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On the Internal Synergistic Mechanism of Operating System of Beijing's High-Technology Industry Chain: Evidence from Science and Technology Service Industry

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Abstract: Based on the then high-tech industry policy documents issued by Beijing in 2017, this paper builds a complex network model to reflect the internal structure of Beijing's High-Technology Industry Chain (BHIC), and then analyzes the coevolutionary mechanisms of ten top high-technology industries and their detailed sectors. Especially for the science and technology service (S&T) industry, this paper measures its function and status in the system and studies its concrete approach to stabilize the development of the industry chain. Finally, policy suggestions to promote the development of the S&T service industry in specialization, networking, and scale are put forward.

Keywords: high-technology industry chain; policy text analysis; complex network model; network characteristics; science and technology service industry

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1. Introduction

Based on its "four centers" positioning, Beijing is committed to serving the national strategic needs, and developing ten high-tech industries since 2018, to achieve innovative and high-quality development. In line with the strategic positioning of Beijing's urban development in the new era and driven by high-level scientific and technological innovation and systemic innovation, high-tech technological industries feature intensive high-tech elements, strong driving and radiation capabilities, eco-friendly mode, and intensive resource utilization. They are technology-intensive, efficiency-leading industries that can drive the sustainable development and restructuring of the regional economy.

Based on logistics, information flow, and capital flow, and led by the chain leaders, Beijing's High-Technology Industrial Chain (BHIC) follows the law of industrial development and establishes a complex network structure with the precise and high-quality matching of supply and demand by coordinating upstream and downstream industries. Its function is to promote the transformation and upgrading of the high-tech industrial structure from the low end of the value chain to the middle and high end, in the hope of integrated development, value creation, and the competitiveness of high-precision industries. BHIC forms internal synergy through the chain leaders. The upstream enterprises stimulate innovation from the supply side through structural reform, and fundamentally solve the pain points through independent research and development; the downstream enterprises alleviate the negative impact of the loose chain through data sharing on the demand side, thus effectively enhancing the risk management capability and competitiveness of the BHIC in the face of market uncertainty. In this sense, the BHIC requires chain leaders to play a leading role in promoting technological innovation on the supply side of the chain and uses information sharing on the demand side based on synergistic cooperation between upstream and downstream, to achieve high-quality development.

Although we realize that understanding the internal synergistic mechanism of BHIC will help the government formulate industrial upgrading policies, it is not only necessary but also very difficult to describe the topological structure of this complex industrial system. The reason is that it is difficult for us to define whether there is a synergistic relationship between the industrial sectors related to economic development, even though their industrial orientation and function seem to be related, or whether there is an exchange of products or services between them. Therefore, many researchers in this field can only carry out some qualitative research at the level of the industrial system or quantitative research on a very specific industrial chain.

Therefore, considering that the industrial policy texts issued by the government contain a large number of industrial positioning and linkage information, which are the results of repeated argumentation by experts and scholars and are scientific and forward-looking, this paper aims to use this information to build an industrial complex network model, study the internal synergistic mechanism of the industrial operating system on this basis, and select the science and technology (S&T) service industry as the empirical research object to analyze its impact on the BHIC.

2. Literature Review

By optimizing the knowledge structure and innovative resource allocation of the industrial economic system, the S&T service industry has directly promoted industrial transformation and upgrading [1], and indirectly driven economic growth [2]. Accelerating its development can promote the transformation of scientific and technological innovation achievements, and further promote the integration of S&T with the economy, which is crucial to the high-level and high-quality development of the economy. For China, it is a key link in implementing the innovation-driven development strategy, so it is necessary to conduct relevant research on the S&T service industry.

The concept of the S&T service industry has not been put forward by foreign academic circles, and more often, the concept of knowledge-intensive business services (KIBS) is used for corresponding studies [2]. For example, Corrocher studied the models of many types of technology services based on Lombardy [3]. Chichkanov discussed the consumption structure of KIBS in many different industries [4]; Giacinto studied the geographical distribution characteristics of the Italian KIBS [5]. As developed economies gradually enter the era of the service economy, the role of KIBS in promoting the new economy is increasingly obvious, so the research focus on the service industry turns to the role of KIBS in promoting innovation output, business incubation, innovation ecosystem, etc. [6–8]. The existing research can be roughly divided into three directions. The first type is research on the layout structure of the S&T service industry located in cities or urban agglomerations, especially for the phenomenon of industrial agglomeration. For example, Wang et al. analyzed the agglomeration degree of the S&T service industry in 31 provinces of China [9]; Wu et al. studied the mechanism of S&T service industry agglomeration to improve innovation efficiency by measuring the innovation efficiency of Chinese provinces [10]. The second one is research on the synergy between the S&T service industry and the high-tech industry [1,11], and the research shows that there is an inverted U-shaped relationship between the degree of synergistic aggregation and the level of regional innovation [12]. Li et al. also found that spatial clustering of the S&T service industry significantly improved the innovation efficiency of high-technology firms in China [13]. The third one is research on the function of the S&T service industry to improve the economic efficiency and innovation capability of the manufacturing industry [14]. Zhang found through industry correlation analysis that the correlation between the S&T service industry and the high-end technology manufacturing industry is much higher than that of the mid-range and low-end manufacturing industries [15]. Lafuente et al. referred to the interdependence between manufacturing and KIBS as territorial servitization, and the study found it was good for manufacturing employment creation [16]. Meng et al. investigated the intrinsic mechanisms of knowledge transfer and innovation in the S&T service industry and manufacturing industry by developing a system dynamics model [17]. From the development experience of developed countries, the main driving force for the development of the S&T service industry is the industrial guidance policies issued by the government and industry regulators [18]. Zhang et al. pointed out in their study that the development of China's science and technology service industry is largely driven by the Chinese government to build and develop [19]. However, China has more qualitative research in this area, while quantitative research is blank. Therefore, this paper selects Beijing's S&T service industry as the empirical research object, and through the quantitative analysis of industrial policy text information, discusses the internal synergistic mechanism of the operating system of BHIC, and focuses on the role of the S&T service industry in this system.

In previous studies, scholars used many research methods to analyze the function and status of the S&T service industry. For example, some of them use data envelopment analysis (DEA) to measure their development efficiency [10,20], while others use grey relevance analysis (GRA) to analyze their industry correlation [21,22], and more people use the more general measurement methods to make the statistical description of the S&T service industry [1,23]. To depict the complex structure of the industrial economic system and reflect the technical and economic relationship between the S&T service industry and other industries, this paper conducts modeling research based on social network analysis (SNA). This method can not only obtain clearer and more intuitive results than traditional quantitative or qualitative research but also mine valuable structured information from big data.

3. Modeling

3.1. Data Sources

Since 2014, when Beijing determined to implement the strategy of developing high-tech industries, the policy framework has been gradually improved and the working mechanism gradually established. Especially in 2017, ten industries, including new information technology, integrated circuits, medicine and health, smart equipment, energy conservation, environmental protection, new energy vehicles, new materials, artificial intelligence (AI), software and information service, and S&T service, were selected as the focus industries.

This paper takes the "Notice of the Issuance of a Series of Documents on Accelerating Scientific and Technological Innovation to Build a High-tech Economic Structure" issued by Beijing Municipality on 26 December 2017 [24], involving ten individual policy documents, which are ***New Generation Information Technology Industry, Integrated Circuit Industry, Medicine and Health Industry, Intelligent Equipment Industry, Energy Saving and Environmental Protection Industry, New Energy and Intelligent Automobile Industry, New Material Industry, Artificial Intelligence Industry, Software and Information Service Industry, Science and Technology Service Industry***, as the basis for analyzing the structure of high-tech industries in Beijing. Natural language processing (NLP) was conducted to extract the synergistic relationships of the industry chains, according to the policy documents that focus on the 210 industry subcategories of the abovementioned ten industry categories as divided by the "Beijing Top Ten High-tech Industries Registration Guidance Catalogue (2018 Edition)" (see Supplementary File S1). The process is shown in Figure 1, and the Python program is in Supplementary File S2.

It is worth noting that one of the features of Chinese policy documents is that each sentence in the text is an imperative sentence with the subject omitted. If the subject is a government regulator, a list will be used at the end of the text to clarify the corresponding relationship between them and the task. In the ten high-tech industrial policy texts studied in this paper, the subject of each sentence is implied in the title of the sentence; that is, there is an industrial relationship between industry A in the title and industry B involved in the following content. However, because what is listed in the title is often a relatively general industrial sector, we have supplemented the subject of each sentence by manual annotation with the help of expert experience.

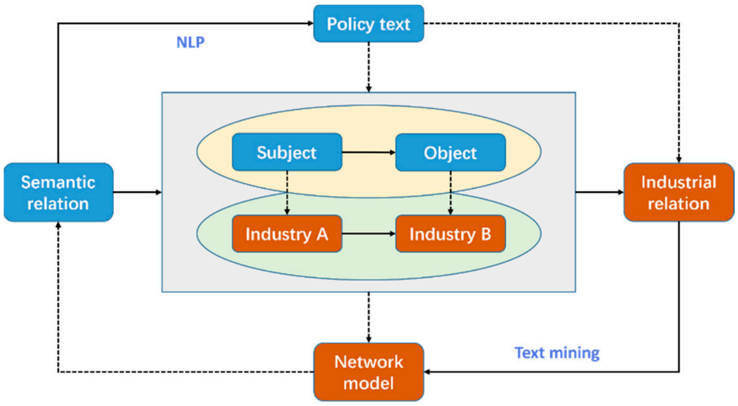

Figure 1. Extracting process for synergistic relationships in the BHIC.

3.2. Network Modeling

Based on the quantitative data of the synergistic relationships of the BHIC, this paper depicts the operation system of the BHIC by constructing a complex network model named the **Beijing High-Tech Industries Relationship Network (HTIRN-BJ)** model. The HTIRN-BJ model is a weighted directed network in which each sub-industry is denoted as a node, the synergistic relationship between industries as an edge, and the frequency of the synergistic relationship in the document as the edge weight. The total number of nodes in the network is N, the node set $V = \{V_1, V_2, \cdots, V_N\}$, the edge set $E = \{e_{11}, e_{12}, \cdots, e_{ij}, \cdots, e_{N(N-1)}, e_{NN}\}$, and the set of weights $W = \{w_{11}, w_{12}, \cdots, w_{ij}, \cdots, w_{N(N-1)}, w_{NN}\}$, which can be used to represent the edge set E in the weighted network. $G = (V, E, W)$ portrays the role of each segment in the BHIC network and the synergistic relationship between industries, as shown in Figure 2 (see Supplementary File S3).

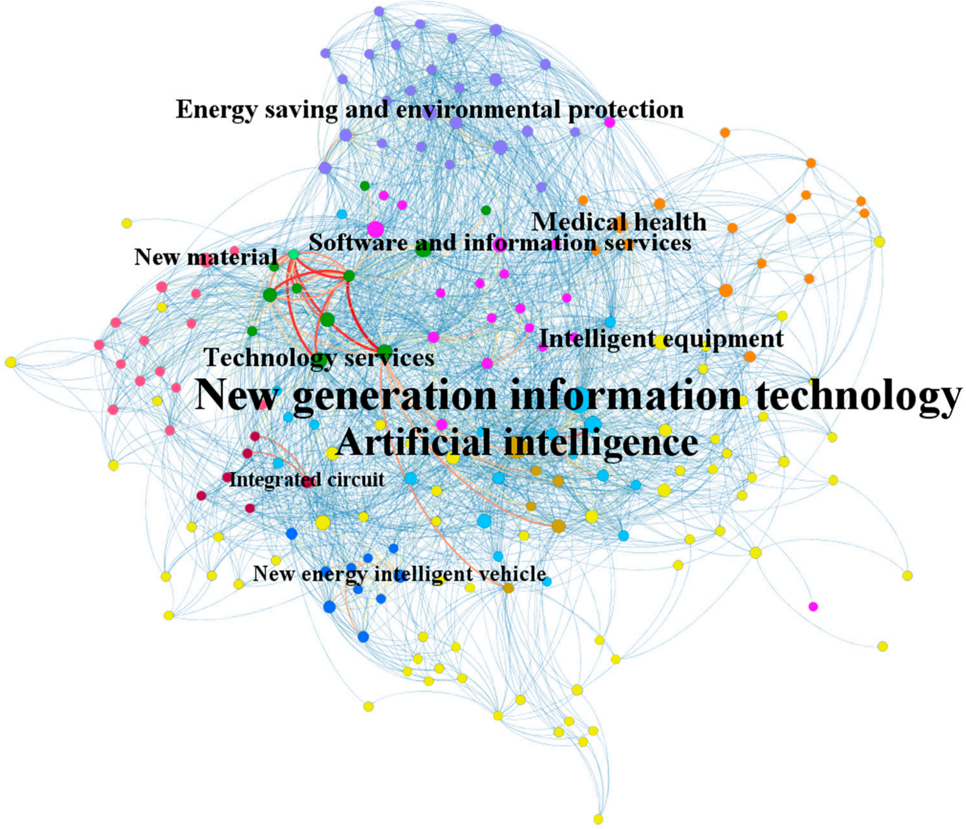

Figure 2. HTIRN-BJ model incorporating 210 industry subcategories.

In this paper, each sub-industry of the HTIRN-BJ model is aggregated into the ten high-tech industries, as shown in Figure 3 (see Supplementary File S4). It can be seen that Beijing has formed a high-end industry chain operation system with new generation information technology as the major driving force, the S&T service industry as the industrial link, and intelligent equipment, artificial intelligence, and new energy vehicles as the first movers. These industries have experienced a shift of orientation from the low- and mid-end to the high-end, a shift of sources of technologies from introduction and imitation to independent innovation, a shift of operating pattern from incremental expansion to inventory optimization, and the shift of sectors from heavy chemical industries such as machinery and chemicals to high-tech manufacturing industries, and then to the present-day pharmaceuticals, software, and information services. These shifts will fit Beijing's position as the capital city of China and its requirements for economic development and industrial upgrading therefrom [25].

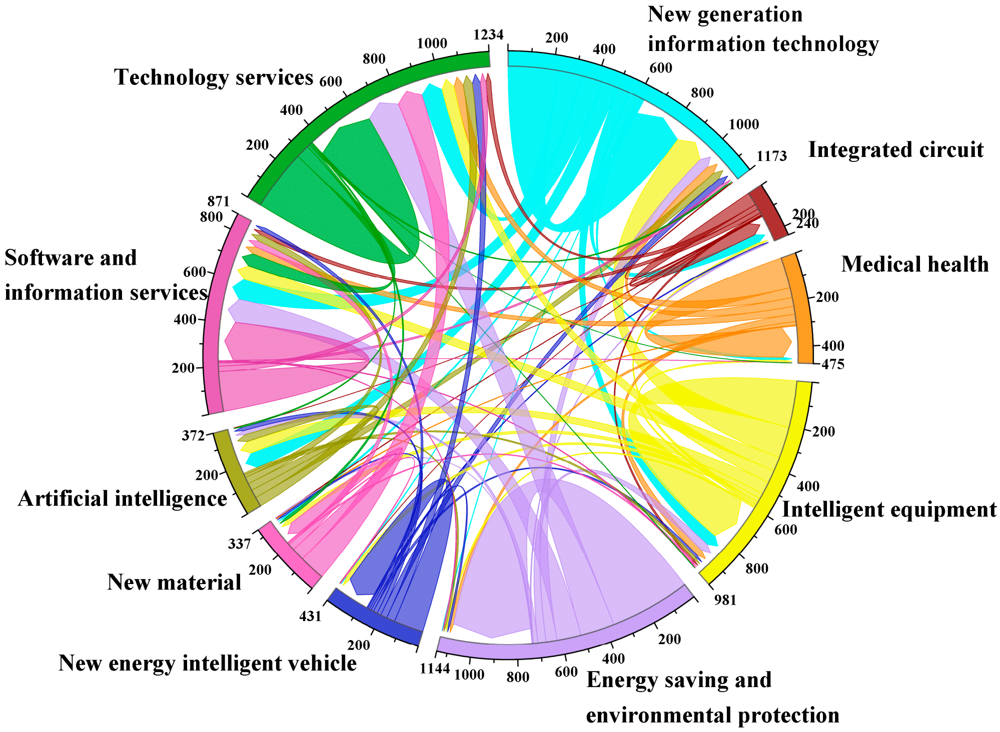

Figure 3. Internal synergic relationship of the operating system of HTIC.

4. Methodology

4.1. Overall Network Analysis

The HTIRN-BJ model portrays the techno-economic linkages among the ten high-tech industries. By measuring seven indicators of the HTIRN-BJ model, including network density, network global efficiency, average path length, clustering coefficient, in-degree relative central potential, out-degree relative central potential, and network assortativity (as shown in Table 1), this paper explores the network structure of the HTIRN-BJ model and reveals the relationship between the closeness of node connections and their behavior.

Among them, the density and global efficiency of the network reflect the closeness of connections between nodes and the average efficiency of information transfer; the average distance and clustering coefficient reflect the connecting relationship between nodes; the in-degree relative central potential and the out-degree relative central potential [26] reflect the tendency of nodes strengthening or weakening their connections; and the network assortativity reflects the tendency of whether high-degree nodes tend to connect with high-degree nodes or low-degree nodes.

Table 1. Network indicators.

Indicator	Equation	Description	Meaning
Network density	$ND = \frac{L}{N(N-1)}$	where L is the actual number of directed edges in the network, and N is the number of nodes in the network. The value range of ND is $[0,1]$.	The greater the network density, the more connected the network members are to each other.
Global efficiency	$GE = \frac{\sum_{i \neq j} \frac{1}{d_{ij}}}{N(N-1)}$	where d_{ij} is the shortest path between nodes i and j. In its calculation, $d_{ij}^{(k)} = \min_{i,j,k \in \{1,2,\ldots,N\}} \left\{ d_{ij}^{(k-1)}, d_{ik}^{(k-1)} + d_{kj}^{(k-1)} \right\}$, which works by first computing $d_{ij}^{(k)}$ for all pairs of source-to-sink nodes for $k = 1$, then $k = 2$, etc.	The greater the global efficiency, the greater the ability of the network to disseminate information.
Average distance	$APL = \frac{\sum_{i \neq j} d_{ij}}{N(N-1)}$		The shorter the average distance of the network, the lower the degree of separation between nodes.
Clustering coefficient	$C(i) = \frac{2A(i)}{K(i)(K(i)-1)}$	where $A(i)$ is the actual number of edges among the adjacent edges of node i. If there is only one adjacent node or none of node i, $C(i) = 0$.	The larger the clustering coefficient, the higher the degree of node clustering in the network.
In-degree relative central potential	$C_{RD}^{IN} = \frac{\sum_{i=1}^{N} \left(C_{RDmax}^{IN} - C_{RD}^{IN}(i) \right)}{N-2}$	where C_{RDmax}^{IN} and C_{RDmax}^{OUT} are the maximum values of relative degree in two directions.	When $C_{RD}^{OUT} > C_{RD}^{IN}$, the nodes in the network tend to connect; when $C_{RD}^{OUT} < C_{RD}^{IN}$, the node connections tend to be disconnected.
Out-degree relative central potential	$C_{RD}^{OUT} = \frac{\sum_{i=1}^{N} \left(C_{RDmax}^{OUT} - C_{RD}^{OUT}(i) \right)}{N-2}$		
Network assortativity	$r_{io} = r(\alpha, \beta) = \frac{E^{-1} \sum_i \left[\left(j_i^{\alpha} - \overline{j^{\alpha}} \right) \left(k_i^{\beta} - \overline{k^{\beta}} \right) \right]}{\sigma^{\alpha} \sigma^{\beta}}$	where E is the number of edges in the network, j_i^{α} or k_i^{β} is the degree of source node or sink node of edge i, $\overline{j^{\alpha}} = E^{-1} \sum_i j_i^{\alpha}$, $\sigma^{\alpha} = \sqrt{E^{-1} \sum_i \left(j_i^{\alpha} - \overline{j^{\alpha}} \right)^2}$, as well as $\overline{k^{\beta}}$ and σ^{β}.	If $r_{io} > 0$, the network is homogeneous, i.e., high-degree nodes tend to connect with high-degree nodes; if $r_{io} < 0$, it indicates that the network is heterogeneous, i.e., high-degree nodes tend to connect with low-degree nodes.

4.2. Betweenness Centrality of the Node

Median centrality can measure the transit effect of a node or a connected edge on the flow of information among other nodes, especially when the optimal path of information dissemination is the shortest. It is thus widely used in empirical studies to quantify the potential control of information flow by hub nodes/connected edges.

In this paper, Burt's structural hole theory is introduced as an analytical tool, according to which structural holes appear between networks when the networks have multiple separated components. The so-called structural hole refers to the fact that an individual (Ego) in a social network is directly connected to some other individuals (Alters), but these individuals are not directly connected. The phenomenon that these individuals are not directly connected or have intermittent relationships makes the network appear as if there are holes in the network structure. Burt's theory suggests that egos with higher betweenness will benefit from their advantages in information and control over Alters that they are connected to. Freeman proposed betweenness centrality, or betweenness, as a measure of structural holes, generally denoted as C_B. It can measure the conduction role of nodes in the network [27]. If there are a total of d_{jk} shortest paths through a pair of nodes, of which $d_{jk}(i)$ passes through node i, then the contribution of node i to the betweenness of the pair is $d_{jk}(i)/d_{jk}$. The betweenness $C_B(i)$ of node i is obtained by summing the contribution of node i to the betweenness of all nodes in the network and dividing it by the total number of node pairs, as shown in the following equation:

$$C_B(i) = \sum_{i,j,k \in \{1,2,\cdots,N\}} \frac{d_{jk}(i)}{d_{jk}} \quad (1)$$

Nodes with higher betweenness can have a large impact on the network topology if they are removed or restricted. Yet in networks with weight similarity, the characteristics of information dissemination are different from those of Boolean networks. The equation for weighted betweenness centrality of node based on RFWA denoted as C_B^{RFWA}, is as follows:

$$C_B^{RFWA}(i) = \sum_{i,j,k \in \{1,2,\cdots,N\}} SRPL_{jk}^{(N)}(i) \tag{2}$$

where $SRPL_{jk}^{(N)}(i)$ is the number of strongest relevance path length (SRPL) paths that connect any node pairs and pass through node i in the global scope of the network [28].

4.3. Betweenness Centrality of the Edge

Newman generalizes the application of Freeman's betweenness centrality to edges [29] and defines the betweenness centrality of an edge as the fraction of shortest paths between node pairs in a network that pass through a node, i.e.,

$$C_E(i,j) = \sum_{s,i,j,t \in \{1,2,\cdots,N\}} \frac{d_{st}(i,j)}{d_{st}} \quad (i \neq j, s \neq t) \tag{3}$$

where $d_{st}(i,j)$ is the number of shortest paths connecting nodes s and t through $e(i,j)$ and d_{st} is the total number of shortest paths connecting nodes s and t.

The edge-weighted betweenness centrality based on RFWA in similar-weighted networks is calculated as follows [30]:

$$C_E^{RFWA}(i,j) = \sum_{s,i,j,t \in \{1,2,\cdots,N\}} Str_{st}^{(N)}(i,j) \tag{4}$$

where $Str_{st}^{(N)}$ is the number of links between any node pair i and j contained in SRPL at the global level. This number will be added 1 if it denotes the self-loops of the SRPL.

Based on Granovetter's theory of the "strength of weak ties", the weak ties between two heterogeneous communities feature high betweenness centrality, as it plays a crucial role in bridging information. If the context is set in a similar-weighted network, there is likely to be an edge with a small weight but a large C_E^{RFWA}, which we call a "critical weak tie".

The larger the betweenness centrality of an edge in a network, the stronger its capability for dissemination, i.e., the stronger the connectivity of the edge in the network.

5. Results and Discussions

5.1. Overall Network Analysis

The calculating results of the HTIRN-BJ model indicators are shown in Table 2.

Table 2. HTIRN-BJ Model Indicators.

Indicator	ND	GE	APL	C	C_{RD}^{IN}	C_{RD}^{OUT}	r_{io}
Value	0.06	0.26	2.76	0.43	0.12	0.45	0.44

As can be seen in Table 2, the network feathers low density ($ND = 0.06$), relatively loose connections, ineffective resource sharing, low global efficiency ($GE = 0.26$), inefficient information transfer between sub-industries, and consequently restricted industrial development. Most social networks in the real world manifest a small-world phenomenon, i.e., the average node distance in the network grows logarithmically as the node number increases. Valverde et al. argued that "the criterion for small-world networks is that the average distance is less than 10 and the clustering coefficient is greater than 0.1. For networks with a particularly large number of nodes, the criterion can be reduced." The average distance $D = 2.76$ and the clustering coefficient $C = 0.43$ of the HTIRN-BJ model indicate that Beijing's high-tech industrial chain displays an obvious small-world phenomenon. The close connection between similar industries in the network is conducive to information exchange and resource sharing. The in-degree central potential of the network, however, is larger than the out-degree central potential, which indicates that the sub-industries in the network have fewer ties with each other, and the assortativity $r_{io} > 0$ indicates that the sub-industries tend to have alliances of giants.

5.2. Network Analysis by Industries

The indicators of the ten HTIRN-BJ models are calculated and the results are shown in Table 3.

Table 3. HTIRN-BJ model indicators by industries.

High-Tech Industries	*ND*	*GE*	*APL*	*C*	C_{RD}^{IN}	C_{RD}^{OUT}	r_{io}
New information technology	0.26	0.38	1.66	0.74	0.35	0.57	0.55
Integrated circuit	0.80	0.90	1.20	0.90	0.55	0.25	0.85
Medicine and health	0.31	0.45	1.54	0.77	0.22	0.37	0.67
Smart equipment	0.03	0.06	2.30	0.16	0.09	0.20	0.33
Energy conservation and Environmental protection	0.42	0.61	1.58	0.77	0.44	0.62	0.75
New energy vehicles	0.59	0.69	1.27	0.90	0.10	0.51	0.81
New materials	0.25	0.35	1.48	0.55	0.29	0.37	0.58
Artificial intelligence	0.63	0.72	1.21	0.93	0.25	0.55	0.77
Software and information service	0.28	0.47	1.73	0.74	0.30	0.61	0.63
Science and technology service	0.58	0.69	1.33	0.92	0.18	0.51	0.81

As can be seen from Table 3, except for the smart equipment industry, the other nine industries have a greater density and higher efficiency, indicating close intra-industrial connection and efficient information transfer and resource sharing. Meanwhile, the nine industries other than the smart equipment industry evince a high degree of industry clustering, as seen from their clustering coefficient. In comparison, the smart equipment industry is relatively underdeveloped due to a lack of connection among its myriad sub-industries and a low level of clustering. The assortativity of all industries is greater than 0, suggesting that all industries tend to have alliances of giants within them. In addition to the integrated circuit industry, the in-degree central potential of the other nine industries is greater than their out-degree central potential, which implies that the intra-industrial connection is only strengthened in the integrated circuit industry but not in the other nine.

It can be concluded that Beijing's high-tech industrial chain has limited information exchange and resource sharing between different industries, but industrial clusters within each industry have been formed, and the mutual information transfer and resource sharing between sub-industries have driven the development of their umbrella industry. The link between different sub-industries is prone to being weakened, with only the stronger ones connecting. Although the cooperation between more competitive industries can be conducive to their development and the competitiveness of the whole industry, it may also further weaken those less competitive sub-industries, therefore dampening the overall development of the industry. To promote the synergistic development of this industrial chain system, information exchange and resource sharing should be strengthened between different sub-industries, as well as the linkages between the less competitive industries, to boost the competitiveness of the industry.

6. Empirical Study: The Positioning and Role of Science and Technological Service Industry

The S&T service industry originated in European countries and the United States in the 19th century, when it only provided simple consulting services. With the advent of the third industrial revolution in the 1940s and 1950s, science and technology became an important factor in productivity growth, and S&T-related services, such as design, research and development, S&T product promotion, and application, further strengthened the role of S&T in promoting national economic development, and the S&T service industry also leapfrogged to a new type of business as a byproduct. China's S&T service industry was first defined in "Opinions on Strengthening the Development of Science and Technology Consulting, Science and Technology Information and Technology Service Industry" issued by the State Scientific and Technological Commission of the People's Republic of China in 1992. Thereafter, the term S&T service industry has made an increasing appearance in the Chinese government's industrial development policies. Since 2014, when China promulgated "Opinions on Accelerating the Development of Science and Technology Service Industry" [31], the S&T service industry has become an industry sector in its own right and an important part of China's modern service industry. Besides, China has also introduced the National Statistical Classification of Science and Technology Service Industry, based on which the development of the S&T service industry is tracked with statistics. In response to the national industrial development policy and high-quality economic development goals, Beijing, as the political, economic, and cultural center of China, has successively introduced policies to support the development of the S&T service industry and to further classify its sub-categories. The Beijing Municipality has also dedicated funds for the S&T service industry to support leading enterprises and organizations in the S&T service industry. Suffice it to say that the S&T service industry has now become the key to the security and stability of Beijing's high-tech industrial chain system.

6.1. Research Related to the Function and Status of the S&T Service Industry

The continuous development of the S&T service industry has drawn the attention of many scholars. In recent years, relevant research has mainly focused on the development level, development path, and the important role played by the S&T service industry. The development of the S&T service industry has accelerated scientific and technological innovation [10], boosted industrial transformation and upgrading [32], and promoted high-quality economic development [2,33]. Wang studied how the S&T service industry has promoted technological innovation [34]. Wang et al. examined the qualitative relationship and quantitative relationship between the efficiency of S&T services and industrial transformation and upgrading [35]. Li et al. measured the promoting effect of the S&T service industry on economic development based on the input–output model in terms of residential consumption and employment [36]. Xie et al. identified that the clustering of the S&T service industry in Beijing improved the innovation capacity and promoted the economic development of Beijing [37]. Wang et al. found that the clustering of the S&T service industry improved industrial efficiency [38]. Du et al. studied how this industry has promoted China's high-quality economic development [39]. To improve the efficiency and quality of S&T services during high-quality economic development, this industry should optimize the industrial layout, improve the service system, and form a complete innovation service chain [40]. In addition, it should strengthen the connection with S&T innovation-related industries and promote collaborative innovation among industries. Zu et al. proposed the future development direction of the industry based on its current development in China and China's overall economic development [41]. Wang et al. analyzed the development level of the S&T service industry and its changing pattern in six provinces of central China, including Shanxi and Hunan [42]. Zhang et al. studied the spatial layout of the S&T service industry in each province of China and gave recommendations for future development [43]. Wang et al. measured the clustering level, structural evolution, and influencing factors of the S&T service industry in each province of China [44]. Xi et al. discerned the synergistic innovation between the S&T service industry and the government, universities, industries, and the public and provided suggestions for S&T service improvement [45].

6.2. Analysis of the Status of the S&T Service Industry in Beijing

As stated above, the betweenness centrality measures the information and control advantages of nodes in the network. The larger the betweenness, the stronger the node's conduction role in the network. In other words, it has a higher status in the network. In this paper, the conduction efficiency of Beijing's S&T service industry to information, resources, and other factors in the high-tech industrial chain is measured through the node betweenness centrality, and thus the industrial status of the S&T service industry can be analyzed. The specific results are shown in Tables 4 and 5.

Table 4. Top 10 nodes of betweenness centrality in the HTIRN-BJ model.

Rank	Industry	Sub-Industry	Name of Service	C_B^{RFWA}
1	New information technology	IoT and its application	IoT tech support	5405
2	New information technology	Data processing and storage	Internet data services	3311
3	Science and technology service	Research and development (R&D)	Engineering and technology R&D	2845
4	AI	AI applications	Application development	2799
5	Medicine and health	Biologicals manufacturing	Biological pharmacy	2601
6	Science and technology service	S&T consultancy	S&T agency	2506
7	Software and information service	Information system integration	Information system integration	2412
8	Energy conservation and environmental protection	Environmental protection equipment	Environmental protection equipment manufacturing	2354
9	Science and technology service	Quality control technology	Inspection service	2149
10	Energy conservation and environmental protection	Environmental sanitation	Environmental sanitation	2098

Table 5. The betweenness of sub-industries of Beijing's S&T service industry.

Rank	Industry	Sub-Industry	Name of Service	C_B^{RFWA}
3	Science and technology service	R&D	Engineering and technology R&D	2845
6	Science and technology service	S&T consultancy	S&T agency	2506
9	Science and technology service	quality control technology	Quality inspection	2149
14	Science and technology service	R&D	Natural science R&D	1678
15	Science and technology service	Intellectual property (IP) services	IP services	1478
24	Science and technology service	Engineering management	Engineering management	1126
60	Science and technology service	Startup workspace	Startup workspace	467
89	Science and technology service	R&D	Medical sciences R&D	339
94	Science and technology service	Specialized design	Specialized design	337
101	Science and technology service	Engineering investigation and design	Engineering investigation and design	332
133	Science and technology service	R&D	Agricultural sciences R&D	329
134	Science and technology service	Specialized design	Industrial design	329

From Table 4, it can be seen that in Beijing's top 10 high-tech industrial chain systems, IoT and its application, and data processing and storage in new information technology boast the highest betweenness. The continuous improvement of IoT technology has promoted the development of various industries and changed people's lifestyles. Thanks to the application of IoT, industrial production and personal lives now feature efficient information swaps, which lay the foundation for the intelligent development of various industries. In the context of IoT, industrial development needs to be underpinned by large-scale data, which is why data processing and storage have played an important role in disseminating information and maintaining resources.

The betweenness of the AI application software development in the AI industry is 2799, ranking at the fourth place, meaning that it has strong advantages in terms of information and resources in the overall network; that of the information system integration service in software and information service industry is 2412, ranking at the seventh place. The new information technology industry provides the basis for the development of the AI industry and the software and information service industry, and industries such as AI applications and information system integration services promote smart development in various industries with information technology. This makes the three industries—new information technology, AI, and software and information services—the pillars of the industrial chain.

The betweenness of the medicine and health industry is 2601, ranking fifth; that of environmental protection equipment and environmental sanitation in the energy conservation and environmental protection industry is 2354 and 2098—ranking eighth and tenth, respectively. The development of these industries has improved the construction of medical, energy conservation, and environmental protection infrastructures in Beijing, and provided a sound development environment for the high-tech industrial chain in Beijing, by attracting more high-tech talents.

The betweenness of engineering and technology R&D, S&T consulting services, and quality control technology in the S&T service industry are 2845, 2506, and 2149, respectively, ranking third, sixth, and ninth among all industries. Engineering and technology R&D underpins the technological development of related industries, S&T consulting services promote the transfer of S&T among industries, and quality control technology guarantees product quality in related industries. Overall, the S&T service industry promotes inter-industry innovation in terms of technological innovation, technology transfer, and quality control technology.

The improved S&T service is conducive to the synergistic development of Beijing's high-tech industrial chains. The Intellectual property (IP) and Startup workspace service industries help promote scientific and technological innovation and innovation and entrepreneurship; the R&D of natural science, agricultural science, and medicine can boost the development of related industries; specialized design, engineering design, engineering management, and other service industries also provide infrastructure for related industries. Suffice it to say that the S&T service industry promotes the integration and joint development of high-end manufacturing and service industries, thereby contributing to industrial transformation and upgrading. As can be seen from Table 5, except for engineering and technology R&D, S&T consultancy service, and quality control technology, other industries have a relatively lower ability to share information and manage resources, which bolsters other industries in the network. In the future, the S&T service industry should thus further fortify the IP, startup workspace, engineering management, specialized design, and natural science, medical, and agricultural science R&D industries.

6.3. Functional Analysis of Beijing's S&T Service Industry

In this paper, the connectivity of each industry segment in the HTIRN-BJ model is measured by edge centrality. The results of the edge centrality related to the S&T service industry are shown in Tables 6–8, and the results of the edge centrality matrix of the top ten high-tech industries combined by each sub-industry are shown in Figure 4.

It can be seen from Figure 4 that, at the industrial level, the edge betweenness is heterogeneously low between industries in general. Only a few show notably higher betweenness within the industries per se, namely new information technology, intelligent equipment, energy conservation and environmental protection, and S&T service. Relatively higher betweenness can also be found in new information technology → smart equipment, new information technology → AI and smart equipment → information technology. This indicates that the strong pivot between the three industries has promoted the intelligent development of Beijing's high-tech industrial chain system and facilitated the integration and coordinated development of the manufacturing and service industries.

Table 6. Top ten industries in terms of betweenness in the HTIRN-BJ model.

Rank	Upstream Industry	Downstream Industry	C_E^{RFWA}
1	Quality control technology	Biologicals manufacturing	1585
2	Information system integration	Environmental sanitation	1246
3	IoT and application	Rail transportation	1011
4	S&T consultancy	Quality control technology	905
5	Data processing and storage	AI application	879
6	Intellectual property	Rail transportation	868
7	Environmental protection equipment	IoT and its application	832
8	Biologicals manufacturing	Data processing and storage	751
9	Environmental protection equipment	High-end energy equipment	739
10	R&D	Information system integration	719

Table 7. Top 50 betweenness industries whose upstream is the S&T service industry.

Rank	Upstream Industry	Downstream Industry	C_E^{RFWA}
1	Quality control technology	Biologicals manufacturing	1585
4	S&T consultancy	Quality control technology	905
6	Intellectual property services	Rail transportation	868
10	Engineering and technology R&D	Information system integration	719
12	Engineering and technology R&D	S&T consultancy	669
20	S&T consultancy	Online public service platform	404
31	Engineering and technology R&D	AI application	343
39	Engineering management	S&T consultancy	321
41	Engineering and technology R&D	Polymeric optical, electrical, and magnetic materials	315
46	Natural sciences R&D	Polymeric optical, electrical, and magnetic materials	306
47	Intellectual property services	S&T consultancy	306
50	Natural Sciences R&D	Quality control technology	286

Table 8. Top 50 betweenness industries whose downstream is the S&T service industry.

Rank	Upstream Industry	Downstream Industry	C_E^{RFWA}
4	S&T consultancy	Quality control technology	905
12	Engineering and technology R&D	S&T consultancy	669
15	AI system	Natural sciences R&D	569
39	Engineering management	S&T consultancy	321
47	IP services	S&T consultancy	306
50	Natural sciences R&D	Quality control technology	286

The betweenness between the S&T service industry and the other nine industries turns out to be small, implying that the pivotal role of the S&T service industry in Beijing's high-tech industrial chain system is not significant. Among them, the margins between science and technology service → medicine and health and science and technology service → software and information service are relatively small compared with those between S&T service and other industries. This indicates that the S&T service industry has invested more resources in serving the medicine and health and software and information service industries. The results are shown in Tables 6 and 8.

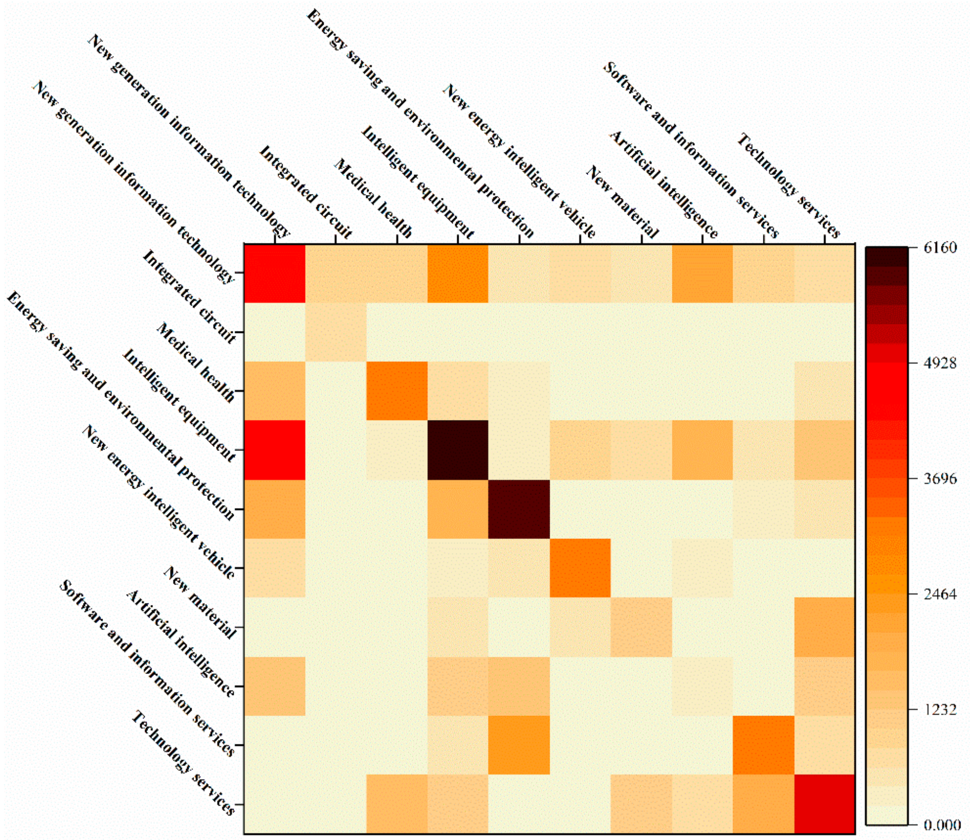

Figure 4. Matrix of edge betweenness of the top ten high-tech industries in Beijing.

As shown in Table 6, the industries with high betweenness are mainly manufacturing industries that are closely related to people's lives, such as biomedical, energy saving, environmental protection, and transportation. The continuous development of these industries has improved the living standards of Beijing residents. Meanwhile, service industries, including information technology and quality control technology, promote the incessant innovation of technological application to manufacturing industries, thus promoting industrial upgrading.

The betweenness of quality control technology → biologicals manufacturing, information system integration services → environmental sanitation, and IoT and application → rail transportation rank among the top three, with their values at 1585, 1246, and 1011, respectively. With improved product quality guaranteed by quality control technology, biologicals manufacturing has been driving the development of the medicine and health industry. Environmental sanitation business has provided technological support with information system integration services and helped the environmental protection industry with its gradual shift towards intelligent and informative environmental management. The rail transportation service has contributed to the optimization of the transportation service system through IoT applications. Overall, with the support of information technology and service-related industries, biologicals manufacturing, environmental sanitation, and rail transportation are enhancing the infrastructure of Beijing. It provides a good environment for overall industrial development and attracts more high-level talents to high-tech industries in Beijing.

As shown in Table 7, the industries that rank in the top 50 of betweenness and whose upstream industries are among the S&T service industries include quality control technology, S&T consultancy services, IP services, and engineering and technology R&D industries. Some of the industries with high betweenness fall into the category of the S&T service industry. Notably, the engineering and technology R&D industry has high betweenness and is closely related to information system integration service, AI application software, and polymeric optical, electrical, and magnetic materials industries.

The betweenness of quality control technology → biologicals manufacturing industry appears to be the highest in value, which is important in the development of Beijing's high-tech industrial chain system. The betweenness of IP services → rail transportation is at 868, ranking sixth, enabling scientific and technological innovation in the rail transportation industry and thus promoting the development of the intelligent equipment industry. Information system integration services, AI application software, and polymeric optical, electrical, and magnetic materials industries are growing rapidly with the support of engineering and technology R&D.

The development of IP services and natural science R&D is conducive to scientific and technological innovation in other industries. The S&T service industry should therefore continuously improve its IP service and natural science R&D system and provide services to various industries in this industrial chain to promote scientific and technological innovation in various industries.

As shown in Table 8, most representatively, quality control technology, S&T consultancy services, and natural science R&D rank in the top 50 in terms of betweenness and whose downstream industries are among the S&T service industry. Most of the upstream industries are within the S&T service industry. The betweenness of AI system → natural science R&D is 569, ranking 15th, which indicates that AI-related industries can promote the progress of the natural science R&D industry.

There are two main reasons why the betweenness from other industries to those in the S&T service industry tends to be smaller. Firstly, industries in the S&T service industry mainly provide services to other industries, not vice versa. Secondly, new information technology-related industries, software and information service-related industries, and AI-related industries can provide technical support for the development of the S&T service industry, while the application of these technologies in various sub-industries in the S&T service industry is insufficient. Looking forward, the S&T service industry should strengthen the technological application, establish a precise demand-oriented S&T service platform, and bolster all aspects of industrial development.

7. Conclusions

This paper mainly draws the following conclusions. First, the industries in Beijing's high-tech industrial chains are more closely connected within industries per se, but less connected with other industries in the chain, reflecting the lack of collaborative innovation at the global level. Second, engineering and technology R&D, S&T agency, and quality control technology have relatively higher status in the Beijing S&T service industry, meaning that they boast stronger service capability in the whole high-tech industrial chain; on the other hand, natural science R&D, IP services, startup workspace, and design are located at a lower status, with insufficient serviceability. Third, the S&T service industry plays an indispensable service role in biological products testing, rail transportation, intellectual property, new materials R&D, AI application software R&D, information system integration R&D, and online public service platforms. It also embodies strong service functions in its development, especially in medicine and health, new materials, intelligent equipment, new information technology, and AI.

Based on the above conclusions, this paper proposes the following recommendations.

(1) To address the bottlenecks in the development of the S&T service industry, it is necessary to dedicate more support from the government side by ensuring consistent government-sponsored programs, avoiding information isolation, beggar-thy-neighbor, and internal competition for profits, and improving the efficiency of industrial resource use. More policy support should be given to S&T financing and business incubation. The comprehensive financial service platform for small and medium-sized enterprises should be better utilized, to establish an online-and-offline financing system with governmental support. The S&T financial institutions shall

serve the development of high-tech industries, and broaden the financing channels for "specialized and new" enterprises.

(2) The dynamic audit system should be built for S&T service entities, with well-developed and detailed evaluation criteria and standardized industrial definitions. Sub-industries that cannot deliver high-quality service and high-level specialization and socialization should be removed from the directory of high-tech industries and deprived of preferential treatment. Instead, those who have played a key role in promoting the innovative development of high-tech industries should be promptly added to the directory and given a certain degree of policy support.

(3) Efficient platforms should be built to promote in-depth cooperation between relevant enterprises and industrial technology alliances, industry associations, research institutions, and higher education institutions in the fields of technology research and development, knowledge transfer, and market application. A cooperation mechanism featuring synergistic development, complementary advantages, resource pooling, and risk sharing should be established between industry and academia, thus forming a symbiotic value chain of market demand, research and development, production, sales, and services.

(4) The serviceability of S&T service institutions shall be improved. As a large proportion of S&T service institutions in Beijing used to have a state-owned background, they usually lack innovation vitality and revenue-generating capacity. Beijing should therefore further promote the transformation and upgrading of these entities and enhance the incentive mechanism. Based on the total workload, performance, and market price factors, a dynamic remuneration adjustment mechanism should be established. While raising the basic salary level, special focus should also be placed on incentive bonuses to highlight "actual contribution" and guarantee the competitiveness of revenue in this industry. In this way, the innovation motivation and profitability of S&T service entities can be uplifted.

All in all, this paper explores a new method to study the internal synergistic mechanisms of industrial operating systems, that not only fully excavates the important industrial information implied in the policy texts as secondary data, but also systematically analyzes the regional industrial structure with the help of cutting-edge network science. Compared with the ordinary ones, it has incomparable timeliness (saving the time of the survey) and comprehensiveness (including the indirect relation analysis). In the future, we plan to apply the analytical framework in this paper to more quantitative research on industrial policy.

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