Research on Patent of Chinese Central Cities: From the Perspective of Cooperative Networks

Yang Peng and Zhang Runqiang

***Abstract*—In the context of a new round of scientific and technological revolution and industrial change, patent cooperation innovation between central cities has increasingly become an important path for central cities to obtain innovative resources and achieve innovative development. This paper takes 20 typical central cities in China as research objects, and studies its patent application, patent structure, patent input-output situation, and patent cooperation in central cities. The study found that the patent application, structure, and input-output situation of Chinese central cities showed typical regional imbalances, and that the regional imbalances were significantly linked to the imbalances of patent cooperation in central cities of China. This paper considers that the research on the patent innovation performance of Chinese central cities based on cooperation networks is more reasonable. It also provides important inspiration and reference for cross-regional cooperation among innovation subjects.**

***Index Terms*—Central cities, patent innovation, China, cooperation network.**

I. Introduction

The salient feature of the fourth industrial revolution is the extensive application of cyber physical systems in the manufacturing environment [1], whose basic background is the deep integration of intelligence and network systems [2]. It can be seen that the concept of "network" has become an important keyword for the Fourth Industrial Revolution. With the rapid development of economic globalization and regional integration, it has gradually formed a cooperation network with major countries or major cities and multinational companies in each country as the main body around the world. Besides, this cooperation network is more reflected in the area of R&D so that some scholars call it "Global R&D Network" or "Global Innovation Network" as well [3], [4]. The formation and development of the global innovation network is a response to the increasingly fierce competition in the global industrial development. The fierce competition in the global industry is more reflected in the competition among cities, such as the layout of industrial manufacturers, the joining of professional talents, and the creation of an innovative environment [5]. The core focus of competition among cities is the city's innovation ability; the city's patent is also a direct reflection of the city's innovation performance. In the context of a new round of technological revolution and industrial change, the patent innovation cooperation among central cities is becoming a significant engine driving an economy to achieve innovative development, improve quality and efficiency as well as transform and upgrade. As the world's largest developing country, China is in a critical period of transition from a high-growth stage to a high-quality development stage [6]. At present, at this critical period of transition in this stage of economic development, how do the innovation merits of China's central cities perform? What are the internal mechanisms and important characteristics of innovation cooperation in Chinese central cities? Answering the above questions has important guiding significance for improving the innovation performance of the central city industry, enhancing the core competitiveness of the central city industry, and promoting the high-quality development of the Chinese economy. In addition, it can also provide an important reference of patent innovation cooperation for central cities of other countries in the world.

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II. Data and Methodology

A. Data

The data in this article are mainly from the two databases of China Intellectual Property Network (CNIPR) and China National Intellectual Property Office Patent Search Platform (SIPO). Some of the data are from *China Statistical Yearbook of Science and Technology* and *China Statistical Yearbook*. In addition, data retrieval is also a more specialized retrieval technology. Thus, this study is mainly based on fields such as patent number, application number, patentee, inventor, classification number, invention name, date, etc.

B. Methodology

This paper mainly uses the social network analysis method to study the patent innovation cooperation network of Chinese central cities. Social network analysis (SNA) can scientifically analyze the correlation between subjects and their related attributes. As a highly applicable research method, it has attracted increasing attention. The social network analysis method was first proposed by Barnes (1954). The research of Freeman (1979), Scott (1988) and Wasserman (1993) further enriched the concepts and methods of social network analysis [7]-[10]. It has been widely used in related fields, such as inter-organizational relations (Noel, 1979), political and social fields (Knoke, 1990), and engineering project alliance (Stephen, 2004), etc. [11]-[13]. Social network analysis is based on the premise of the interconnectedness and interaction of determinable social relationships. It is considered that the world is composed of networks rather than groups. The main tools are Ucinet,

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Netdraw, AUREKA, etc., and Ucinet is the most commonly used and objective analysis tool for the analysis of the relationship between social networks. Therefore, this article mainly uses Ucinet software for social network analysis, and uses Netdraw for visualization analysis of patent innovation cooperation in central cities.

C. Study Sample Cities

The subjects of this study are Chinese central cities. The central cities are generally considered to be large cities and mega-cities that have a comprehensive function or multiple leading functions and play a pivotal role in a certain area and in the national economic and social activities. This paper systematically studies 4 municipalities, 15 sub-provincial cities and one key city which are especially focused on, namely Beijing, Shanghai, Chongqing, Tianjin, Harbin, Changchun, Shenyang, Dalian, Jinan, Qingdao, Nanjing, Hangzhou, Ningbo, Xiamen, Xi'an, Wuhan, Chengdu, Guangzhou, Shenzhen and Changsha. In 2018, the cumulative GDP of the above 20 urban areas reached 28.79 trillion yuan (RMB), accounting for 31.98% of Chinese GDP. Studying the above-mentioned central cities has important typicality and representativeness.

III. Result

This article studies the internal mechanism of the patent innovation cooperation network of Chinese central cities from the aspects of the status of patent applications in the center cities, the structure of patent applications in the center cities, the comparison of patent output and R&D investment, and the patent cooperation networks of Chinese center cities.

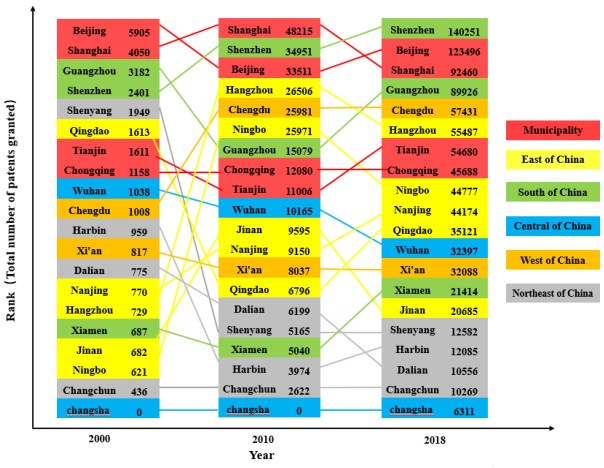
A. Research on the Status of Patent Application in Chinese Central Cities

First, the number of patent applications in Chinese central cities and their internal evolution are studied. According to Fig. 1, it can be seen that the number of patent applications and the internal evolution law of Chinese central cities show the characteristics of an increasing number of patent applications but a gradually steady trend of dynamic ranking changes. In terms of the number of patent applications, the number of patent applications in Chinese central cities have increased exponentially, indicating that the independent innovation capabilities of Chinese central cities have been significantly improved.

From the perspective of the evolution of the number of patents, from 2000 to 2010 is an important adjustment period for the patent ranking of each central city, and from 2010 to 2018 is a relatively stable period for the patent ranking of each central city. It shows that the innovation capabilities of Chinese central cities and urban function positioning have entered a stable period.

From the perspective of the region to which the central city belongs, the number of patents in eastern China and southern China has surged, making these two main areas of Chinese innovation clusters. Relatively speaking, the rank of patent application in northeastern China patent have gradually declined and gathered from the 16th to 19th in 2018. It indicates that the overall innovation capacity of the Northeast China has declined obviously, which is closely related to the industrial structure in the area.

From the perspective of specific central cities, the number of patent applications in Shenzhen has grown the fastest. By 2018, the number of patent applications in Shenzhen has far surpassed Beijing and has become the city with the largest number of patent applications, which also indicates that Shenzhen has become the core innovation city in China. In addition, the number of patent applications in Beijing and Shanghai still maintains the top three among the central cities, showing the three regional innovation poles of Beijing, Shanghai and Shenzhen in geographical space. The patent applications in Hangzhou, Ningbo, and Guangzhou in the eastern China and the southern China showed an increasing trend, and gradually evolved into new innovation centers after Beijing, Shanghai, and Shenzhen. However, it is regrettable that the number of patent applications in Harbin, Changchun, Dalian, Shenyang in Northeast China, and Qingdao and Xiamen in eastern China and southern China is relatively small, which have gradually evolved into marginal cities of innovation. The reasons for this are worth pondering.



Note: This chart is based on the patent applications (units) of Chinese central cities in 2000, 2010 and 2018. Different colors represent different regions in China. The data comes from the State Intellectual Property Office of China.
Fig. 1. Comparison of the number and ranking of patent applications in Chinese central cities.

B. Comparative Study of Patent Application Structure in Central Cities

According to *Patent Law of the People's Republic of China*, patent applications are divided into domestic grants for patents according to service and non-service. The domestic grants for patents according to service (DGPS) is a kind of invention and innovation completed by the support of the applicant's entity, and the patent achievements belong to the entity; while for the domestic grants for patents according to non-service (DGPNS), the patent achievements belong to the inventor or creator. Generally speaking, the quality of patent innovation for DGPS applications is higher, and patented inventions are more specialized and sustainable. However, DGPNS applications represent to a certain extent the innovation and creativity of society in the region.

According to the comparison of Fig. 2, Fig. 3 and Fig. 4, as seen that from 2000 to 2018, the patent application structure of central cities in China showed a gradual increase in the proportion of DGPS applications, but a gradual decrease in the proportion of DGPNS applications. In particular, as can

be seen from Fig. 4 that DGPS application curve and DGPNS applications curve of Chinese central cities in 2018 have been completely separated without any overlap, and the proportion of DGPNS applications in each central city has remained at about 10%.

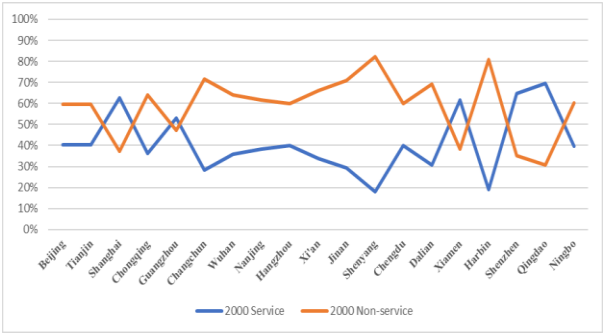


Fig. 2. The structure of patent job applications in Chinese central cities in 2000.

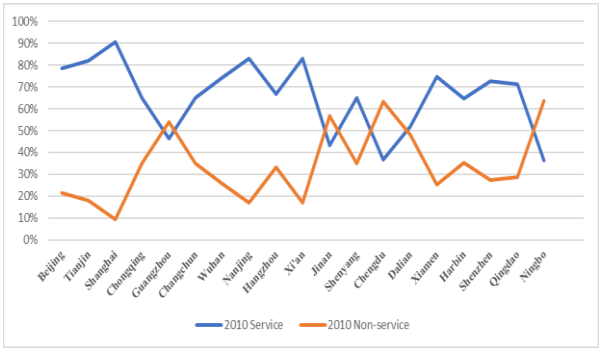


Fig. 3. The structure of patent job applications in Chinese central cities in 2010.

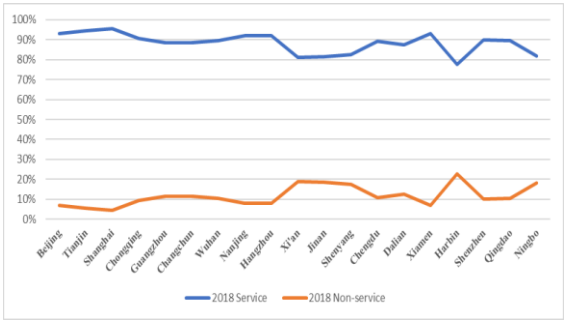


Fig. 4. The structure of patent job applications in Chinese central cities in 2018.

In addition, the higher innovation ability the region possesses, the higher the proportion of the DGPS is while the lower that of the DGPNS is, such as Beijing, Shanghai, Tianjin, Shenzhen and other cities. Instead, a city with lack of innovation ability has a relatively high proportion of the DGPNS, such as Xi'an, Jinan, Shenyang, Ningbo and other regions. It can also explain to some extent that the spillover effect of innovation activities is more significant in the cooperation and exchange of professional R&D organizations, and it also shows that the folk innovation power of Chinese central cities is relatively weak.

C. Comparative Analysis of Patent Output and R&D Investment

In general, R&D investment is highly correlated with patent output. This article selects the R&D input of the central city divided by the GDP as the comparative index of R&D input and the number of patent output in the central city divided by the total number of national patent output as the comparative index of patent output. The comparison of two sets of indexes is used to evaluate the actual situation of patent output and R&D investment in Chinese central cities (Fig. 5).

It can be seen that the R&D investment and patent output of the four municipalities in Beijing, Tianjin, Chongqing and Shanghai show a close positive correlation. The patent output index of Wuhan, Nanjing, Hangzhou, Xi'an, Jinan, Dalian, Xiamen and Changsha is obviously lower than the R&D input index. On the contrary, the patent output indexes of Guangzhou and Shenzhen are significantly larger than the R&D input indexes. It indicates that R&D investment can explain some patent output to some extent, and patent output is likely to include the impact of the degree of cooperation in central cities.

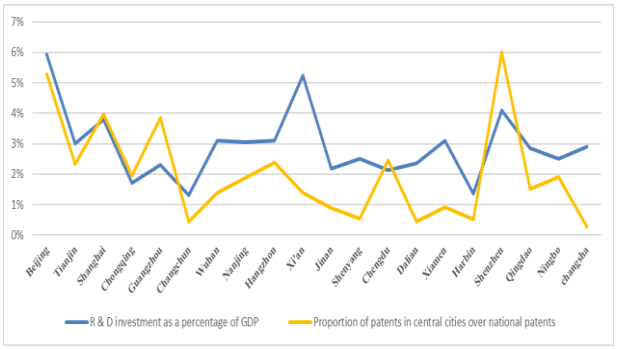


Fig. 5. Comparison of patent output and R&D investment in 2018.

D. Research on Patent Innovation Cooperation Network of Chinese Central Cities

According to the foregoing analysis, the number of patent applications, the structure of patent applications, and the input and output of patents in central cities of China are related to cooperation of patent innovation in central cities of China to certain extent. Therefore, this article will conduct a study on the cooperation of patent innovation in the central cities of China, so as to reveal the internal mechanism of patent innovation cooperation networks of the central cities in China.

First, the patent cooperation data of 20 central cities (Changsha data can be found) were collected from the website of the State Intellectual Property Office of China. Then the data was organized into a matrix table of patent cooperation for 20 central cities, and the matrix table was imported into Ucinet 6.1 for analysis, and a visual analysis tool Netdraw was used to construct a map of patent cooperation networks for 20 central cities in China (Figure 6).

It should be noted that there are 20 nodes in the network graph. The size of the node shape is determined by the degree of each node in the network, which represents the number of connections between each city and other cities, and the thickness of the connection represents the strength of cooperation between cities. In addition, in order to study the position of each central city in the cooperative network, this paper uses Ucinet6.1 to analyze the centrality of network nodes. In the analysis process, the binarization of threshold 10 is carried out, and the degree, betweenness centrality, and power index of each node are calculated respectively (Table 1).

TABLE I: CENTRALITY ANALYSIS OF PATENT NETWORK COOPERATION IN CHINESE CENTRAL CITIES

Citys Rank	Degree	Citys Rank	Betweenness Centrality	Citys Rank	Power
Shanghai	19.000	Shanghai	60.825	Beijing	18.000
Beijing	18.000	Beijing	53.256	Shanghai	18.000
Shenzhen	16.000	Shenzhen	26.404	Shenzhen	16.000
Nanjing	9.000	Nanjing	11.331	Nanjing	14.000
Tianjin	14.000	Tianjin	8.455	Tianjin	12.000
Chengdu	13.000	Guangzhou	7.587	Guangzhou	12.000
Xi'an	13.000	Qingdao	6.011	Xi'an	12.000
Guangzhou	12.000	Xi'an	4.988	Wuhan	11.000
Qingdao	12.000	Hangzhou	3.783	Chongqing	9.000
Chongqing	11.000	Ningbo	3.700	Hangzhou	9.000
Wuhan	11.000	Chongqing	3.050	Qingdao	9.000
Hangzhou	9.000	Chengdu	3.004	Shenyang	8.000
Shenyang	9.000	Wuhan	1.604	Dalian	8.000
Xiamen	8.000	Shenyang	0.933	Chengdu	8.000
Ningbo	8.000	Dalian	0.667	Ningbo	7.000
Dalian	8.000	Jinan	0.167	Changchun	4.000
Harbin	6.000	Xiamen	0.125	Xiamen	4.000
Jinan	4.000	Harbin	0.111	Harbin	3.000
Changchun	4.000	Changchun	0.000	Jinan	3.000
Changsha	4.000	Changsha	0.000	Changsha	1.000
Mean	10.700	Mean	9.800	Mean	——

Data source: Calculated by Ucinet 6.1 and ranked in descending order according to the corresponding indicator values.

According to the research on social cooperation networks, innovation subjects in a good position on social networks are conducive to improve the innovation performance [14]. Moreover, the centrality analysis of network nodes is an important and effective measure for network location [15], [16]. Generally speaking, degree centrality of a node is a measure of the number of connections established between a node and other nodes. The more connections established, the higher degree centrality. The betweenness centrality of nodes are measures to what extent a point is located in the "middle" of other points in the network. The higher the betweenness centrality of a node, the more the node is in the center of the network. The power index more directly indicates that the relationship between numerical value and position, and higher index shows better network location.[17].

It can be seen from Table I that the central cities such as Beijing, Shanghai, Shenzhen, Nanjing, Tianjin, and Guangzhou have relatively good positions in the patent innovation cooperation network and are in relatively core network positions. Relatively speaking, Harbin, Dalian, Jinan Changchun, Changsha, Xiamen and other central cities have a poor network position in patent innovation cooperation, and are in a more marginal network position. Since the network location is directly related to innovation performance, this can explain the imbalance of patent output and R&D investment to a certain extent. It is precise that because the central cities have different positions in the patent innovation cooperation network, their performance output is also different.

In addition, it can be seen from Fig. 6 that the patent innovation cooperation network among the 20 central cities in China presents a star topology. The cooperation between Shenzhen, Beijing and Shanghai is the strongest, showing a typical triangle of patent cooperation. Among the 35,916 cooperative patents whose sources can be traced, Shanghai has contributed 8,118, and the incidence of cooperation is as high as 22.60%. The incidence of cooperation between Beijing and Shenzhen is 19.36% and 15.90%, respectively. The cumulative number of patent cooperation in the above three cities reached 57.86%. In other words, nearly 60% of the patent cooperation in Chinese central cities are directly related to these three cities, followed by Nanjing (5.46%), Tianjin (4.67%), Guangzhou (4.49%), and there is a big gap between the aforementioned three cities. This fully shows that Shanghai, Beijing and Shenzhen have become three major cities in China's regional innovation cooperation.

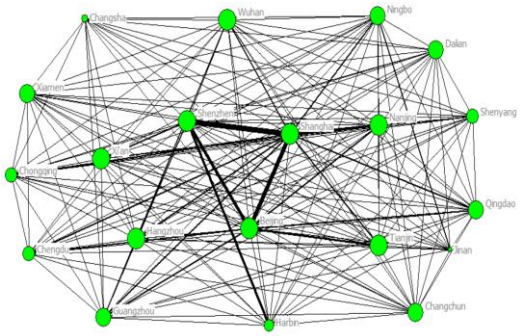


Fig. 6. Network diagram of patent innovation cooperation in Chinese central cities.

At the same time, it can also be seen from Figure 6 that Shanghai, Beijing and Shenzhen have the thickest connections, indicating that their patent cooperation is the closest. In addition, it can be seen from the figure that Shanghai and Nanjing, Beijing and Tianjin have higher cooperation intensity, but Shenzhen and Harbin, Xi'an and Shanghai also have higher cooperation intensity. It shows that geographical distance is no longer an important factor affecting patent innovation cooperation in Chinese central cities, but the city's important innovation subjects (universities and scientific research institutions) are the core influencing factors of innovation cooperation in central cities. For example, the relatively high cooperation between Xi'an and Shanghai is partly due to the close communication between the two innovation centers with Xi'an Jiaotong University and Shanghai Jiaotong University as the core nodes. Similarly, the cooperation between Harbin and Shenzhen is relatively high, partly because Harbin Institute of Technology has set up a branch in Shenzhen, which is a good bridge for innovation and cooperation between these two cities.

IV. CONCLUSION AND SUGGESTION

Through the above analysis, the following conclusions can be drawn. First, the patent output of Chinese central cities show obvious regional imbalances. Specifically, central cities such as Beijing, Shanghai, Shenzhen, and Guangzhou have become important core cities for China's patent output. And central cities such as Harbin, Changchun, Shenyang, and Dalian have gradually become marginal cities in China's

patent output. Second, the patent output structure of Chinese central cities are characterized by professionalism and institutionalization. The proportion of domestic grants for patents according to service in each central city is increasing, to a certain extent, indicating that the strength of private innovation is relatively weak. Third, R&D investment and patent output show typical non-matching characteristics. High R&D investment does not necessarily bring high patent output. Innovation cooperation between cities plays an important role in patent output. Fourth, through social network analysis, it was found that the patent cooperation network of Chinese central cities has initially shown a triangular cooperation domain with three major nodes: "Beijing-Shanghai-Shenzhen". In addition, Beijing, Shanghai, and Shenzhen, as the core cities of the patent cooperation network, have a radiating role in the innovation and development of other central cities. To this end, this article makes the following recommendations.

The first is to accelerate the pace of collaborative innovation and give full play to the comparative advantages of collaborative innovation in various central cities. At present, the collaborative innovation mechanism of Chinese central cities has not yet taken shape. It is necessary to further cultivate and enhance the awareness of patent innovation among enterprises, give full play to the role of enterprises as the mainstay of innovation, and enhance the ability of collaborative innovation.

The second is to guide and cultivate the ability of folk innovation. In the new round of technological revolution and industrial transformation, the capacity of folk innovation is crucial to the development of society and economy. This requires encouraging and stimulating the creative capacity of the subject of folk innovation.

Third, according to the leading innovation advantages of central cities, the industrial innovation policies should be based on local conditions. Due to the heterogeneity of regional innovation resources and the gap in industrial base development, different industrial innovation policies should be adopted for different central cities, so as to achieve the coordinated development of R&D investment and patent output.

The fourth is to cultivate a platform for cooperation in the central city. In particularly, innovation centers are represented by universities and research institutions. The introduction of colleges and universities or scientific research institution branches in major central cities can often efficiently establish a platform for innovation and cooperation in the central cities, thereby providing an important carrier for the interaction of innovation resources in the central cities.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Yang Peng put forward research content and carried out research design, Zhang Runqiang conducted data analysis and paper writing; all authors had approved the final version.

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