Received 8 August 2025
Revised 29 December 2025
Accepted 13 January 2026

Research on the policies of high-tech enterprises in typical regions based on social network analysis

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Abstract

Purpose – This paper aims to quantitatively analyze the intergovernmental network structures within China's high-tech enterprise (HTE) policies, with a focus on how these networks influence policy formulation and innovation support. The study seeks to provide both theoretical foundations and practical recommendations for optimizing the development and implementation of HTE policies.

Design/methodology/approach – Using social network analysis (SNA), this research systematically examines the interactive relationships among policy actors during the policy-making process for HTEs in four representative regions: Shanghai, Jiangsu, Beijing and Guangdong. The study analyzes the structural characteristics and dynamic evolution patterns of policy networks across these regions.

Findings – Regional economic development levels and innovation environments significantly influence collaboration models – taking Beijing and Shanghai as examples, both cities leverage their strong economic foundations and well-established industrial policies to foster favorable innovation ecosystems, thereby enhancing the synergistic effects of HTE policies. Fiscal and science and technology departments play a dominant role in HTE policy formulation, though their influence exhibits notable regional heterogeneity. Departments with structural hole advantages (characterized by high effective size and low constraint) often exhibit greater policy autonomy. This feature contributes to divergent HTE governance patterns across different regions.

Originality/value – This study innovatively uses SNA to deeply investigate intergovernmental policy network relationships within the context of HTE development in China. By systematically identifying the differentiated characteristics and underlying implications of regional policy networks, the research not only enriches the theoretical foundations of innovation policy networks but also provides significant insights for policy practice. The findings offer scientific evidence for policymakers to optimize governance frameworks, thereby more effectively promoting the sustainable development of HTEs.

Keywords High-tech enterprise, Social network analysis, Innovation policy

Paper type Research paper

Asia Pacific Journal of Innovation and Entrepreneurship
Vol. 20 No. 2, 2026
pp. 166-192
Emerald Publishing Limited
e-ISSN: 2398-7812
p-ISSN: 2071-1395
DOI 10.1108/APJIE-08-2025-0111

1. Introduction

Enterprises serve as the primary agents of innovation and key drivers of technological advancement (Xi, 2020). High-tech enterprises (HTE), characterized by intensive capital investment, substantial innovation outputs and high-value returns, have garnered significant attention from both governmental authorities and market stakeholders. HTE are typically defined as enterprises that continuously engage in research and development (R&D) and technology commercialization within the scope of the National Key Supported High-Tech Fields officially promulgated by the government (Ministry of Science and Technology, Ministry of Finance, State Taxation Administration, 2016). Through these activities, they establish core proprietary intellectual property rights, which form the operational foundation for their business activities, ultimately constituting knowledge- and technology-intensive economic entities. Since the implementation of the "Certification Criteria and Procedures for HTE in National High-Tech Industrial Development Zones" in 1991, China's HTE ecosystem has undergone systematic cultivation, evolving from nascent stages to robust growth phases (Wang and Tang, 2024). By the end of 2023, China hosted 454,449 certified HTE, with emerging clusters exhibiting industry-leading innovation capabilities (Torch High Technology Industry Development Center, Ministry of Science and Technology, 2024; Ministry of Science and Technology, Ministry of Finance, State Taxation Administration, 2016). Notably, this expansion reflects not only numerical growth but also qualitative enhancements in technological innovation.

The HTE policy serves as a core instrument in China's national innovation system construction, demonstrating distinct phased characteristics throughout its evolution: during the exploratory phase (1980s to early 2000s), the policy primarily featured regional pilots and tax incentives, focusing on scaling up enterprises; The introduction of the "High-Tech Enterprise Certification Management Measures" in 2008 marked the beginning of a standardized development phase, establishing a unified national certification system that shifted policy emphasis toward key indicators like R&D intensity and intellectual property quality; The 2016 revision of the certification measures initiated a deepened coordination phase, with policy orientation increasingly highlighting "innovation quality," and support mechanisms expanding from pure fiscal incentives to a diversified innovation ecosystem encompassing financial support, talent recruitment and platform development. The policy exhibits dual dimensions in its objective setting: At the micro level, it implements measures like 15% preferential tax rates and 75%–100% super-deduction for R&D expenses to reduce innovation costs, while providing specialized loans and other financial support to alleviate funding pressures, directly stimulating corporate R&D investment; At the macro level, it focuses on optimizing industrial structure (particularly cultivating strategic emerging industries), enhancing regional innovation capacity (promoting innovation cluster development) and serving national strategic goals of achieving technological self-reliance.

To accelerate the development of China's HTE and enhance the innovation capability of high-tech industries as well as national technological competitiveness, a series of incentive policies have been implemented by multi-level governments, including R&D expense super-deduction, tax incentives, financing support and talent incentives (Wang *et al.*, 2024; Que *et al.*, 2025; He *et al.*, 2025). The formulation of HTE policies exemplifies intergovernmental network dynamics, where governmental agencies at various tiers dominate the policymaking process. As Rhodes and Marsh (1992) emphasized, intergovernmental networks represent tightly interconnected systems formed through collaborative interactions among governmental entities during policy formulation and implementation (Rhodes and Marsh, 1992). The structural configuration and coordination situation of these networks critically determine the efficacy of policy development and execution. Some researchers have used

social network analysis (SNA) to investigate intergovernmental collaboration in policymaking. For instance, Huang *et al.* (2015) constructed a joint policy-document network among central government departments to analyze the evolutionary characteristics of science and technology innovation policies (Huang *et al.*, 2015). The intergovernmental network governing HTE policies constitutes a multilevel, multi-actor and proactively coordinated system, rendering structural analysis indispensable for understanding its operational logic.

In this study, the SNA method is used to conduct a quantitative examination of structural configurations within intergovernmental networks governing HTE policies. Through comparison of intergovernmental network structures across regions, interactive relationships among policy actors during policy formulation are systematically characterized and the impacts of distinct network structure on policy development and network construction are elucidated. In addition, unique network concerning diverse policy stakeholders are elaborated.

2. Selection and collection of research data

2.1 Selection of typical regions

Based on the number, scale and technological innovation activities of HTE in different regions, four typical provinces and cities, namely, Shanghai, Jiangsu, Beijing and Guangdong, are selected for further research.

The number and scale of HTE. In terms of the number of HTE, by the end of 2023, the regions with the highest number of HTE in the country are Guangdong (74,724), Jiangsu (51,563), Zhejiang (41,709), Beijing (26,481), Hubei (25,024) and Shanghai (23,984). Quantitative data of technological input and economic output of HTE in Beijing, Guangdong, Jiangsu and Shanghai in 2023 are shown in Table 1. Guangdong takes a leading position in terms of total industrial output value, net profit, tax contributions and foreign exchange earnings from exports, with Jiangsu, Beijing, Shanghai following behind.

Status of technological innovation activities in HTE. A key to technological innovation in HTE lies in scientific researchers. The innovation performance of R&D researchers in HTE determines the economic performance of the enterprise. The competitiveness of new products dictates the enterprise's production, profits and tax contributions. In terms of scientific researchers, Guangdong has the largest number (2,147,716), followed by Jiangsu, Beijing and Shanghai. Regarding expenditure on scientific researches, Guangdong also tops the list (7,468.3 billion), followed by Beijing, Jiangsu and Shanghai. In terms of the proportion of scientific researchers to the total workforce at the end of the year, Beijing is in a leading position, accounting for more than 30%. Considering the proportion of R&D

Table 1. Comparison of total input–output indicators (2023年)

Region	HTE quantity	Industrial output value (thousand yuan)	Net profit (thousand yuan)	Tax paid (thousand yuan)	Earn foreign exchange through export (thousand yuan)
Beijing	26,481	1,012,294,056	503,109,104	232,066,678	191,620,668
Guangdong	74,724	9,523,345,949	864,883,144	426,108,736	2,149,762,886
Jiangsu	51,563	7,556,702,085	515,131,279	288,248,500	1,223,208,676
Shanghai	23,984	1,901,939,605	263,491,366	170,687,540	494,011,252

*__Source(s)__: 《China Torch Statistical Yearbook 2024》, China Statistics Press, 2025.2

investment in expenditure on scientific researches, Jiangsu ranks highest (52.58%), followed by Guangdong (49.74%) (Table 2).

2.2 Collection of policy text

This study systematically examines intergovernmental network structures and interagency relationships in HTE policymaking across four provincial-level regions. Policy documents were collected through full-text searches using the keyword "high-tech enterprises" on official government portals, including Science and Technology Departments, Finance Departments, Economic and Information Technology Departments and Human Resources and Social Security Departments. Initial retrieval covered all articles containing the target keyword from 2010 to 2024, followed by rigorous screening to exclude nonpolicy documents, weakly relevant policies and informal directives. To ensure policy comprehensiveness, all legal, policy and regulatory documents are subjected to manual item-by-item verification, confirming the adequacy of keyword-based policy collection. Furthermore, locally reproduced national policies, expired regulations and redundant directives were systematically eliminated, resulting in a high-value policy corpus aligned with research objectives. To further clarify the relationships among government departments involved in policy formulation, policies are categorized based on the issuing authorities and classified into three types according to the nature of the policy-making entities: collaborative formulation, single-entity formulation and joint formulation.

Statistics on the policy system and quantity of Shanghai (Table 3). A total of 40 policies on HTEs in Shanghai were collected. Quantitative analysis of promulgation authorities reveals four predominant entities: General Office of Shanghai Municipal People's Government, Shanghai Municipal Finance Bureau, Shanghai Municipal Development and Reform Commission and Shanghai Municipal Science and Technology Commission. Overall, most departments formulate policies jointly with other departments, while a minority of departments formulate policies independently. A very small number of departments both formulate policies independently and collaborate with other departments. This indicates that a single policy may cover multiple aspects, involving the jurisdictions of different government departments. Moreover, stable cooperative relationships have been established among these departments where accuracy and rationality of policies can be enhanced through joint decision-making.

Statistics on the policy system and quantity of Jiangsu (Table 4). A total of 42 policies on HTEs in Jiangsu were collected. Quantitative analysis of promulgation authorities reveals three predominant entities: Jiangsu Provincial People's Government, General Office of Jiangsu Provincial People's Government and Jiangsu Provincial Department of Science and

Table 2. Comparison of total input–output indicators (2023年)

Region	HTE quantity	Research professionals	Internal expenditure on scientific research activities (thousand yuan)	Proportion of research professionals to employees (%)	Proportion of R&D funding in Sci-Tech activities (%)
Beijing	26,481	1,146,025	493,244,408	39.74	27.90
Guangdong	74,724	2,147,716	746,829,675	23.71	49.74
Jiangsu	51,563	1,229,612	453,112,798	22.85	52.58
Shanghai	23,984	826,384	373,448,688	21.80	23.81

*__Source(s)__: 《China Torch Statistical Yearbook 2024》, China Statistics Press, 2025.2

Table 3. Analysis of policy release by various government departments in Shanghai municipality

Department	Participation in formulation	Sole formulation	Joint formulation
Shanghai municipal people's government	7	6	1
General office of shanghai municipal people's government	11	11	0
Communist party of China shanghai committee	1	0	1
Shanghai municipal people's government Taiwan affairs office	1	0	1
Shanghai municipal finance bureau	12	0	12
Shanghai municipal science and technology commission	12	1	11
Shanghai municipal development and reform commission	10	0	10
Shanghai municipal commission of economy and informatization	8	0	8
Shanghai municipal commission of commerce	6	0	6
Shanghai municipal financial services office	4	0	4
Shanghai municipal intellectual property office	4	0	4
Shanghai municipal taxation bureau of the state taxation administration	7	1	6
Shanghai municipal education commission	3	0	3
Shanghai municipal human resources and social security bureau	2	0	2
Shanghai municipal commission for the supervision and administration of state-owned assets	2	0	2
Shanghai municipal bureau of statistics	2	0	2
Shanghai municipal administration for industry and commerce	2	0	2
Shanghai municipal agriculture commission	1	1	0
Shanghai municipal quality and technical supervision bureau	1	0	1
Shanghai municipal copyright bureau	1	0	1
Shanghai municipal bureau of foreign experts affairs	1	0	1
Shanghai municipal public security bureau	1	0	1
China securities regulatory commission shanghai bureau	1	0	1
Zhangjiang national innovation demonstration zone management committee	1	0	1
People's bank of China Shanghai branch	1	0	1
Shanghai municipal justice bureau	1	1	0

Table 4. Analysis of policy release by various government departments in Jiangsu province

Department	Participation in formulation	Sole formulation	Joint formulation
Jiangsu provincial people's government	11	11	0
General office of Jiangsu provincial people's government	17	17	0
Jiangsu provincial department of science and technology	9	2	7
Jiangsu provincial commission of economy and informatization	2	2	0
Jiangsu provincial finance department	5	0	5
Jiangsu provincial transport department	2	2	0
Jiangsu provincial department of industry and information technology	1	1	0
Jiangsu provincial development and reform commission	2	0	2

Technology. The majority of policies are formulated by the General Office of Jiangsu Provincial People's Government, while policies from individual departments are relatively fewer and predominantly developed through independent formulation.

Statistics on the policy system and quantity of Beijing (Table 5). A total of 30 policies on HTEs in Beijing were collected. Quantitative analysis of promulgation authorities reveals two predominant entities: Beijing Municipal Science and Technology Commission and Zhongguancun Science Park Management Committee. The former's policies are primarily formulated in collaboration with other departments, while the latter engages in both independent and collaborative policy-making, with a predominant emphasis on joint formulation.

Statistics on the policy system and quantity of Guangdong (Table 6). A total of 44 policies on HTEs in Guangdong were collected. Quantitative analysis of promulgation authorities reveals two predominant entities: Guangdong Provincial People's Government, General Office of Guangdong Provincial People's Government. However, there are variations in policy formulation practices among departments. The Guangdong Provincial People's Government and General Office of Guangdong Provincial People's Government exclusively formulate policies independently. The Guangdong Provincial Finance Department predominantly engages in joint policy formulation. The Guangdong Provincial Department of Science and Technology adopts both independent and joint formulation approaches. The Guangdong Provincial Economy and Information Technology Commission and the State Taxation Administration Guangdong Provincial Taxation Bureau mainly formulate policies in collaboration with other departments.

3. Analysis of the intergovernmental network structure of policies for high-tech enterprise

3.1 Construction of intergovernmental network structure model

Drawing on the characteristics of HTE policies and considering the types of participating entities in the policy network as well as the relationships between them, this study constructs an intergovernmental network analysis model for HTE policies based on social network theory (Henry and Lubell, 2011). After establishing the intergovernmental network model, the next step involves measuring the network structure. To provide a clearer analysis of the core actors within the policy network of HTE and to investigate their control capabilities over this network, this paper primarily selects two indicators: centrality and structural holes, for description (Provan and Kenis, 2008; Wasserman and Faust, 1994).

Table 5. Analysis of policy release by various government departments in Beijing municipality

Department	Participation in formulation	Sole formulation	Joint formulation
Beijing municipal people's government	6	4	2
Beijing municipal science and technology commission	10	1	9
Beijing municipal finance bureau	5	0	5
State taxation administration Beijing municipal taxation bureau	5	1	4
General office of Beijing municipal people's government	5	5	0
Beijing municipal commission of urban and rural development	1	0	1
Zhongguancun science park management committee	7	0	7
Beijing municipal development and reform commission	2	0	2
Beijing municipal commission of economy and informatization	1	0	1
Beijing municipal administration for industry and commerce	1	1	0
Beijing municipal human resources and social security bureau	2	1	1
Beijing municipal state-owned assets supervision and administration commission	2	1	1
Beijing municipal commission of agriculture and rural affairs	1	0	1
Beijing municipal commission of urban management	1	0	1
Beijing municipal water authority	1	0	1
Communist party of China Beijing municipal committee	2	0	2
Beijing municipal health commission	1	0	1
Beijing municipal drug administration	1	0	1
Beijing municipal administration of traditional Chinese medicine	1	0	1
Beijing municipal bureau of economy and information technology	1	1	0
Beijing municipal financial supervision and administration bureau	2	0	2
People's bank of China business management department	1	0	1
China banking and insurance regulatory commission Beijing bureau	1	0	1
China securities regulatory commission Beijing bureau	1	0	1
Haidian district people's government of Beijing municipality	1	0	1
Beijing economic-technological development area management committee	1	1	0
Office of the foreign affairs commission of the CPC Beijing municipal committee	1	0	1
Beijing municipal people's government foreign affairs office	1	0	1
Beijing municipal talent work bureau	1	0	1
Beijing municipal education commission	1	0	1
Beijing municipal commission of commerce	1	0	1
Beijing municipal intellectual property office	1	0	1
Beijing association for science and technology	1	0	1

Table 6. Analysis of policy release by various government departments in Guangdong province

Department	Participation in formulation	Sole formulation	Joint formulation
Guangdong provincial people's government	21	21	0
General office of Guangdong provincial people's government	13	13	0
Guangdong provincial finance department	6	2	4
Guangdong provincial science and technology department	6	3	3
Guangdong provincial economy and information technology commission	1	0	1
Guangdong provincial department of industry and information technology	1	1	0
State taxation administration Guangdong provincial taxation bureau	2	0	2

3.1.1 Construction of models. The intergovernmental network for HTE policies is a typical multilevel, multientity and proactively collaborative network, making the structural analysis of this intergovernmental network particularly crucial. To gain a deep understanding of the structure of the intergovernmental network, it is first necessary to construct an intergovernmental network structure matrix to outline the fundamental structure of this social network. Subsequently, a quantitative analysis of the structural characteristics of the intergovernmental network should be conducted to identify and analyze key nodes, primary connections and the overall structural features of the network (Tang *et al.*, 2018).

Based on collected HTE policy data, an interagency collaboration adjacency matrix using joint policy-document data is constructed and is subsequently visualized through UCIENT software to output governmental cooperation network diagram (Borgatti, 2005). In the resultant network diagram, nodes represent governmental departments while their connecting lines indicate collaborative policy issuances between paired agencies. The size of nodes is set according to the degree centrality of the department, where larger nodes signify departments with more collaborative partners, thereby resulting in increased nodal connections within the network diagram (Loscalzo and Yu, 2008).

3.1.2 Selection of indicators. Centrality serves to identify the departments playing central roles in the intergovernmental network and the overall agglomeration level of the network (Borgatti, 2005; Everett and Borgatti, 2005). Structural holes, on the other hand, reflect the control capacity and constraint situations of core departments in the overall network operation and policy coordination processes (Burt, 2004; Ahuja, 2000). The measurement methods for these two indicators are as follows:

(1) *Centrality:* In terms of centrality, degree centrality, closeness centrality and betweenness centrality are selected to measure the centrality index of government departments within the intergovernmental network (Freeman, 1978; Berardo and Scholz, 2010).

Degree centrality: In a social network, an actor possesses significant power if it has direct connections with numerous other actors, indicating that it occupies a central position. Actors located at the center tend to have multiple connections (associations) with others, whereas those at the periphery have fewer. Guided by this principle, the degree centrality of a node is

measured by calculating the number of nodes directly connected to it. The calculation formula is as follows:

$$C_d(N_i) = d(n_i)$$

Betweenness centrality: A node possesses high betweenness centrality if it lies on many shortest paths (geodesic connections) between other pairs of nodes, thereby serving as a bridge that facilitates communication across the entire network. Specifically, let g_{jk} denote the number of shortest paths between nodes j and k. The ability of a third node, i, to control the interaction between j and k is represented by $b_{jk}(i)$, which is the probability that i lies on a shortest path between j and k. This probability can be calculated as the ratio of the number of shortest paths between j and k that pass through i, denoted as $g_{jk}(i)$, to the total number of shortest paths between j and k, i.e. $b_{jk}(i) = g_{jk}(i)/g_{jk}$. In an undirected network, the absolute betweenness centrality (denoted as C_B) of node i is computed by summing its betweenness values for all pairs of nodes in the network graph, formulated as:

$$C_B = \sum_{j}^{n} \sum_{k}^{n} b_{jk}(i), \ j \neq k \neq i \ and \ j < k$$

Closeness centrality: Closeness centrality refers to the proximity of a node to all other nodes within a network. The measurement of closeness centrality is based on the distances between nodes. Shortcuts are commonly among nodes in a network, with the length of these shortcuts representing the distance between two nodes. A node is deemed to have high closeness centrality (also known as overall centrality) if it maintains short distances to all other nodes in the network. In such a network configuration, such a node is in close proximity to numerous other nodes.

The closeness centrality of a node is defined as the reciprocal of the sum of distances from that node to all other nodes in the graph. The mathematical expression for this is given as follows:

$$C_C = \left(\sum_{j=1}^{n} d_{ij}\right)^{-1}$$

Herein, d_{ij} represents the shortest path distance between node i and node j (i.e. the number of edges included in the shortest path).

(2) *Structural hole:* A structural hole refers to the gap between two groups possessing complementary resources and knowledge. When a third party connects these two groups, the gap is filled, thereby gaining a competitive advantage (Scott, 2007). Effective size pertains to the nonredundant factors in a network; a larger effective size indicates a higher likelihood of the existence of structural holes among government departments. Constraint refers to the extent to which a particular government department possesses the ability to leverage structural holes; a higher constraint implies stronger restrictions and fewer structural holes in the network (Burt, 1992).

Effective size: The effective size is the total size of the network minus the redundancy of the network. The measurement method for the effective scale ES_i of node i is as follows:

$$ES_i = \sum_{j} \left(1 - \sum_{q} p_{iq} m_{jq}\right), \ q \neq i, \ j$$

In this context, j represents all nodes connected to i, while q denotes every third node excluding i or j. The $p_{iq}m_{jq}$ represents the redundancy between i and q. In addition, the proportion of the relationship from i to q is denoted by p_{iq}.

The efficiency of a node is the effective size of the node divided by the actual size of the network it is in:

$$EF_i = \sum_j \left[1 - \sum_q p_{iq} m_{jq}\right] / n, \ q \neq i, \ j$$

Constraint: Constraint refers to the degree to which a node possesses the capacity to leverage structural holes within its own network. Burt notes that "an individual's opportunities are constrained by two factors: the other actor q, on whom individual i has invested substantial time and effort; and the extent to which actor q invests significant effort in actor j." This formulation introduces a method for calculating constraint:

$$C_{ij} = p_{ij} + \sum_q p_{iq} p_{qj}$$

$$C_j = \sum_j C_{ij}$$

$$C_{ij} = \text{Direct investment}(P_{ij}) + \text{Indirect investment}$$

Herein, p_{iq} represents the proportion of the relationship with q to the total relational ties in actor i's entire network of relationships.

3.2 Characterization of intergovernmental network structure

3.2.1 Analysis of the intergovernmental network structure in Shanghai. The intergovernmental network model of HTE policies in Shanghai: A total of 26 departments are involved in the policy issuance for HTE in Shanghai, forming an intergovernmental network with 26 nodes. The network diagram is generated using UCINET software (Figure 1). It is evident that the Shanghai Municipal Finance Bureau possesses most connections, indicating the closest cooperation with other departments and a core position within the network. It also shows that financial instruments play a crucial role in Shanghai's HTE policies. In contrast, the General Office of Shanghai Municipal People's Government, Shanghai Municipal Justice Bureau and Shanghai Municipal Agriculture Commission are in isolated positions. The primary reason lies in the fact that the General Office of Shanghai Municipal People's Government serves as the apex coordination authority, whose policies possess the highest level of coordination. In contrast, the other two departments are crucial functional authorities with relatively specific jurisdictions, primarily focusing on judicature and agriculture. Consequently, they possess the capability to independently formulate corresponding policies.

Intergovernmental network centrality analysis of Shanghai: The results for degree centrality, closeness centrality and betweenness centrality, calculated based on the adjacency matrix, are presented in Table 7. It can be observed that the Shanghai municipal finance bureau has the highest degree centrality, with joint document issuance occurring with 16 other departments. This indicates that the Shanghai municipal finance bureau is the main

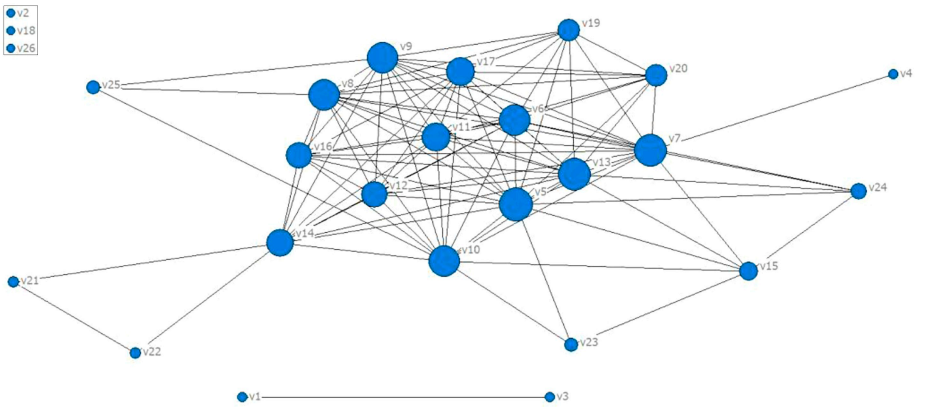

Figure 1. Intergovernmental network relationship diagram of policies for HTE in Shanghai

Note(s): v1 = Shanghai Municipal People's Government; v2 = General Office of Shanghai Municipal People's Government; v3 = Communist Party of China Shanghai Committee; v4 = Shanghai Municipal People's Government Taiwan Affairs Office; v5 = Shanghai Municipal Finance Bureau; v6 = Shanghai Municipal Science and Technology Commission; v7 = Shanghai Municipal Development and Reform Commission; v8 = Shanghai Municipal Commission of Economy and Informatization; v9 = Shanghai Municipal Commission of Commerce; v10 = Shanghai Municipal Financial Services Office; v11 = Shanghai Municipal Intellectual Property Office; v12 = Shanghai Municipal Taxation Bureau of the State Taxation Administration; v13 = Shanghai Municipal Education Commission; v14 = Shanghai Municipal Human Resources and Social Security Bureau; v15 = Shanghai Municipal Commission for the Supervision and Administration of State-owned Assets; v16 = Shanghai Municipal Bureau of Statistics; v17 = Shanghai Municipal Administration for Industry and Commerce; v18 = Shanghai Municipal Agriculture Commission; v19 = Shanghai Municipal Quality and Technical Supervision Bureau; v20 = Shanghai Municipal Copyright Bureau; v21 = Shanghai Municipal Public Security Bureau; v22 = Shanghai Municipal Public Security Bureau; v23 = China Securities Regulatory Commission Shanghai Bureau; v24 = Zhangjiang National Innovation Demonstration Zone Management Committee; v25 = People's Bank of China Shanghai Branch; v26 = Shanghai Municipal Justice Bureau

entity formulating policies for HTE. It also suggests that most policies involve fiscal-related content, and fiscal instruments remain an important tool for regulating HTE. The Shanghai municipal human resources and social security bureau has a degree centrality of 48, with numerous joint document issuances with other departments. This indicates that HTE policies contain numerous preferential welfare systems for talent introduction, and the government attaches great importance to talent cultivation within HTE. Except for the Shanghai Municipal Agriculture Commission and Shanghai municipal justice bureau, which have a closeness centrality of zero; Shanghai municipal people's government, General Office of Shanghai Municipal People's Government and Communist Party of China Shanghai Committee, which have a closeness centrality of four, the closeness centrality of the remaining departments is relatively similar. This indicates that the departments have a similar degree of proximity and relatively little dependence on each other, allowing for a certain degree of independence when formulating policies. The Shanghai Municipal Human Resources and Social Security Bureau has the highest betweenness centrality, indicating that it is located at the core of the network and serves as an intermediary for joint document

Table 7. Shanghai intergovernmental network centrality

Department	Degree centrality	Closeness centrality	Betweenness centrality
Shanghai municipal people's government	4	4	0
General office of Shanghai municipal people's government	0	4	0
Communist party of China Shanghai committee	4	4	0
Shanghai municipal people's government Taiwan affairs office	4	14.205	0
Shanghai municipal finance bureau	64	16.234	5.835
Shanghai municipal science and technology commission	56	16.026	1.879
Shanghai municipal development and reform commission	60	15.924	8.182
Shanghai municipal commission of economy and informatization	56	16.026	2.505
Shanghai municipal commission of commerce	56	16.026	2.505
Shanghai municipal financial services office	56	16.026	5.228
Shanghai municipal intellectual property office	52	15.924	0.736
Shanghai municipal taxation bureau of the state taxation administration	44	15.723	0.2
Shanghai municipal education commission	60	16.129	3.002
Shanghai municipal human resources and social security bureau	48	15.723	12
Shanghai municipal commission for the supervision and administration of state-owned assets	24	15.06	0.592
Shanghai municipal bureau of statistics	44	15.723	0.2
Shanghai municipal administration for industry and commerce	52	15.924	0.736
Shanghai municipal agriculture commission	0	0	0
Shanghai municipal quality and technical supervision bureau	36	15.337	0
Shanghai municipal copyright bureau	36	15.337	0
Shanghai municipal bureau of foreign experts affairs	8	14.124	0
Shanghai municipal public security bureau	8	14.124	0
China securities regulatory commission Shanghai bureau	12	14.706	0
Zhangjiang national innovation demonstration zone management committee	20	14.881	0.067
People's bank of China Shanghai branch	12	14.62	0
Shanghai municipal justice bureau	0	0	0

issuance among other departments, largely controlling cooperation between them. A portion of other departments have a betweenness centrality of zero, such as the China Securities Regulatory Commission Shanghai Bureau, the Shanghai copyright bureau and Shanghai municipal public security bureau, indicating that they have weak control over resources and do not affect cooperation between other departments.

Intergovernmental network structural hole analysis of Shanghai: The measurement results for the structural hole indices of each node are presented in Table 8. It is observable that the Shanghai municipal finance bureau, Shanghai municipal development and reform commission, Shanghai Municipal Financial Services Office, Shanghai municipal education commission and Shanghai Municipal Human Resources and Social Security Bureau exhibit larger effective sizes while simultaneously possessing lower constraint levels. This indicates that these departments possess a certain degree of independence when formulating policies, are less susceptible to influence from other departments, occupy numerous structural holes and are capable of acquiring more nonredundant information. Conversely, the Shanghai foreign experts bureau and Shanghai municipal public security bureau demonstrate smaller limited sizes and higher constraint levels, suggesting that they lack independence when formulating policies, face stronger constraints and find it difficult to obtain effective information.

3.2.2 Analysis of the intergovernmental network structure in Jiangsu. Intergovernmental network model for HTE policies in Jiangsu: The policy issuance for HTE in Jiangsu involve

Table 8. Intergovernmental network structural holes of Shanghai

Department	Effective size	Efficiency	Constraint
Shanghai municipal people's government	1	1	1
General office of Shanghai municipal people's government	0	0	0
Communist party of China Shanghai committee	1	1	1
Shanghai municipal people's government Taiwan affairs office	1	1	1
Shanghai municipal finance bureau	8.65	0.541	0.303
Shanghai municipal science and technology commission	5.848	0.418	0.356
Shanghai municipal development and reform commission	7.444	0.496	0.351
Shanghai municipal commission of economy and informatization	6.67	0.476	0.34
Shanghai municipal commission of commerce	6.744	0.482	0.336
Shanghai municipal financial services office	7.925	0.566	0.319
Shanghai municipal intellectual property office	5.331	0.41	0.364
Shanghai municipal taxation bureau of the state taxation administration	11	3.986	0.362
Shanghai municipal education commission	7.747	0.516	0.31
Shanghai municipal human resources and social security bureau	7.676	0.64	0.305
Shanghai municipal commission for the supervision and administration of state-owned assets	3.452	0.575	0.66
Shanghai municipal bureau of statistics	4.972	0.452	0.383
Shanghai municipal administration for industry and commerce	6.3	0.485	0.326
Shanghai municipal agriculture commission	0	0	0
Shanghai municipal quality and technical supervision bureau	3.891	0.432	0.436
Shanghai municipal copyright bureau	3.891	0.432	0.436
Shanghai municipal bureau of foreign experts affairs	1	0.5	1.125
Shanghai municipal public security bureau	1	0.5	1.125
China securities regulatory commission Shanghai bureau	1.5	0.5	1.092
Zhangjiang national innovation demonstration zone management committee	2.778	0.556	0.768
People's bank of China Shanghai branch	1.333	0.444	1.138
Shanghai municipal justice bureau	0	0	0

a total of eight government departments, forming an intergovernmental network comprising eight nodes. The network diagram generated using UCINET software is shown in Figure 2. It is evident that Jiangsu government departments prefer to issue documents as single entities. Specifically, only Jiangsu Provincial Finance Department, Jiangsu Provincial Department of Science and Technology and Jiangsu Provincial Development and Reform Commission have engaged in joint document issuance, potentially related to the emphasis on the synergistic effects of financial and technological support in Jiangsu's HTE policies. Furthermore, the Jiangsu Provincial People's Government, as the core governmental entity, has issued the highest number of documents, covering the most comprehensive aspects. Second, both the provincial transport department and the provincial commission of economy and informatization also have issued documents, albeit in smaller quantities, primarily targeting policy support for HTE in the transportation and information sectors.

Intergovernmental network centrality analysis of Jiangsu: The results for degree centrality, closeness centrality and betweenness centrality, obtained by analyzing the adjacency matrix, are presented in Table 9. It is observed that only the Jiangsu Provincial Finance Department, Jiangsu Provincial Department of Science and Technology and Jiangsu Provincial Development and Reform Commission have jointly issued documents. For all other departments, the three types of centrality measures are 0. The degree centrality of 28 for the Jiangsu Provincial Department of Science and Technology indicates its significant position within the existing network of jointly issued documents. The Jiangsu Provincial Department of Science and Technology exhibits the highest betweenness centrality, indicating that this department serves as a key intermediary for joint publications among other agencies and plays a significant role in controlling interdepartmental collaborations. In contrast, all other departments show zero betweenness centrality, demonstrating their limited influence over resource allocation and minimal impact on collaboration networks between other departments.

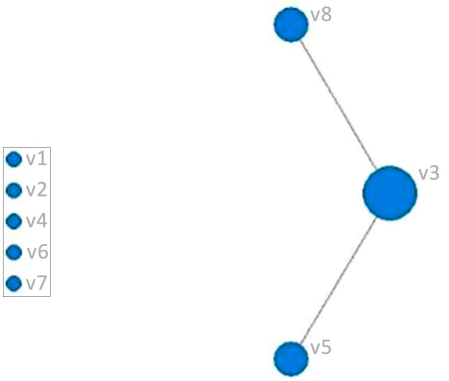

Figure 2. Intergovernmental network relationship diagram of policies for HTE in Jiangsu

Note(s): v1 = Jiangsu Provincial People's Government; v2 = General Office of Jiangsu Provincial People's Government; v3 = Jiangsu Provincial Department of Science and Technology; v4 = Jiangsu Provincial Commission of Economy and Informatization; v5 = Jiangsu Provincial Finance Department; v6 = Jiangsu Provincial Transport Department; v7 = Jiangsu Provincial Department of Industry and Information Technology; v8 = Jiangsu Provincial Development and Reform Commission

Table 9. Jiangsu Intergovernmental network centrality

Department	Degree centrality	Closeness centrality	Betweenness centrality
Jiangsu provincial people's government	0	0	0
General office of Jiangsu provincial people's government	0	0	0
Jiangsu provincial department of science and technology	28.571	16.667	4.762
Jiangsu provincial commission of economy and informatization	0	0	0
Jiangsu provincial finance department	14.286	16.279	0
Jiangsu provincial transport department	0	0	0
Jiangsu provincial department of industry and information technology	0	0	0
Jiangsu provincial development and reform commission	14.286	16.279	0

Intergovernmental network structural hole analysis of Jiangsu: The measurement results for the structural hole indices of each node are presented in Table 10. It is evident from the data that the current co-publication network is relatively sparse, with only three entities, namely, the Jiangsu Provincial Finance Department, Jiangsu Provincial Department of Science and Technology and Jiangsu Provincial Development and Reform Commission engaging in joint publications. Among them, only the Jiangsu Provincial Department of Science and Technology has a relatively large effective scale and a lower degree of constraint. This indicates that this department has a certain level of independence in policy formulation, is less susceptible to influence from other departments, occupies more structural holes and can access more nonredundant information.

3.2.3 Analysis of the intergovernmental network structure in Beijing. The intergovernmental network model for HTE policies in Beijing: A total of 33 departments are involved in the policy issuance for HTE in Beijing, forming an intergovernmental network with 33 nodes. The network diagram generated using UCINET software is shown in Figure 3. As illustrated, Beijing has a multitude of departments involved in formulating policies for HTE, leading to a relatively complex landscape of joint document issuance. First, the highest number of connections in the diagram are associated with the Beijing Municipal Science and Technology Commission, indicating its closest cooperation with other departments and its central position within the network. This also reflects Beijing's emphasis on technological development within HTE. Second, there are instances of joint document issuance between the Beijing Municipal People's Government and Communist Party of

Table 10. Intergovernmental network structural holes of Jiangsu

Department	Effective size	Efficiency	Constraint
Jiangsu provincial people's government	0	0	0
General office of Jiangsu provincial people's government	0	0	0
Jiangsu provincial department of science and technology	2	1	0.592
Jiangsu provincial commission of economy and informatization	0	0	0
Jiangsu provincial finance department	1	1	1
Jiangsu provincial transport department	0	0	0
Jiangsu provincial department of industry and information technology	0	0	0
Jiangsu provincial development and reform commission	1	1	1

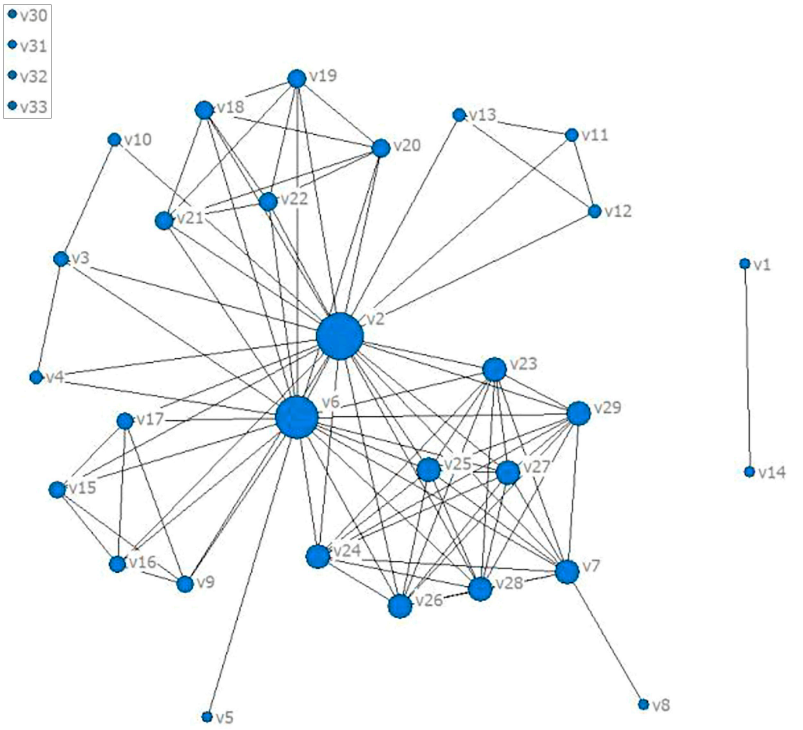

Figure 3. Intergovernmental network relationship diagram of policies for HTE in Beijing

Note(s): v1 = Beijing Municipal People's Government; v2 = Beijing Municipal Science and Technology Commission; v3 = Beijing Municipal Finance Bureau; v4 = State Taxation Administration Beijing Municipal Taxation Bureau; v5 = Beijing Municipal Commission of Urban and Rural Development; v6 = Zhongguancun Science Park Management Committee; v7 = Beijing Municipal Development and Reform Commission; v8 = Beijing Municipal Commission of Economy and Informatization; v9 = Beijing Municipal Human Resources and Social Security Bureau; v10 = Beijing Municipal State-owned Assets Supervision and Administration Commission; v11 = Beijing Municipal Commission of Agriculture and Rural Affairs; v12 = Beijing Municipal Commission of Urban Management; v13 = Beijing Municipal Water Authority; v14 = Communist Party of China Beijing Municipal Committee; v15 = Beijing Municipal Health Commission; v16 = Beijing Municipal Drug Administration; v17 = Beijing Municipal Administration of Traditional Chinese Medicine; v18 = Beijing Municipal Financial Supervision and Administration Bureau; v19 = People's Bank of China Business Management Department; v20 = China Banking and Insurance Regulatory Commission Beijing Bureau; v21 = China Securities Regulatory Commission Beijing Bureau; v22 = Haidian District People's Government of Beijing Municipality; v23 = Office of the Foreign Affairs Commission of the CPC Beijing Municipal Committee; v24 = Beijing Municipal People's Government Foreign Affairs Office; v25 = Beijing Municipal People's Government Foreign Affairs Office; v26 = Beijing Municipal Education Commission; v27 = Beijing Municipal Commission of Commerce; v28 = Beijing Municipal Intellectual Property Office; v29 = Beijing Association for Science and Technology; v30 = General Office of Beijing Municipal People's Government; v31 = Beijing Municipal Administration for Industry and Commerce; v32 = Beijing Municipal Bureau of Economy and Information Technology; v33 = Beijing Economic-Technological Development Area Management Committee

China Beijing Municipal Committee, both of which are core departments within the government, closely related and possess broad jurisdiction and the ability to jointly formulate policies. Similarly, the Beijing Municipal Commission of Economy and Information Commission and the Beijing Municipal Development and Reform Commission, both key functional departments, also engage in joint document issuance. Finally, the General Office of Beijing Municipal People's Government, Beijing Municipal Administration for Industry and Commerce, Beijing Municipal Bureau of Economy and Information Technology and Beijing Economic-Technological Development Area Management Committee independently formulate policies without engaging in joint document issuance with other government departments.

Intergovernmental network centrality analysis of Beijing: The results for degree centrality, closeness centrality and betweenness centrality derived from the adjacency matrix are presented in Table 11. It is observed that the Beijing municipal science and technology commission has the highest degree centrality, indicating its status as a key entity in formulating policies for HTE and suggesting that most policies involve science and technology-related content. Departments such as the Beijing Municipal Human Resources and Social Security Bureau, Beijing municipal drug administration, Beijing Municipal Administration of Traditional Chinese Medicine and Beijing municipal health commission have a higher degree centrality, indicating that policies encompass talent cultivation welfare systems and support for the development of pharmaceutical HTE. The Beijing municipal finance bureau, with a degree centrality of 12.5, is also a crucial policy-making entity, demonstrating that financial support remains a significant means of promoting the growth of HTE. Furthermore, apart from the Beijing Municipal Education Commission, Beijing Municipal Commission of Commerce, Beijing Municipal Intellectual Property Office, Beijing Association for Science and Technology, which have relatively low closeness centrality, the remaining departments exhibit similar closeness centrality values, suggesting a comparable degree of proximity and minimal dependency among them, thereby enabling a certain degree of independence in policy formulation. Finally, the Beijing municipal science and technology commission has the highest betweenness centrality, indicating its central position in the network and its role as a mediator in joint document issuance among other departments, thereby largely controlling cooperation among them. A subset of departments, including the Beijing Municipal Drug Administration and Beijing Municipal Health Commission, have a betweenness centrality of zero, suggesting their limited ability to control resources and negligible impact on cooperation among other departments.

Intergovernmental network structural hole analysis of Beijing: The measurement results for the structural hole indices of each node are presented in Table 12. It is evident that the Beijing municipal science and technology commission and Beijing Municipal Commission of Urban and Rural Development exhibit relatively large effective sizes, accompanied by low constraint levels. This indicates that these departments possess a certain degree of independence when formulating policies, are less susceptible to the influence of other departments, occupy numerous structural holes and are capable of accessing more nonredundant information. In contrast, the remaining departments display smaller limited sizes and higher constraint levels, suggesting a lack of independence in policy formulation, stronger constraints and difficulties in obtaining effective information.

3.2.4 Analysis of the intergovernmental network structure in Guangdong. Intergovernmental network model for HTE in Guangdong: The policy documents pertaining to HTE in Guangdong province involve a total of seven government departments, forming an intergovernmental network comprising seven nodes. The network diagram generated using UCIENT software is shown in Figure 4. The node representing the Guangdong Provincial Finance Department is the largest, with the most connections to other departments,

Table 11. Beijing intergovernmental network centrality

Department	Degree centrality	Closeness centrality	Betweenness centrality
Beijing municipal people's government	3.125	3.125	0
Beijing municipal science and technology commission	75	14.159	31.653
Beijing municipal finance bureau	12.5	12.955	0.302
State taxation administration Beijing municipal taxation bureau	9.375	12.903	0
General office of Beijing municipal people's government	3.125	12.598	0
Beijing municipal commission of urban and rural development	65.625	13.974	18.851
Zhongguancun science park management committee	31.25	13.333	5.04
Beijing municipal development and reform commission	3.125	12.075	0
Beijing municipal commission of economy and informatization	15.625	13.008	0
Beijing municipal administration for industry and commerce	6.25	12.8	0
Beijing municipal human resources and social security bureau	9.375	12.851	0
Beijing municipal state-owned assets supervision and administration commission	9.375	12.851	0
Beijing municipal commission of agriculture and rural affairs	9.375	12.851	0
Beijing municipal commission of urban management	3.125	3.125	0
Beijing municipal water authority	15.625	13.008	0
Communist party of China Beijing municipal committee	15.625	13.008	0
Beijing municipal health commission	15.625	13.008	0
Beijing municipal drug administration	18.75	13.061	0
Beijing municipal administration of traditional Chinese medicine	18.75	13.061	0
Beijing municipal bureau of economy and information technology	18.75	13.061	0
Beijing municipal financial supervision and administration bureau	18.75	13.061	0
People's bank of China business management department	18.75	13.061	0
China banking and insurance regulatory commission Beijing bureau	28.125	13.278	0
China securities regulatory commission Beijing bureau	28.125	13.278	0
Haidian district people's government of Beijing municipality	28.125	13.278	0
Beijing economic-technological development area management committee	28.125	13.278	0
Office of the foreign affairs commission of the CPC Beijing municipal committee	28.125	13.278	0
Beijing municipal people's government foreign affairs office	28.125	13.278	0
Beijing municipal talent work bureau	28.125	13.278	0
Beijing municipal education commission	0	0	0
Beijing municipal commission of commerce	0	0	0
Beijing municipal intellectual property office	0	0	0
Beijing association for science and technology	0	0	0

Table 12. Intergovernmental network structural holes of Beijing

Department	Effective size	Efficiency	Constraint
Beijing municipal people's government	1	1	1
Beijing municipal science and technology commission	17.688	0.737	0.203
Beijing municipal finance bureau	2.409	0.602	0.826
State taxation administration Beijing municipal taxation bureau	1.556	0.519	0.981
General office of Beijing municipal people's government	1	1	1
Beijing municipal commission of urban and rural development	13.684	0.652	0.239
Zhongguancun science park management committee	3.967	0.397	0.337
Beijing municipal development and reform commission	1	1	1
Beijing municipal commission of economy and informatization	2	0.4	0.694
Beijing municipal administration for industry and commerce	1	0.5	1.62
Beijing municipal human resources and social security bureau	1	0.333	0.926
Beijing municipal state-owned assets supervision and administration commission	1	0.333	0.926
Beijing municipal commission of agriculture and rural affairs	1	0.333	0.926
Beijing municipal commission of urban management	1	1	1
Beijing municipal water authority	2	0.4	0.694
Communist party of China Beijing municipal committee	2	0.4	0.694
Beijing municipal health commission	2	0.4	0.694
Beijing municipal drug administration	1.833	0.306	0.63
Beijing municipal administration of traditional Chinese medicine	2.306	0.384	0.595
Beijing municipal bureau of economy and information technology	2.306	0.384	0.595
Beijing municipal financial supervision and administration bureau	2.306	0.384	0.595
People's bank of China business management department	2.306	0.384	0.595
China banking and insurance regulatory commission Beijing bureau	2.296	0.255	0.403
China securities regulatory commission Beijing bureau	2.296	0.255	0.403
Haidian district people's government of Beijing municipality	2.296	0.255	0.403
Beijing economic-technological development area management committee	2.296	0.255	0.403
Office of the foreign affairs commission of the CPC Beijing municipal committee	2.296	0.255	0.403
Beijing municipal people's government foreign affairs office	2.296	0.255	0.403
Beijing municipal talent work bureau	2.296	0.255	0.403
Beijing municipal education commission	0	0	0
Beijing municipal commission of commerce	0	0	0
Beijing municipal intellectual property office	0	0	0
Beijing association for science and technology	0	0	0

indicating that it maintains the closest cooperative relationships with other departments and occupies a central position in the network. The Guangdong Provincial Science and Technology Department follows closely behind. In contrast, the Guangdong Provincial People's Government, General Office of Guangdong Provincial People's Government and Guangdong Provincial Department of Industry and Information Technology are in an isolated state, formulating policies entirely independently.

Intergovernmental network centrality analysis of Guangdong: The results for degree centrality, closeness centrality and betweenness centrality calculated from the adjacency matrix are presented in Table 13. It is evident that the Guangdong provincial finance department holds the highest degree centrality. This indicates that the Guangdong Provincial Finance Department occupies a central position within the network, suggesting that fiscal policy remains an effective tool for promoting the development of HTE. The Guangdong Provincial Science and Technology Department and State Taxation Administration Guangdong Provincial Taxation

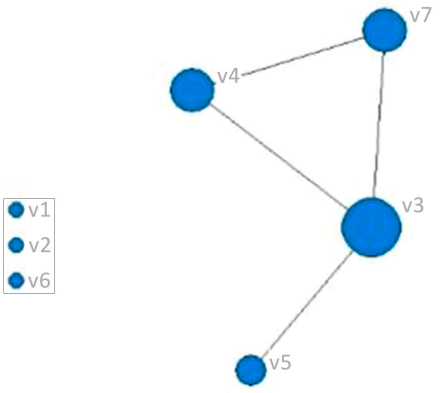

Figure 4. Intergovernmental network relationship diagram of policies for HTE in Guangdong
Note(s): v1 = Guangdong Provincial People's Government; v2 = General Office of Guangdong provincial people's government; v3 = Guangdong Provincial Finance Department; v4 = Guangdong Provincial Science and Technology Department; v5 = Guangdong Provincial Economy and Information Technology Commission; v6 = Guangdong Provincial Department of Industry and Information Technology; v7 = State Taxation Administration Guangdong Provincial Taxation Bureau

Table 13. Guangdong Intergovernmental network centrality

Department	Degree centrality	Closeness centrality	Betweenness centrality
Guangdong provincial people's government	0	0	0
General office of Guangdong provincial people's government	0	0	0
Guangdong provincial finance department	50	25	13.333
Guangdong provincial science and technology department	33.333	24	0
Guangdong provincial economy and information technology commission	16.667	23.077	0
Guangdong provincial department of industry and information technology	0	0	0
State taxation administration Guangdong provincial taxation bureau	33.333	24	0

Bureau follow closely in degree centrality, with numerous co-issued documents with other departments and most policies related to HTE involve sci-tech and taxation affairs. In contrast, the Guangdong provincial people's government, General Office of Guangdong provincial people's government and Guangdong Provincial Department of Industry and Information Technology have a degree centrality of zero, indicating no joint policymaking with other departments and a tendency toward independent policymaking. In addition, regarding closeness

centrality, the table reveals that aside from the Guangdong provincial people's government, General Office of Guangdong provincial people's government and Guangdong Provincial Department of Industry and Information Technology, the closeness centrality of the remaining departments is relatively similar, suggesting a comparable degree of proximity and minimal interdependence among them. This indicates a certain degree of independence in policymaking. Finally, in terms of betweenness centrality, the Guangdong Provincial Finance Department exhibits relatively high betweenness centrality, indicating that this departments serves as intermediaries in the joint issuance of documents among other departments, exerting significant control over cooperation between them. Conversely, the betweenness centrality of other departments are zero, suggesting weak resource control capabilities and minimal impact on cooperation among other departments.

Intergovernmental network structural hole analysis of Guangdong: The measurement results for the structural hole indicators of each node are presented in Table 14. It is observable that the Guangdong provincial finance department exhibits a relatively large effective size, accompanied by a low constraint level. This indicates that the department possesses a certain degree of independence when formulating policies, being less susceptible to the influence of other departments. Occupying numerous structural holes, it is capable of accessing more nonredundant information.

3.3 Comparative analysis of intergovernmental network structures among different regions

3.3.1 Comparison of overall network structure. There are interregional variations in both the types and quantities of governmental departments involved in HTE policymaking can be identified according to the participant composition. Specifically, 26 participating agencies in Shanghai, 33 in Beijing, 8 in Jiangsu province and 7 in Guangdong province. In this study, the node count within each provincial intergovernmental cooperation network directly corresponds to the number of involved policymaking departments, where a greater node quantity signifies expanded network scale. It indicates that the greater the diversity and heterogeneity of government departments involved in formulating policies for HTE in a given province or municipality, the broader the scope of support targets or funding coverage included in the content of these HTE policies.

Regarding connectivity, the overall connectivity of government department collaboration networks involved in HTE policy formulation differs among various regions. Beijing and Shanghai exhibit better connectivity, with the Shanghai municipal finance bureau having the

Table 14. Intergovernmental network structural holes of Guangdong

Department	Effective size	Efficiency	Constraint
Guangdong provincial people's government	0	0	0
General office of Guangdong provincial people's government	0	0	0
Guangdong provincial finance department	2.278	0.759	0.757
Guangdong provincial science and technology department	1.133	0.567	1.05
Guangdong provincial economy and information technology commission	1	1	1
Guangdong provincial department of industry and information technology	0	0	0
State taxation administration Guangdong provincial taxation bureau	1	0.5	1.28

most connections, indicating its closest cooperation with other government departments and a central position in the network. Beijing has numerous departments involved in formulating HTE policies, with complex joint document issuance. Jiangsu and Guangdong provinces show poorer connectivity, with their government departments tending to issue documents as single entities. In this study, a higher degree of connectivity and network density in the intergovernmental collaboration network suggests a higher level of overall cooperation and coordination among government departments in HTE policy formulation in that region, necessitating greater interdepartmental collaboration during policy implementation.

In terms of departmental synergies, there are differences in the performance of various departments in the HTE policy formulation collaboration network among different regions. The Shanghai municipal finance bureau has the closest cooperation with other government departments, while the General Office of Shanghai municipal people's government, Shanghai municipal justice bureau and Shanghai municipal agriculture committee are isolated. The Beijing municipal science and technology commission has the closest cooperation with other government departments. The Beijing municipal people's government and the Communist Party of China Beijing Municipal Committee jointly issue documents, as do the Beijing municipal commission of economy and information technology and the Beijing municipal development and reform commission. The General Office of Beijing Municipal People's Government, Beijing Municipal Administration for Industry and Commerce, Beijing Municipal Bureau of Economy and Information Technology and Beijing Economic-Technological Development Area Management Committee formulate policies independently, without joint document issuance with other departments. In Jiangsu, only the Jiangsu provincial department of finance, Jiangsu provincial department of science and technology and the Jiangsu Provincial Development and Reform Commission jointly issue documents. The Guangdong provincial finance department has the closest cooperation with other government departments, occupying a central position in the network, followed by the Guangdong Provincial Science and Technology Department. However, the Guangdong Provincial People's Government, General Office of Guangdong Provincial People's Government and Guangdong Provincial Department of Industry and Information Technology are isolated, formulating policies entirely independently.

3.3.2 Comparison of centrality. From the perspective of degree centrality, the financial bureaus (departments) and science and technology commissions (departments) of various regions rank prominently in the intergovernmental cooperation network, serving as primary participants in formulating policies for HTE. The Shanghai Municipal Finance Bureau exhibits the highest degree centrality, having co-issued documents with 16 other departments, indicating its pivotal role in shaping policies for HTE. This also suggests that fiscal-related content is prevalent in most policies, with fiscal instruments remaining a crucial lever for regulating HTE. The Beijing Municipal Science and Technology Commission boasts the highest degree centrality with the largest number of co-issuing departments, highlighting its significance in policy formulation for HTE. This implies that most policies incorporate science and technology-related content. The Guangdong Provincial Finance Department holds the highest degree centrality among its peers, suggesting its central position in the network. Consequently, this suggests that fiscal policy remains an effective tool for promoting the development of HTE. The Guangdong Provincial Science and Technology Department and State Taxation Administration Guangdong Provincial Taxation Bureau follow closely in degree centrality, with numerous co-issued documents with other departments and most policies related to HTE involve sci-tech and taxation affairs. In contrast, the Guangdong provincial people's government, General Office of Guangdong provincial people's government and Guangdong Provincial Department of Industry and

Information Technology have a degree centrality of zero, indicating no joint policymaking with other departments and a tendency toward independent policymaking. The Jiangsu provincial finance department, Jiangsu science and technology department and Jiangsu Provincial Development and Reform Commission have co-issued documents, while the degree centrality of other departments are zero.

In terms of closeness centrality, the overall variation among different departments across provinces and municipalities within the intergovernmental cooperation network is insignificant, suggesting a relative independence among departments and a low level of interdependence. In Shanghai, aside from the Shanghai Municipal Agriculture Commission and Shanghai municipal justice bureau, which have a closeness centrality of zero; Shanghai municipal people's government, General Office of Shanghai Municipal People's Government and Communist Party of China Shanghai Committee, which have a closeness centrality of four, the closeness centrality of the remaining departments is relatively similar. This indicates that the departments have a similar degree of proximity and relatively little dependence on each other, allowing for a certain degree of independence when formulating policies. Similarly, in Beijing, with the exception of the Beijing Municipal Education Commission, Beijing Municipal Commission of Commerce, Beijing Municipal Intellectual Property Office, Beijing Association for Science and Technology, which show lower closeness centrality, the other departments exhibit comparable closeness centrality, reflecting similar levels of proximity and minimal dependency, thus enabling a degree of independence in policy-making. In Guangdong, aside from the Guangdong Provincial People's Government, General Office of Guangdong Provincial People's Government and Guangdong Provincial Department of Industry and Information Technology, the closeness centrality of the remaining departments is relatively similar, indicating a comparable degree of proximity and minimal dependency among them, which allows for some independence in policy formulation. In Jiangsu, aside from Jiangsu Provincial People's Government, General Office of Jiangsu Provincial People's Government, Jiangsu Provincial Commission of Economy and Informatization, Jiangsu Provincial Transport Department and Jiangsu Provincial Department of Industry and Information Technology with closeness centrality of zero, the closeness centrality of the remaining departments is relatively similar, indicating a comparable degree of proximity and minimal dependency among them, which allows for some independence in policy formulation.

From the perspective of betweenness centrality, there exist certain variations among different departments of various provinces and municipalities within the intergovernmental cooperation network, indicating that these departments possess differing degrees of control within the network. The Shanghai Human Resources and Social Security Bureau holds the highest betweenness centrality, suggesting its position at the core of the network, serving as an intermediary for joint publications among other departments and exercising significant control over collaborations between them. A number of departments exhibit a betweenness centrality of zero, such as the China Securities Regulatory Commission Shanghai Bureau, the Shanghai copyright bureau and the Shanghai municipal public security bureau, indicating their weak control over resources and negligible impact on collaborations between other departments. Similarly, the Beijing Municipal Science and Technology Commission holds the highest betweenness centrality, placing it at the network's core and acting as an intermediary for joint publications, with considerable control over collaborations. A subset of departments, including the Beijing Municipal Drug Administration and the Beijing Municipal Health Commission, exhibit a betweenness centrality of zero, indicating their limited resource control and negligible influence on interdepartmental collaborations. The Guangdong Provincial Finance Department possess relatively high betweenness centralities, signifying its roles as intermediaries in joint publications and significant control over

collaborations among other departments. Conversely, other departments exhibit a betweenness centrality of zero, reflecting their weak resource control and minimal impact on collaborations. The Jiangsu Provincial Department of Science and Technology exhibits the highest betweenness centrality, indicating that this department serves as a key intermediary for joint publications among other agencies and plays a significant role in controlling interdepartmental collaborations. In contrast, all other departments show zero betweenness centrality, demonstrating their limited influence over resource allocation and minimal impact on collaboration networks between other departments.

3.3.3 Comparison of structural holes. The structural hole characteristics of nodes within intergovernmental cooperation networks reflect the extent to which different government departments serve as bridges and intermediaries within the network. A larger effective size indicates a higher likelihood of structural holes existing among government departments; conversely, a higher constraint intensity signifies stronger restrictions and fewer structural holes within the intergovernmental cooperation network. The computational results reveal variations in the structural hole indices among departments within the HTE policy-making networks of Shanghai, Beijing, Guangdong and Jiangsu, suggesting differences in their ability to access non-redundant information, degree of constraint and independence within the network across provinces and cities.

In Shanghai, departments such as the Shanghai municipal finance bureau, Shanghai municipal development and reform commission, Shanghai Municipal Financial Services Office, Shanghai Municipal Education Commission and Shanghai Municipal Human Resources and Social Security Bureau exhibit larger effective sizes and lower constraint intensities. This indicates that these departments possess a certain degree of independence in policy-making, are less susceptible to influence from other departments, occupy numerous structural holes and can access more non-redundant information. In contrast, the Shanghai Foreign Experts Bureau and Shanghai Municipal Public Security Bureau have smaller effective sizes and higher constraint intensities, suggesting that they lack independence in policy-making, face stronger constraints and struggle to obtain effective information.

In Beijing, the Beijing Municipal Science and Technology Commission and the Beijing Municipal Commission of Urban and Rural Development demonstrate larger effective sizes and lower constraint intensities, indicating their independence in policy-making, resistance to influence from other departments, occupation of multiple structural holes and ability to access more nonredundant information. The remaining departments have smaller effective sizes and higher constraint intensities, indicating their lack of independence in policy-making, stronger constraints and difficulty in obtaining effective information.

In Guangdong province, the Guangdong Provincial Finance Department exhibits a larger effective size and lower constraint intensity, suggesting its independence in policy-making, resistance to influence from other departments, occupation of multiple structural holes and ability to access more nonredundant information.

In Jiangsu province, only the Jiangsu Provincial Finance Department, Jiangsu Provincial Department of Science and Technology have jointly issued documents. Among them, only the Jiangsu Provincial Department of Science and Technology has a relatively large effective scale and a lower degree of constraint. This indicates that this department has a certain level of independence in policy formulation, is less susceptible to influence from other departments, occupies more structural holes and can access more nonredundant information.

4. Conclusion

In this research, the intergovernmental network structure and primary characteristics of China's HTE policies from a policymaking perspective are examined. Beijing, Guangdong,

Jiangsu and Shanghai are selected as typical cases. Using text analysis to extract data on collaborative policy releases among government departments, four regional intergovernmental networks are constructed. The network structures are analyzed using the indicators of centrality and structural holes and comparisons are drawn among the intergovernmental network structures of the four regions. The research findings are as follows:

(1) Regarding the overall structure of the intergovernmental networks, there exist regional variations in the types and numbers of participating entities involved in the policymaking process for HTE, as well as in the degree of collaboration among them. Beijing has the largest number of participating entities, followed by Shanghai, with Guangdong and Jiangsu having fewer. Beijing and Shanghai exhibit higher levels of collaboration among departments, whereas departments in Jiangsu and Guangdong tend to issue policies independently. This is likely because Beijing and Shanghai have relatively higher economic development levels, more comprehensive industrial policies and a more favorable innovation environment (Yang *et al.*, 2022; Fan *et al.*, 2022). In Shanghai, fiscal departments dominate the issuance of policies, whereas in Beijing, science and technology departments are the primary issuers.

(2) In terms of centrality, finance bureaus (departments) and science and technology commissions (departments) of various provinces and municipalities rank prominently in degree centrality within the intergovernmental cooperation networks, serving as the main participants in formulating HTE policies. The Shanghai municipal finance bureau has the highest degree centrality, implying that fiscal-related content is frequently involved in most policies and fiscal instruments remain a crucial tool for regulating HTE. The Beijing municipal science and technology commission holds the highest degree centrality as a significant entity in formulating HTE. The Guangdong provincial finance department has the highest degree centrality, occupying a core position in the network. Collaborative policy releases are observed among the Jiangsu provincial finance department, Jiangsu Provincial Department of Science and Technology and Jiangsu Provincial Development and Reform Commission.

(3) Concerning structural holes, various departments across provinces and municipalities differ in their ability to access nonredundant information, constraints faced and degree of independence within the network. Departments such as the Shanghai municipal finance bureau, Shanghai municipal development and reform commission, Shanghai Municipal Financial Services Office, Shanghai municipal education commission and Shanghai Municipal Human Resources and Social Security Bureau possess larger effective sizes, indicating a certain degree of independence when formulating policies. The Beijing Municipal Science and Technology Commission and Beijing Municipal Commission of Urban and Rural Development exhibit larger effective sizes and lower constraint levels. Similarly, the Guangdong Provincial Finance Department has a larger effective size and lower constraint level.

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