent research or small-scale team collaboration, which indicates that this research field may still be in its developmental stage and has not yet formed a mature academic community.

Nevertheless, some local collaborative clusters centered around prolific authors have emerged in the network. Combining the publication statistics in Table 3, Hu, Sumin, Chen, Jihong, and Cuerva, Maria C are the most published scholars in this field (all with 3 papers). They also occupy relatively central positions in the network and have established collaborative relationships with multiple other scholars. For example, Hu, Sumin has formed a relatively distinct collaborative group with scholars such as Zhang, Shengling and Gao, Ganxiang. Local clusters represent active and influential research teams within the field, serving as the core force for knowledge production and dissemination.

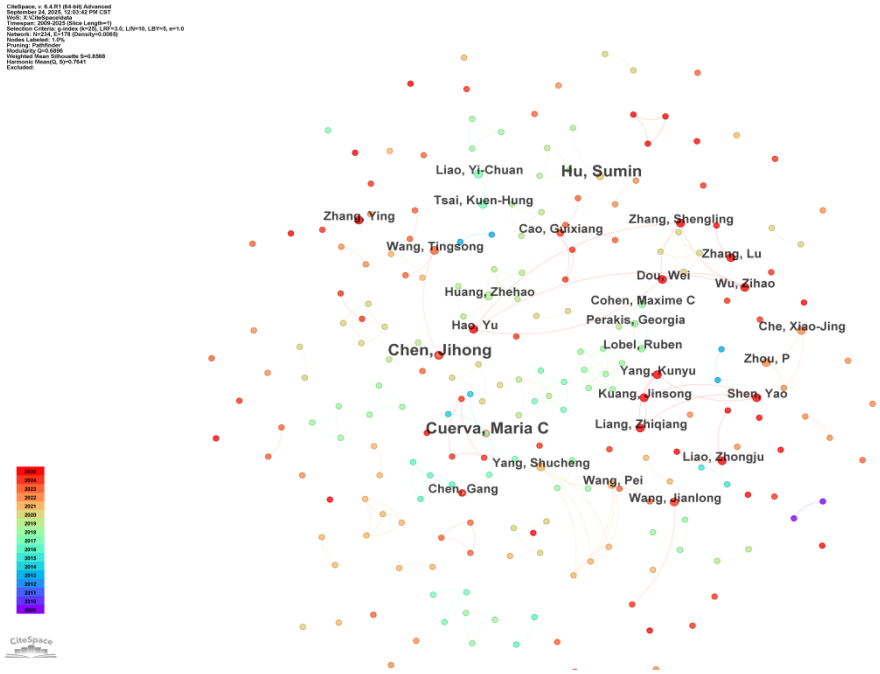

Fig.5：Author Atlas

Table 3：Top 30 Author Publication Statistics

No.	Author	Year	Number of publications	No.	Author	Year	Number of publications
1	Cuerva, Maria C	2014	3	11	Lobel, Ruben	2016	2
2	Chen, Jihong	2023	3	12	Shen, Yao	2025	2
3	Hu, Sumin	2019	3	13	Zhang, Lu	2025	2
4	Liao, Yi-Chuan	2017	2	14	Perakis, Georgia	2016	2
5	Liao, Zhongju	2025	2	15	Wang, Pei	2021	2
6	Yang, Kunyu	2025	2	16	Chen, Gang	2022	2
7	Wang, Tingsong	2023	2	17	Yang, Shucheng	2021	2

8	Tsai, Kuen-Hung	2017	2	18	Liang, Zhiqiang	2025	2
9	Wu, Zihao	2025	2	19	Zhou, P	2022	2
10	Che, Xiao-Jing	2022	2	20	Cohen, Maxime C	2016	2

4.6.National Cooperation Network Analysis

An analysis of the countries/regions of origin for 325 documents is presented in Figure 6 and Table 4. The international collaboration network in this field exhibits a pattern of "one core with multiple points, highlighting the center." From the collaboration network map in Figure 6 and the publication volume data in Table 4, China (Peoples R China) holds an absolute core position in this field, with a high publication volume of 286 articles, far exceeding other countries. It acts as a central node in the network, establishing cooperative relationships with multiple countries. This indicates that China is not only the primary contributor to knowledge output in this field but also a core hub in the international collaboration network.

In addition to China, developed countries such as the United States (USA), Spain, England, and Australia also constitute significant research forces in this field, each with over 10 publications. They form multiple secondary nodes in the network, collaborating to varying degrees with China and other countries. The connections in the collaboration network primarily point from China to other countries, or occur between several other major research countries. However, the intensity of inter-country cooperation appears relatively loose compared to China's central position. This suggests that current research on "government subsidies and corporate green innovation" is mainly led by Chinese scholars, who collaborate with scholars from other major global economies, but a global, multilateral, and balanced cooperation network has not yet fully formed.

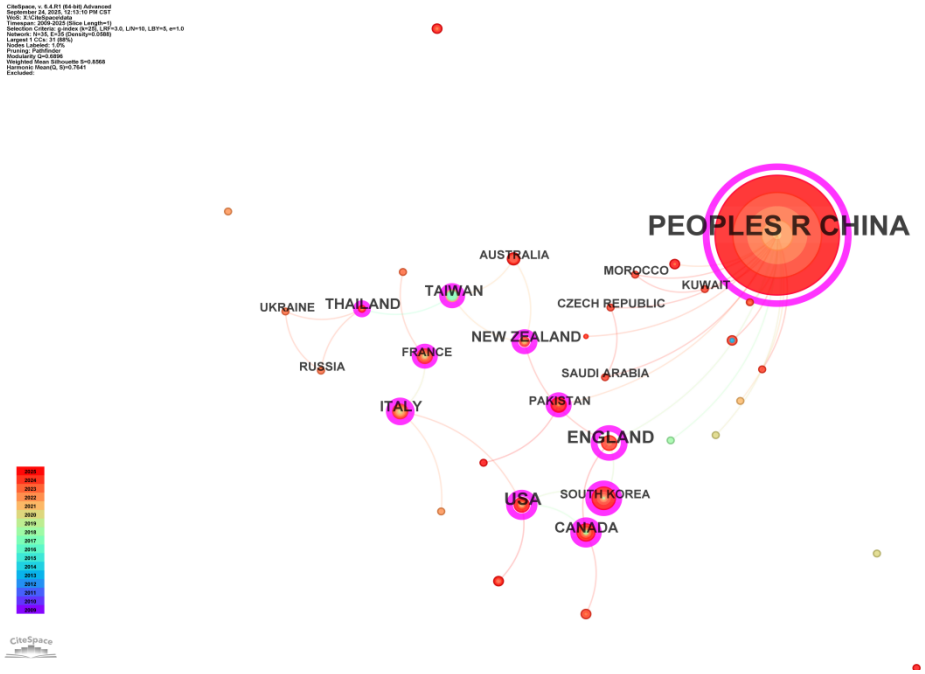

Fig.6: National Cooperation Map

Table 4: Top 20 Countries by Publication Volume

No.	Country	Year	Number of publications	No.	Country	Year	Number of publications
1	PEOPLES R CHINA	2016	286	11	TAIWAN	2017	4
2	USA	2016	15	12	MALAYSIA	2022	4

3	SPAIN	2014	12	13	JAPAN	2022	3
4	ENGLAND	2019	11	14	SINGAPORE	2022	3
5	AUSTRALIA	2021	10	15	THAILAND	2017	3
6	SOUTH KOREA	2019	9	16	NEW ZEALAND	2021	2
7	CANADA	2018	7	17	POLAND	2023	2
8	FRANCE	2019	6	18	NETHERLANDS	2013	2
9	ITALY	2013	6	19	INDIA	2023	2
10	PAKISTAN	2022	5	20	CZECH REPUBLIC	2024	1

4.7.Analysis of Institutional Collaboration Networks

An analysis of the publishing institutions of 325 documents was conducted, and the results are shown in Figure 7 and Table 5. The institutional collaboration network in this field exhibits characteristics of being "**China's universities as the main body, multi-centered, and networked**." From the statistics of publications in Table 5, the vast majority of top-ranked institutions are well-known Chinese universities and research institutes. Among them, Sichuan University and the Chinese Academy of Sciences are tied for first place with 8 publications each, followed closely by Hunan University, Renmin University of China, and Capital University of Economics & Business, each with 7 publications. This indicates that Chinese academic institutions are the absolute main force in knowledge production in this field.

From the collaborative network map in Figure 7, a relatively dense collaborative network has formed, with no single dominant entity, but rather a multi-centric pattern. Institutions such as the Chinese Academy of Sciences, China University of Mining & Technology, Hunan University, and the University of California System are all in relatively central positions within the network, having established cooperative relationships with multiple domestic and international institutions. This indicates that research in this field has evolved from independent exploration among institutions to a networked collaborative stage. The University of California System in the United States also appears in the core area of the network and has cooperative links with Chinese universities such as Shanghai University, reflecting a certain degree of international cooperation in this field, although the main body of cooperation remains highly concentrated among Chinese universities.

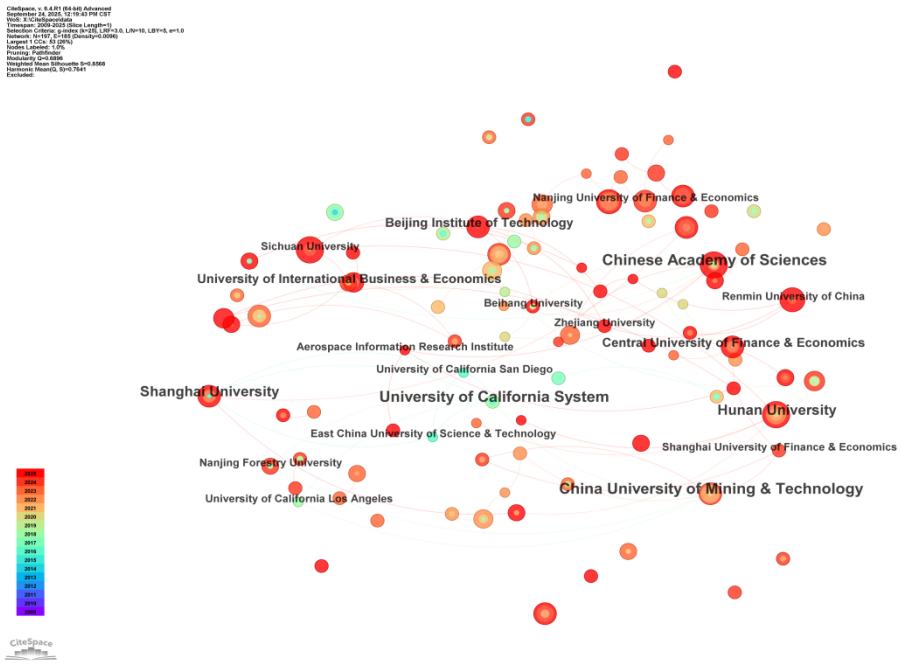

Fig.7: Institutional Collaboration Network Map

Table 5: Top 20 Institutions by Publication Volume

No.	Institution	Year	Number of publications	No.	Institution	Year	Number of publications
1	Sichuan University	2020	8	11	Nanjing University of Finance & Economics	2023	5
2	Chinese Academy of Sciences	2017	8	12	Shanghai University	2016	5
3	Hunan University	2019	7	13	Dalian Maritime University	2023	5
4	Renmin University of China	2021	7	14	Beijing Institute of Technology	2024	4
5	Capital University of Economics & Business	2022	7	15	Chongqing University	2022	4
6	Central University of Finance & Economics	2020	6	16	Guangzhou University	2019	4
7	China University of Mining & Technology	2018	6	17	Tianjin University	2018	4
8	China University of Geosciences	2024	5	18	Shenzhen University	2021	4
9	Tongji University	2019	5	19	Xiamen University	2023	4
10	China University of Petroleum	2021	5	20	Harbin Engineering University	2018	4

4.8.Discussion

This study conducts a knowledge graph visualization analysis of 325 relevant documents from the Web of Science Core Collection between 2005 and 2025 to explore the knowledge structure, hot topics, and evolving frontiers in the research field of "government subsidies empowering corporate green innovation." The analysis reveals that this field has formed a network pattern with China as the absolute core research context (accounting for over 87% of publications) and Chinese universities and research institutions as the main research forces. In a bibliometric analysis of green finance and banking performance, Khadka et al. (2024) also found that research in the field is growing rapidly, with China serving as the absolute core of global research output and a hub for international collaboration. However, cooperation among scholars shows a characteristic of "overall loose, locally tight." Research hotspots are highly focused on exploring the "impact" and "performance" of "government subsidies" on corporate "green innovation," and have differentiated into four core thematic dimensions: macro-level subsidy policy design and effectiveness evaluation, micro-level corporate innovation strategies and commercialization paths, deep-mechanism-level theoretical issues such as information asymmetry and financial support mechanisms like credit, and emerging frontier-level new drivers such as digital transformation. From an evolutionary trend perspective, the research path in this field clearly demonstrates an evolution from early basic concept definition and influencing factor exploration, to large-scale empirical testing and diversified policy tool comparison in the mid-term, and then to recent deepening of influence mechanisms, focusing on sustainable development system integration, and concentrating on specific industries (such as electric vehicles). This indicates that the entire field is developing towards a more refined, in-depth, and systematic direction.

The visualization analysis results of this study not only depict the panoramic knowledge of the field but also offer important insights for future policy practice and academic research. For policymakers, the evolution of research hotspots from "whether subsidies are effective" to "how subsidies become effective" indicates that future policy design should go beyond simple fund disbursement and shift

towards more refined and systematic mechanism building. For example, by strengthening information disclosure requirements to mitigate "information asymmetry" issues, and promoting the synergy between green financial credit and fiscal subsidies to improve fund allocation efficiency. At the same time, "digital transformation" as an emerging research frontier suggests that policymakers should actively explore how to combine digital strategies with green incentive policies to create synergistic effects and amplify policy influence. For academic research, this knowledge map reveals that foundational impact studies are relatively mature, and future research opportunities lie in deepening the mechanisms of action and expanding research boundaries. Scholars can conduct in-depth explorations along emerging frontiers such as "digital transformation," carry out comparative studies of different policy tools (e.g., direct subsidies versus market-based tools like "cap-and-trade"), or test the universality of existing conclusions in different institutional environments through cross-national comparative analysis, thereby advancing this field from contextualized descriptions to the construction of universal theories.

5. Conclusion

This study utilized CiteSpace software to conduct a systematic bibliometric analysis of 325 core articles from the Web of Science Core Collection on "government subsidies empowering corporate green innovation" published between 2005 and 2025, employing a visualized scientific knowledge map approach. The findings clearly indicate that a mature knowledge system has formed in this field, centered on China as the core research context and with "subsidies-innovation-performance" as the main theme. Through co-authorship networks of authors, institutions, and countries, as well as co-occurrence, clustering, burst detection, and timeline analyses of keywords, this study systematically depicted the knowledge base, research hotspots, and frontier evolution of the field. Research hotspots not only cover macroscopic policy design and empirical evaluation but also delve into microscopic corporate strategies, innovation pathways, and commercialization stages, touching upon deep theoretical mechanisms such as information asymmetry. The evolutionary path analysis reveals a dynamic trend in research frontiers, moving from early foundational explorations to current concerns with emerging drivers like digital transformation and systemic integration.

Despite objectively revealing the macroscopic landscape of this field, this study has certain limitations. Firstly, this study only used English literature from the Web of Science Core Collection as its data source; future research could incorporate literature from more databases and languages to obtain a more comprehensive picture. Secondly, knowledge mapping analysis focuses on revealing the structure and trends of research but cannot deeply evaluate the intrinsic quality of individual articles. Based on the findings of this study, future academic research in this field can be expanded in the following aspects: First, deepen the exploration of emerging frontiers such as "digital transformation" and study its synergistic mechanisms with government subsidy policies; second, conduct more comparative studies on different policy instruments (e.g., direct subsidies versus market-based instruments) to evaluate their differentiated effects; third, strengthen cross-national comparative research to examine the applicability of conclusions drawn in the Chinese context to other institutional environments, thereby promoting the field from contextualized research to more universal theoretical construction.

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