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Spatial Economic Network of China's Lithium Industry: A Geo-Analytical Perspective on Lithium-Related Listed Firms

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Abstract: Lithium, as a critical resource underpinning strategic emerging industries, has garnered significant global attention due to its pivotal role in energy storage and clean energy applications. This study delineates the spatial economic network of China's lithium industry by analysing data derived from lithium-related listed firms and their subsidiaries registered within the country. Employing social network analysis (SNA) and GeoDetector methods, the spatial characteristics and determinants of the economic network are systematically investigated. The findings reveal that lithium-related listed firms are predominantly concentrated in economically developed regions, including the Yangtze River Delta, Pearl River Delta, Hubei Province, and Henan Province. The economic network exhibits sparse connectivity but displays a small-world effect, characterised by a hierarchical structure with Shenzhen as the central hub, supported by significant nodes in Ningde and Shanghai. A distinct east-west disparity is observed, with dense linkages in the east contrasting with sparse connections in the west. Core cities within the network, primarily located in coastal regions, are identified as possessing strong economic development, favourable resource endowment, or well-established industrial foundations. These cities exhibit notable spatial agglomeration patterns around regional cores. Furthermore, the economic network is profoundly influenced by factors including economic development levels, local innovation capacity, openness to trade and investment, and policy environments conducive to industrial growth. These findings provide valuable insights into the spatial structure and driving mechanisms of China's lithium industry, offering a robust basis for formulating targeted strategies to enhance the sector's development and competitiveness.

Keywords: Lithium industry economic network; Spatial structure; Lithium-related firms; GeoDetector; Social network analysis (SNA)

1 Introduction

The global energy landscape is undergoing a transformative revolution, marked by a shift from fossil fuels to clean energy sources. Lithium, as a core material for rechargeable batteries, plays a pivotal role in driving this transition. Its high energy density, particularly in the context of electric vehicles, extends driving ranges, significantly reduces carbon dioxide emissions, and accelerates the adoption of clean energy solutions, all of which are crucial for global sustainable development. Consequently, lithium is recognised as a critical mineral resource by major

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economies, including the United States, the European Union, and China [1, 2]. In China, it is designated as a strategic mineral, reflecting its prioritisation within the national agenda. The sustainable development of the lithium industry, therefore, constitutes an integral component of China's new energy strategy [3, 4]. As a nation endowed with abundant lithium reserves, China holds considerable resource advantages for cultivating its lithium industry as a strategic emerging sector [5, 6]. Nonetheless, recent years have witnessed a heightened external dependency and a strained supply-demand dynamic for lithium within the country [7]. The spatial network structure of lithium-related listed firms, which serve as the driving force behind the economic advancement of the lithium industry, exerts a profound influence on the sector's development trajectory. In the context of accelerated industrial upgrading and the rapid expansion of new energy technologies, examining the network structure of China's lithium industry is not only essential for fostering its growth but also pivotal for catalysing the emergence of high-quality productivity. This investigation represents a critical step toward achieving the nation's dual carbon objectives of peak emissions and carbon neutrality.

The spatial connection of economic factors in a region is the basis for the formation of economic networks. From the proposal of the law of retail gravitation to the presentation of the economic gravity model [8], followed by the continuous improvement and innovation by researchers such as Roberts and Ullman [9] and Keum [10], many theoretical achievements have been made from different perspectives and spatial frameworks, creating a strong foundation for research on economic networks. The rapid development of the global economy has enhanced economic ties between cities. Numerous empirical analyses have been performed on inter-city economic networks based on virtual flows, e.g., innovation cooperation and information interaction, and physical flows, e.g., human and material flows, which provide a reliable perspective for understanding the economic evolution of an entire region [11–18]. In terms of methodology, most studies investigated the centrality, betweenness, and other network attributes using SNA based on complex network theory [19–22].

Firms, as primary economic entities, serve as both the core factors and key enablers of regional economic development. Therefore, inter-firm networks are an important component of research on economic networks [23–28]. Extensive research has been conducted on urban economic networks based on firms. For example, economic linkages between cities around the world or in a country or region have been investigated based on data of advanced production service firms, logistics firms, listed firms, and Fortune 500 firms, thereby evaluating the evolutionary pattern, organizational characteristics, and mechanism of action of economic networks [25, 26, 29–33].

In this study, a network constructed from the parent–subsidiary linkage data of lithium-related listed firms is used to characterize the economic network of the lithium industry. Most research on the lithium industry can be classified into three categories. The first category focuses on lithium resources and investigates the global supply of lithium resources, the recycling of lithium waste, and lithium extraction techniques [34–37]. For example, Song et al. [38] investigated the kinetics and mechanism of hydrometallurgical recycling of lithium from waste saggar and Sverdrup [39] predicted that lithium resources will be exhausted in 400 years by analyzing the current global lithium supply.

The second category focuses on lithium application and investigates the industrial use of lithium, the supply chain risks of lithium-ion batteries, and the economic benefits of lithium-ion battery materials. For example, Sun et al. [40] investigated the supply chain of lithium-ion batteries; King and Boxall [41] characterized the current and future situation of lithium-ion battery recycling in Australia and evaluated the potential economic benefits of lithium materials [42–44].

The third category focuses on lithium trade and investigates the current situation, competition, policies, and other aspects of lithium trade [45–49]. For example, Chen et al. [50] examined the spatial characteristics of global lithium trade and described the lithium trade pattern from the perspective of the industrial chain, and Jin et al. [51] developed a lithium supply chain network and evaluated its structure and resilience.

Based on the above discussion, this study attempts to (1) determine the spatial characteristics of the economic network of China's lithium industry using SNA based on data from lithium-related listed firms and their subsidiaries, and (2) identify factors influencing the network using GeoDetector. This study offers two contributions. First, it investigates industrial development in terms of social networks and characterizes the spatial structure of industrial linkages, which presents a new perspective for investigating industrial development and extends the understanding of industrial research. The findings help understand the current status of China's lithium industry and identify the key factors affecting the economic network of the lithium industry using GeoDetector, thereby providing guidelines for developing strategies to promote the lithium industry. Second, it expands the research on urban networks and the theoretical research of regional economic geography by transforming the linkages between lithium-related listed firms and their subsidiaries into inter-city linkages.

2 Data and Methodology

2.1 Data

Lithium-related listed firms and their subsidiaries registered in China were included in this study. To this end, listed firms registered in China whose business scope contains the word “lithium” were retrieved using the batch search function of the Qixin Huiyan platform (https://www.qixin.com/, Qixin Huiyan is a Chinese corporate credit investigation product. The platform provides services such as querying Chinese corporate industrial and commercial information, court judgment information, affiliated enterprise information, judicial auction information, default information, information on persons subject to execution, intellectual property information, and company news.). On this basis, a total of 394 A-share, B-share, and China-concept-stock-listed firms, such as Tianqi Lithium Corporation and Luoyan g Dasheng New Energy Development Co., Ltd., were collected using the China Stock Market and Accounting Research (CSMAR) database. Furthermore, a total of 11,032 subsidiaries of the included lithium-related listed firms, such as Hunan Jinyuan New Materials Recycling Co., Ltd. and Jiangxi Jinchi Mining Co., Ltd., were identified using the corporate relationship section of the Qixin Huiyan platform. The data search was performed on July 25, 2024.

A point layer of the lithium-related listed firms was created using ArcGIS based on the longitude and latitude of their registered addresses (Figure 1). As shown in subgraph (a) of Figure 1, lithium-related listed firms are concentrated in the Yangtze River Delta and Pearl River Delta and in Hubei and Henan provinces. Shenzhen, Yangzhou, Ningbo, Suzhou, and Guangzhou are the top five cities in terms of the number of lithium-related listed firms. In terms of sector composition, most of the firms are in the manufacturing sector, followed by scientific research and technical services, then wholesale and retail trade, accounting for 69.79%, 16.75%, and 7.86% of all firms, respectively.

Kernel density analysis (subgraph (b) of Figure 1) reveals that most areas (the light-colored areas) are low-value areas, with the high-value areas concentrated around Shenzhen and Yangzhou. In particular, Shenzhen radiates to the Pearl River Delta, such as Dongguan; meanwhile, Yangzhou radiates to the Yangtze River Delta, such as Ningbo and Suzhou. The medium- and low-value areas are cities such as Xinyu, Zhengzhou, Luoyang, and Beijing.

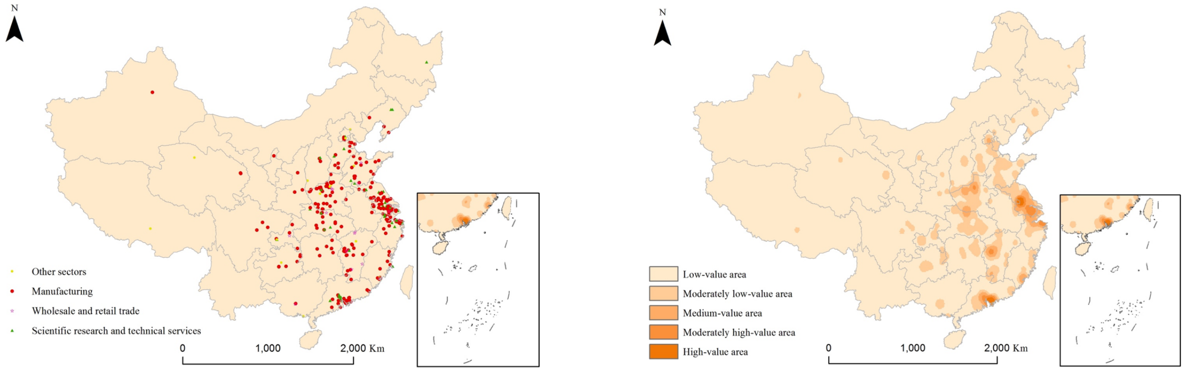
2.2 Methodology

2.2.1 Economic network construction of the lithium industry

Economic linkages between cities are identified based on parent–subsidiary linkages and their locations. For example, when lithium-related listed firms A, B, and C have subsidiaries D and E, subsidiary F, and subsidiaries I, G, and H, respectively, the network linkages are AD + AE + BF + CG + CH + CI. In this way, network linkages are established for the cities where the firms are registered, thereby forming a directed inter-city economic network [52, 53].

2.2.2 SNA

To assess the characteristics of the economic network of China’s lithium industry, the changes in network density (closeness of linkages), centrality (level and control of nodes in the network), and betweenness (transit hub function of nodes in the network) were analyzed by social networks analysis using Ucinet and Gephi software [54–57].



(a) (b)

Figure 1. Spatial distribution of lithium-related listed firms in China: (a) Sector composition; (b) Kernel density

2.2.3 GeoDetector

GeoDetector is a spatial analytic model for analyzing the relationship between a certain type of geographical attribute and its explanatory factors. It can be widely applied to assessing influential factors in various situations. The core advantage of this method is that it has only a few prerequisites, especially in research using various types of data [58, 59]. This study analyzed the factors influencing the weighted centrality of cities in the economic network of China's lithium industry using the factor detector of GeoDetector.

3 Characteristics of the Economic Network of China's Lithium Industry

3.1 Overall Network Characteristics

The overall characteristics of the network were assessed using SNA. As shown in Table 1, 342 cities can be considered as participating in the economic network of China's lithium industry, resulting in 2,030 inter-city linkages. This finding indicates that the network covers most cities in China. However, the network density is only 0.033, representing sparse linkages. The average clustering coefficient is 0.785, and the average path length is 2.121, representing a small-world effect, which suggests that the cities in the network tend to link with high-centrality cities.

3.2 Overall Structural Characteristics of Network Linkages

The economic network of China's lithium industry was analyzed using the line density tool. As shown in Figure 2, the urban network is characterized by a dual-core structure with the Pearl River Delta as the primary core linking to the Yangtze River Delta as the secondary core. Specifically, the trunk linkages are concentrated in slightly inland eastern coastal areas. High-level linkages are mainly found in Guangzhou, Shenzhen, Ganzhou, Xuancheng, and other cities on the trunk corridor. Medium-level linkages are concentrated in the central region, and inter-city linkages in the western and northeastern regions are mostly low-level. Most of the spatial economic inter-city linkages in the network are highly associated with urban economic development and technological innovation. Other linkages are mainly related to urban resource endowment or industrial foundation.

Table 1. Overall characteristics of the economic network of lithium industry in China

Network Overview	Nodes	Edges	Network Diameter	Network Density	Average Clustering Coefficient	Average Path Length
Characteristics	342	2030	4	0.033	0.785	2.121

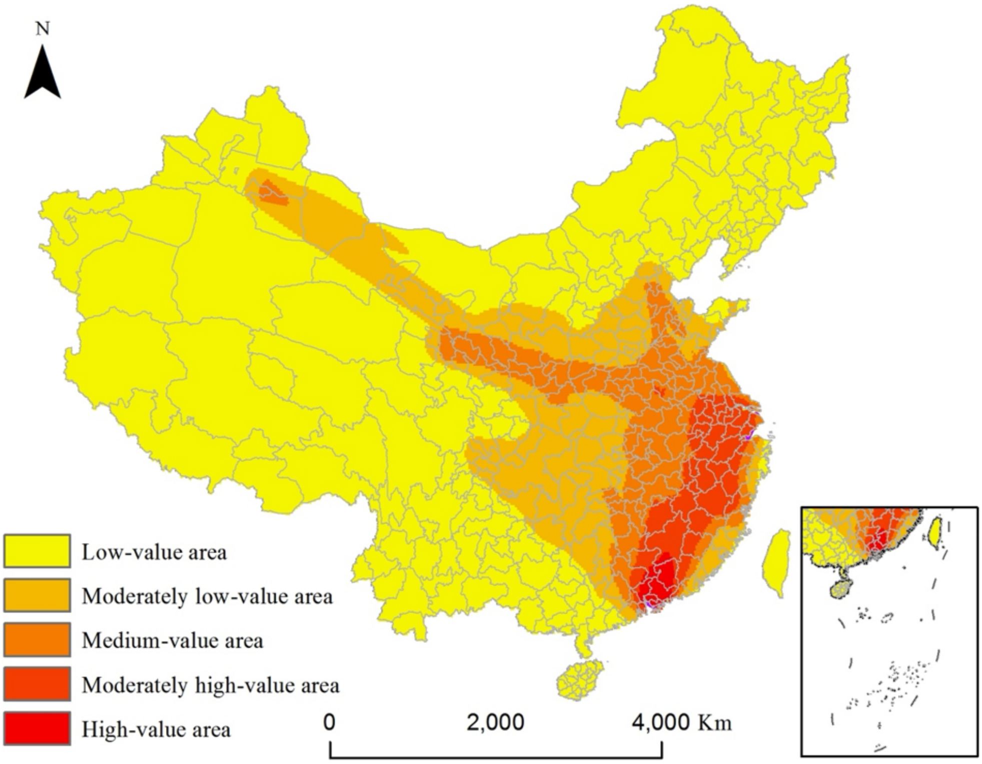


Figure 2. Line density of linkages in the economic network of China's lithium industry

3.3 Hierarchical Structural Characteristics of Network Linkages

The economic network of China's lithium industry was stratified into four levels by natural breaks using ArcGIS (Figure 3). The first-level linkages are core trunk lines with Shenzhen as the core radiating to Shanghai, Guangzhou, Beijing, Huizhou, and Suzhou. There are five first-level linkages in total, with Shenzhen as the leading city for this network level. This is closely related to its locational advantages as a special economic zone and its leading position in technological innovation.

Next, 32 second-level linkages were identified. These involve 29 cities, such as Changzhou, Chengdu, and Fuzhou, and more than half (19) have Shenzhen as the core. Five of them have Ningde as the core, accounting for approximately 16%. The second-level linkages are mainly located in the eastern and central cities. It is noteworthy that western cities, such as Urumqi and Xining, are node cities at this level of the network. The analysis also identified 137 third-level linkages in total, involving 89 cities. Of them, 45 and 25 have Shenzhen and Ningde as the core, respectively. At this level of network, inter-city linkages have been expanded to the central and western regions, and more western cities, such as Changji, Altay, and Hotan, have become important nodes. Finally, a total of 962 fourth-level linkages were found. The network linkages at this level are denser, and the network nodes cover most cities in China.

On the whole, the economic network of China's lithium industry has an obvious hierarchical structure with Shenzhen as the core and Ningde and Shanghai as major nodes, and with dense linkages in the east and sparse ones in the west.

3.4 Network Node Characteristics

Table 2 presents the node characteristics of the economic network of China's lithium industry calculated by Ucinet software. Cities such as Shenzhen, Ningde, Shanghai, Xining, and Urumqi rank in the top ten in terms of out-degree centrality. These cities, which are scattered across China, have significant resource factor output capabilities, occupy an important position in the network, and act as core areas for lithium industry development. In contrast, cities such as Qingyang, Danzhou, Zunyi, and Kaifeng rank in the bottom ten in terms of out-degree centrality and are located at the edge of the network.

Meanwhile, cities such as Shanghai, Beijing, Guangzhou, Tianjin, and Suzhou rank in the top ten in terms of indegree centrality. Most of these cities are municipalities directly under the central government or provincial capitals. Featuring strong industrial foundations, they are major areas of industrial development. In contrast, cities such as Sansha, Lijiang, Tiemenguan, and Nujiang rank in the bottom ten in terms of indegree centrality, with low industrial connection capabilities.

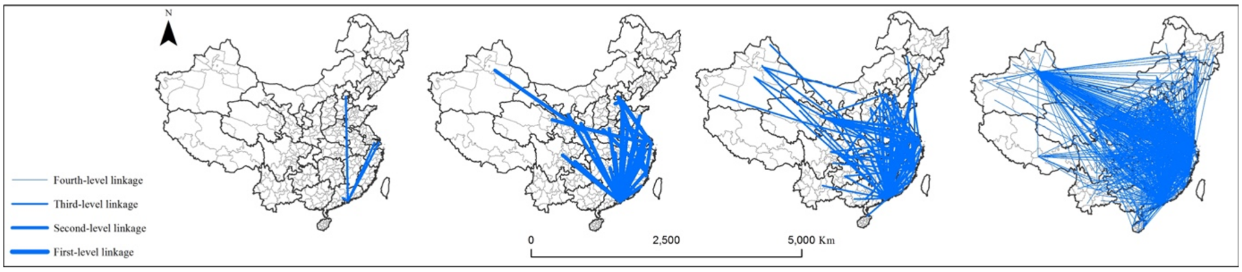


Figure 3. Different levels of linkages in the economic network of China's lithium industry

Table 2. Node characteristics of the economic network of China's lithium industry

Index	Top Ten	Bottom Ten
Outdegree centrality	Shenzhen, Ningde, Shanghai, Xining, Urumqi, Nantong, Baoding, Chongqing, Binzhou, and Jining	Qingyang, Danzhou, Zunvi, Kaifeng, Nanping, Tongliao, Tai'an, Guang'an, Luzhou, and Shangrao
Indegree centrality	Shanghai, Beijing, Guangzhou, Tianjin, Suzhou, Shenzhen, Xi′ an, Nanjing, Hangzhou, Wuxi, and Wuhan	Sansha Lijiang, Tiemenguan, Nujiang Hanzhong, Heihe, Siping, Tianshui, Tonghua, and Wanning
Betweenness centrality	Shenzhen, Ningde, Shanghai, Urumqi, Xining, Nantong, Chongqing, Suzhou, Binzhou, and Lhasa	Guilin, Hebi, Hegang, Lincang, Loudi, Lughe, Nanchong, Neijiang, Shanwei, and Siping

In total, 20 cities were identified as having higher out-degree than in-degree centrality. This means that these cities have resource factor radiating capabilities greater than their absorptive capabilities. Of them, the top ten are Shenzhen, Ningde, Xining, Urumqi, Shanghai, Baoding, Binzhou, Nantong, Chongqing, and Shiyan. The remaining cities had out-degree centrality less than or equal to their in-degree centrality. The resource factor radiating capabilities of these cities are less than their absorptive capabilities. Among them, Beijing, Guangzhou, Tianjin, Xi'an, Hangzhou, Nanjing, Wuxi, Changsha, Chengdu, and Qingdao are in the top ten. These features suggest that the network has low symmetry and significant imbalances.

In terms of betweenness centrality, cities such as Shenzhen, Ningde, Shanghai, Urumqi, and Xining are among the top ten. These cities have high control over the resource factors of the lithium industry and play the role of hubs and bridges in the network. Conversely, cities such as Guilin, Hebi, Hegang, and Lincang have low betweenness centrality and are highly dependent on other nodes in the network.

3.5 Core-Edge Structure of the Network

The core–edge structure of the economic network of China's lithium industry as calculated by Ucinet software is presented in Table 3. It can be seen that there are 29 core cities, most of which are economically developed coastal cities, and some are cities with excellent resource endowment or an established industrial foundation, such as Xining, Urumqi, Aba, and Ningde. The rest are edge cities. Ningde, for example, is the largest production site of polymer lithium-ion batteries worldwide and is home to Contemporary Amperex Technology Co., Limited (CATL), a leading Chinese lithium-ion battery firm. A strong industrial foundation makes it a core city in the economic network of China's lithium industry. As another example, Xining has established a relatively complete lithium industry chain based on leading firms, such as FinDreams Battery Co., Ltd. and Qinghai Taifeng Pulead Lithium-Energy Technology Co., Ltd., by taking advantage of the abundant lithium resources located in Qinghai Province.

In terms of network density, the closest inter-city linkages are observed in the core area, with a density of 3.798, whereas the density in the edge area is only 0.007, representing very sparse linkages. The linkage between the core and edge cities is 0.527. This may be because the weak foundation of the lithium industry in these cities makes it difficult for them to introduce lithium-related industries.

3.6 Clusters in the Network

The economic network of the lithium industry in China was divided into eight clusters using the cluster function of Gephi software. As shown in Figure 4, the network has a significant cluster structure, with very different numbers of cities in each cluster. More than 34% of the cities belong to Cluster 1, with Shenzhen as the core and Beijing, Chongqing, Suzhou, Baoding, and Guangzhou as secondary cores. Cluster 2 has Ningde, Xiamen, and Changzhou as the core and contains 21.93% of the cities. Cluster 3 has Urumqi as the core and comprises more than 14% of the cities. Cluster 4 has Shanghai as the core and Jining as the secondary core and contains 12.28% of the cities. Cluster 5 has Xining, Nantong, and Wuxi as the core and includes 11.11% of the cities. Clusters 6, 7, and 8 are composed of Jiaxing, Ganzhou, Lhasa, and other cities, accounting for 2.92%, 2.05%, and 1.17% of the cities, respectively. Cities in each cluster present significant spatial agglomeration around the regional core cities.

3.7 Structural Characteristics of the Network by Sector of Lithium-Related Listed Firms

Most lithium-related listed firms are in the manufacturing, scientific research and technical services, and wholesale and retail trade sectors. Due to the wide range of sectors that lithium-related listed firms are involved in, large differences in inter-city linkages exist across sectors. This section analyzes the structural characteristics of the economic network of China's lithium industry by sector of the lithium-related listed firms to understand the deeper mechanisms of the network.

As shown in Table 4, in the manufacturing sector, the network is characterized by long-distance radiation and presents a dual-core radial structure with Shenzhen and Ningde as the cores. In particular, Shenzhen→Shanghai has the highest linkage strength, followed by Ningde→Shanghai, Shenzhen→Beijing, Ningde→Fuzhou, and Shenzhen→Guangzhou. The linkages between lithium-related listed firms in the manufacturing sector are obviously dominated by cities with high economic status and strong industrial foundations.

Table 3. Core–edge structure of the nodes in the economic network of lithium industry in China

Core-Edge	City
Core	Aba, Anging, Anyang, Baotou, Baoding, Beijing, Binzhou, ($n = 29$) Changzhou, Chengdu, Dongguan, Foshan, Guangzhou, Hangzhou, Huizhou, Jining, Jiangmen, Nanjing, Nantong, Ningde, Xiamen, Shanghai, Shenzhen, Suzhou, Tianjin, Urumqi, Wuxi, Wuhan, Xining, and Chongqing
Edge	Chaozhou, Shantou, and Baoji, etc. ($n = 313$)

In the scientific research and technical services sector, Shanghai sits at the network's core, and Beijing, Changzhou, and Nanjing act as secondary cores. The top five linkages are Shanghai→Changzhou, Shanghai→Chengdu, Changzhou→Linyi, Beijing→Shanghai, and Nanjing→Beijing. Further analysis reveals that lithium-related listed firms in this sector mainly invest in manufacturing and technology promotion services in target cities. This suggests that these firms promote the development achievements of the lithium industry in other cities, thereby facilitating the development of downstream sectors.

In the wholesale and retail trade sector, the network has Shenzhen as the core. Lithium-related listed firms in this sector prefer small- and medium-sized cities with high market potential when choosing the location of subsidiaries. The top 20 strongest linkages are all from Shenzhen to other cities that display a substantial demand for the development of the lithium industry and high market potential.

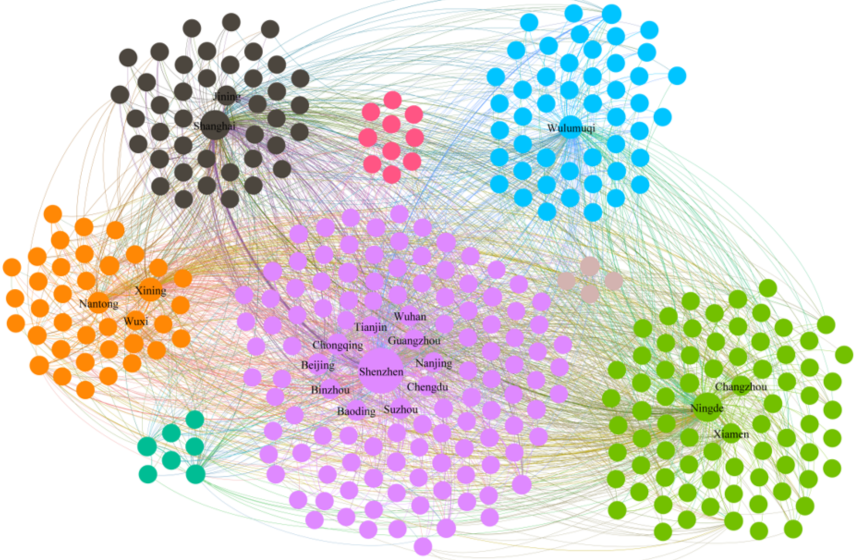


Figure 4. Clusters in the economic network of China's lithium industry

Table 4. Node characteristics of the economic network of China's lithium industry

	Manufacturing				**Scientific Research and Technical Services**				**Wholesale and Retail Trade**			
Rank	City degree	Weighted	Linkage strength	Linkage	City degree	Weighted	Linkage strength	Linkage	City degree	Weighted	Linkage strength	Linkage
1	Shenzhen	1859	Shenzhen→Shanghai	117	Shanghai	58	Shanghai→Changzhou	9	Shenzhen	162	Shenzhen→Changzhou	10
2	Ningde	1226	Ningde→Shanghai	64	Beijing	19	Shanghai→Chengdu	7	Changzhou	11	Shenzhen→Xiamen	9
3	Shanghai	1185	Shenzhen→Beijing	55	Changzhou	18	Changzhou→Linyi	5	Xiamen	9	Shenzhen→Jiangmen	8
4	Xining	644	Ningde→Fuzhou	54	Nanjing	17	Beijing→Shanghai	4	Jiangmen	8	Shenzhen→Jixi	6
5	Urumqi	589	Shenzhen→Guangzhou	54	Shenzhen	14	Nanjing→Beijing	4	Jixi	6	Shenzhen→Heze	5
6	Nantong	386	Shanghai→Beijing	50	Wuxi	12	Shanghai→Dongguan	4	Heze	5	Shenzhen→Qingdao	5
7	Chongqing	311	Shenzhen→Chengdu	47	Chengdu	9	Shanghai→Shenzhen	4	Qingdao	5	Shenzhen→Tianjin	5
8	Beijing	306	Xining→Wuxi	47	Taiyuan	8	Beijing→Guangzhou	3	Tianjin	5	Shenzhen→Chongqing	5
9	Baoding	273	Urumqi→Xi'an	44	Linyi	5	Shanghai→Binzhou	3	Chongqing	5	Shenzhen→Beijing	4
10	Suzhou	260	Shenzhen→Changsha	42	Yancheng	5	Shanghai→Jiujiang	3	Beijing	4	Shenzhen→Harbin	4
11	Binzhou	227	Ningde→Luoyang	38	Yunfu	5	Beijing→Wuhan	2	Harbin	4	Shenzhen→Ma'anshan	4
12	Jining	215	Shanghai→Tianjin	38	Guangzhou	4	Nanjing→Ezhou	2	Ma'anshan	4	Shenzhen→Yibin	4
13	Wuhan	200	Shenzhen→Wuhan	38	Hangzhou	4	Nanjing→Hangzhou	2	Yangzhou	4	Shenzhen→Dongguan	3
14	Guangzhou	194	Shenzhen→Nantong	37	Dongguan	4	Nanjing→Wuxi	2	Yibin	4	Shenzhen→Hegang	3
15	Xiamen	184	Jining→Shanghai	36	Jiujiang	4	Shanghai→ Haikou	2	Dongguan	3	Shenzhen→Jining	3
16	Tianjin	178	Shenzhen→Huizhou	36	Binzhou	3	Shanghai→Meishan	2	Hegang	3	Shenzhen→Shanghai	3
17	Changzhou	161	Shenzhen→Suzhou	36	Haikou	3	Shanghai→Ulanqab	2	Jining	3	Shenzhen→Shuangyashan	3
18	Jiaxing	160	Baoding→Tianjin	35	Shijiazhuang	3	Shanghai→Wuxi	2	Shanghai	3	Shenzhen→Tangshan	3
19	Chengdu	153	Shenzhen→Dongguan	35	Taizhou	3	Shanghai→Zhaoqing	2	Shuangyashan	3	Shenzhen→Wuhan	3
20	Jiangmen	152	Shenzhen→Xi'an	35	Wuhan	2	Shenzhen→Huizhou	2	Tangshan	3	Shenzhen→Yangzhou	3

4 Factors Influencing the Economic Network of China's Lithium Industry

4.1 Selection of Factors Influencing the Network

The economic network of China's lithium industry reflects the influence of various factors. According to previous studies [12, 13, 16, 60] and taking into account comprehensiveness and data availability, the weighted centrality of cities in the economic network of China's lithium industry is specified as the dependent variable, and independent variables include regional gross domestic product (GDP) to represent economic development, number of patents granted to represent local innovation, imports and exports of goods to represent local openness, local fiscal expenditure on science and technology to represent policy environment factors, and city administrative level to represent political resources. Correlation coefficients were computed using GeoDetector. With regard to city administrative level, a value of 5 is assigned to Beijing, 4 is assigned to Shanghai, Chongqing, and Tianjin, 3 is assigned to provincial capitals, 2 is assigned to cities specifically designated in the state plan, and 1 is assigned to general cities. Data on the influential factors were derived from the China City Statistical Yearbook 2023.

4.2 Interpretation of Results

Table 5 presents the results of the GeoDetector analysis, which revealed that the economic network of China's lithium industry is significantly influenced by economic development, local innovation, local openness, and policy environment factors. Specifically, local innovation and policy environment factors are core factors, with economic development and local openness functioning as secondary factors. However, political resources were found to exert no significant influence.

Policy environment factors and local innovation rank first and second, respectively, each explaining more than 40% of the variance. A high innovation capacity contributes to the high-quality development of the industry because industry development requires the support and guidance of science and technology. A favorable policy environment also facilitates the development of local industry [61–64].

Economic development and local openness rank third and fourth, respectively, with each explaining 30%-40% of the variance. High economic development acts as a significant driver in promoting the lithium industry's development; similarly, high openness facilitates the inflow of international capital and corporate financing [65, 66].

Political resources rank fifth among the influential factors, accounting for only 18.41% of the variance, which is a non-significant level. Cities at a higher administrative level have more political resources and consequently more policy advantages. However, the influence of this factor is found to be weak and insignificant, which to some extent implies that the development of the lithium industry is not sensitive to the city administrative level.

Table 5. Results of factors influencing the economic network of China's lithium industry

Influential Factor	Index	Q Value	Significance
Economic development	Regional GDP	0.3524	0.0291
Local innovation	Number of patents granted	0.4265	0.0140
Local openness	Imports and exports of goods	0.3292	0.0711
Policy environment factors	Local fiscal expenditure on science and technology	0.4317	0.0307
Political resources	City administrative level	0.1841	0.7042

5 Discussion and Conclusion

5.1 Main Findings

The present study investigates the spatial characteristics and influencing factors of the economic network of China's lithium industry based on data of lithium-related listed firms and their subsidiaries in China in 2024. The following conclusions are derived.

First, most lithium-related listed firms are in the manufacturing sector and are located in the Yangtze River Delta and Pearl River Delta and Hubei and Henan provinces. Shenzhen, Yangzhou, Ningbo, Suzhou, and Guangzhou are the cities home to the largest number of lithium-related listed firms. Second, the economic network of China's lithium industry is sparsely connected and exhibits a small-world effect. The urban network is characterized by a dual-core structure with the Pearl River Delta as the primary core linked to the Yangtze River Delta as the secondary core. It presents an apparent hierarchical distribution with Shenzhen as the core and Ningde and Shanghai as major nodes, and it exhibits dense linkages in the east and sparse ones in the west.

Third, most of the core cities in the network are economically developed coastal cities and cities with excellent resource endowment or an established industrial foundation. The network exhibits a significant cluster structure composed of eight clusters. The number of cities was found to vary greatly among clusters. In addition, each cluster exhibits significant spatial agglomeration around the regional core cities.

Fourth and lastly, economic development, local innovation, local openness, and policy environment factors were all found to significantly influence the economic network of China's lithium industry. The core factors were identified as local innovation and policy environment factors, with economic development and local openness as secondary factors. However, political resources showed no significant influence.

5.2 Theoretical Contribution

First, the present study investigates the spatial pattern of the economic network of China's lithium industry using SNA based on data of lithium-related listed firms and their subsidiaries. This offers a new perspective for investigating industrial development and expands the research on urban networks [29, 67]. Second, this study extends the understanding of industrial research and helps to clarify the current situation of China's lithium industry. In terms of methodology, GeoDetector was used to assess the factors influencing the economic network of the lithium industry, providing useful guidelines for formulating strategies to develop this industry [37, 43, 48].

5.3 Policy Implications

First, it is necessary for government decision-makers to regulate and guide innovation of the local lithium industry to enhance competitiveness when implementing top-level design to promote the industry. According to the conclusions of this study, it is recommended to promote the cooperation and connection between edge cities, such as Chaozhou, Shantou, and Baoji, and core cities, such as Beijing and Shanghai, by developing a platform for resource integration and information sharing within the lithium industry, thereby improving the spatial pattern of the lithium industry's economic network.

Second, local governments need to clearly understand the positions and roles of cities in the economic network of China's lithium industry. On this basis, efforts can be devoted to improving the local industrial development policies to reduce administrative barriers in the light of the network's cluster and core–edge structures so as to eliminate obstacles to the flow of innovative resources and promote the economic cooperation and connection of the lithium industry between cities.

Third and lastly, GeoDetector analysis results revealed that policy environment factors and local innovation have significant impacts on the economic network of China's lithium industry. Similarly, high economic development and local openness are also characteristics of key cities in the network. Therefore, local governments should pay attention to these factors to ensure a proper spatial layout of lithium-related firms, thereby promoting the high-quality development of local lithium-related firms.

5.4 Limitations and Directions for Further Research

First, it is not precise enough to select lithium-related firms by searching for the word "lithium" in the business scope. Therefore, the data collected may not exactly reflect the reality. Second, the present study only analyzed the factors influencing the economic network of the lithium industry based on attribute data. Only economic development, local innovation, local openness, and policy environment factors were assessed. A more in-depth analysis can be carried out that includes other factors, such as local policies and traffic location, based on relational data in the future. Finally, the present study investigated the economic network of the lithium industry from a cross-sectional perspective. However, the lithium industry is in a stage of dynamic development because of local industrial development, policy control, and other factors. Therefore, it is necessary to also investigate the network's spatiotemporal evolution from a long-term perspective.

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Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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