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Evolution Characteristics of Government-Industry-University-Research Cooperative Innovation Network for China's Agriculture and Influencing Factors: Illustrated According to Agricultural Patent Case

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Abstract: Under the special background of China, the cooperative innovation between different government-industry-university-research institutes plays an increasingly important role in the agricultural field. However, the existing literature has paid little attention to it. Considering the cooperation patents, published in the agriculture field stemming from the Full-text Database of China Patents as the study object, the spatial and institutional attribute of the authors as the data source, and by combining the social network and spatial econometrics analysis, this paper analyzes the structure evolution characteristics of cooperative innovation networks of agricultural government-industry-university-research institute in the city level of China in 1985–2014, based on the triple helix theory, with the influence factors discussed. This shows that, 1) since 1985, China's agricultural innovation level has been substantially increased, but the development degree of the cooperative innovation network is low, and the patent cooperation mainly relies on authors in the same unit; 2) enterprises play a leading role in the agricultural cooperative innovation. The effect of the government and hybrid organizations driven by the government is not obvious; 3) the cooperative innovation in the province and city dominates, and a multi-pole pattern has been formed. The cooperative innovation network structure evolves from a single helix empty core and double helix multi core to a double helix hierarchical network; 4) the city's science, education funding and personnel investment are key factors determining the agricultural cooperative innovation, while the agricultural development of the city presents slight negative impacts on it. The spatial mismatch of supply and demand is present in the technical cooperative innovation of China's agriculture. Therefore, the science enhancement and education investment to big agricultural provinces should be promptly implemented.

Keywords: cooperation innovation networks; government-industry-university-research institute; China's agricultural patent; Social Network Analysis (SNA)

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1 Introduction

In recent years, the role of network cooperation in innovation has become an important subject of innovation research (Boschma and Frenken, 2010). As an important model of technological innovation, cooperative innova-

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tion is drawing more and more attention from scholars, industrialists and governments (Baige-Gil, 2010). In the knowledge & innovation-driven agricultural economy, the positive interaction among agricultural knowledge production, application organizations and promotion sectors is increasingly crucial to agricultural innovation and involves the participation of governments, industries, universities and research institutions. The government-industry-university-research cooperative innovation is an innovative behavior of complementing each other's advantages made by governments, enterprises, universities and research institutions through mutual collaboration by virtue of their own resources, aiming to make up for their knowledge inadequacy and improve their innovation ability. During cooperative innovation, all parties involved spontaneously for man informal cooperative network and work together through the collaborative innovation of each sector. Agriculture is characterized by long industrial chain, detailed division of sectors, more specialized knowledge and stronger demand for cooperative innovation. In particular, compared with the 'big agriculture' in North America, China's agriculture develops in the special context of small-scale peasant economy and household contract farmers as the business entity. In 2007, the *Construction Plan of National Agricultural Science & Technology Innovation System* dominated by public sectors was issued. All of these factors result in excessive knowledge gap among innovation subjects during knowledge innovation and further lead to serious disjunction of industry, university and research. Therefore, it is necessary to establish an agricultural technology innovation system under the framework of government-industry-university-research cooperative network through government involvement and intervention. After that, the Chinese government has carried out a series of institutional and mechanism reforms. For example, Document No.1 of the Central Government issued in 2010 stressed the necessity to improve the capability of innovating and promoting agricultural science and technology and develop industry-university-research alliance of agriculture. How well does it work? Has the government-industry-university-research cooperative innovation network been established for China's agriculture? How do its network structure and cooperation degree evolve? What are the key influencing factors of network formation and evolution? Solutions to these problems are important to further accelerating the construction of cooperative innovation network among China's agricultural organizations, improving agricultural innovation efficiency and promoting industry-university-research combination.

Recently, scholars have carried out research on cooperative innovation from different perspectives, including the connotation & characteristics of cooperative innovation (Luo and Tang, 2000), network structure and evolution (Walters et al., 2007; Wang et al., 2016), capabilities and governance (Bosch-Sijtsema and Postma, 2009), mode (Chen, 2009) and construction (Wu and Chen, 2007), *etc*. Of them, the Triple Helix Theory is most influential and is the extension of innovation theory (Etzkowitz, 2008; Broström, 2011; Farinha et al., 2016). The theory emphasizes the interaction and close cooperation among academia (including universities and scientific research institutions), industries and governments during innovation. Each party shows some capabilities of the other two, yet still retains its original functions and unique identities. A new organizational form that promotes innovation-hybrid organizations can also be established through the integration of three helix elements, such as incubator, technology transfer office, technology popularization station, technical service center, university science park, science park, *etc*. (Etzkowitz, 2008). The Triple Helix Theory provides a theoretical analytical framework for the function positioning, collaborative relationship and operational mechanism of governments, universities (scientific research institutions) and industries during innovation research. Many scholars have conducted empirical research on innovation system under this framework. For example, Park et al. (2005) compared the knowledge-based innovation systems in the economies of South Korea and the Netherlands using Triple Helix indicators.

Chinese scholars have also conducted empirical research using the Triple Helix model. For example, Zhuang and Wu (2013) measured the closeness of cooperation among Chinese universities, enterprises and governments in industry-university-research collaborative innovation based on the patent application data for inventions in 2002–2011 from SIPO patent retrieval database. They concluded that a relatively stable government-industry-university-research collaborative innovation system had initially taken shaped in China, but it was dominated by enterprise-university cooperation and involved little government participation. Tu et al. (2005) explored a new pattern of technology transfer and interpreted the mechanism of 'Courtyards for Agro-experts' with the case of Baoji City, China, concluding that the Triple Helix in the agro-sector improves technology transfer and accelerates knowledge-based regional development. Ren and Lu (2003) presented the compound Triple Helix innovation system model. However, these scholars excluded governments from independent innovation subjects. All of these researches provide a useful reference for researches on the space structure of cooperative innovation network in agriculture.

However, current researches on innovation collaboration network between sectors focus mainly on manufacturing industry (Broekel and Boschma, 2012; Wang et al., 2016; Lu et al., 2014) and high-tech industry (Liefner and Hennemann, 2011; Li et al., 2011; 2015; Hong et al., 2014) instead of agriculture. The only relevant researches mainly explore the regional construction and structure evolution of cooperative innovation network among different sectors from such micro perspectives as knowledge unit, enterprise or cluster, *etc*. of a specific industry, but focus little on the spatial structure of cooperative innovation network of Chinese organizations at a macro level (Lu and Huang, 2012). Most researches focus on the industry-university-research cooperative innovation, but few involve hybrid organizations that are established or supported by governments, let along the researches at the urban level of China.

The agricultural scientific and technological achievements occur in different forms including new plant varieties, agricultural products, patents, projects, paper, *etc*., of which, the agricultural patents reflect the most advanced, creative and useful technology in agricultural science and technology (Sorenson et al., 2006). The agricultural patents can be applied for by individuals, enterprises, scientific research institutions, universities either separately or jointly. A joint application reflects the cooperative innovation of several organizations in agricultural technology and forms an knowledge-flow based innovation network. This paper, therefore, analyzes the structure and evolution characteristics of government-industry-research cooperative innovation network for agriculture in 1985–2014 at China's urban level and discusses its influencing factors with the help of Ucinet, Arcgis, Coreldraw and Photoshop software, In detail, it selects the cooperative agricultural patents published in CNPAT as research subjects, uses the spatial attribute and institution attribute of patent authors as data sources, and combines social network analysis with spatial analysis.

2 Data Source and Research Method

2.1 Data source and processing

The knowledge of agricultural science and technology covers a wide range of fields, including breeding, herding, planting, fishing, agricultural implements, vegetables & fruits, *etc*. This paper selects 7 time nodes from the agricultural patents in 1985–2014 that have been published and collected in CNKI: Patent Full-text Database (1985, 1990, 1995, 2000, 2005, 2010, 2014) and adopts the patents published by different units cooperatively as research subjects. The specific agricultural science and technology covers the cooperative patents in10 subfields, including agricultural basic science, agricultural engineering, plant protection, gardening, *etc*., without regard to the patents jointly applied for by organizations in China (not including Hong Kong, Macao and Taiwan) together with those in Hong Kong, Macao and Taiwan as well as foreign organizations. The information of two or more organizations is extracted. Different from scientific research institutions, Chinese universities give priority to talent training and teaching. Therefore, contrary to the industry-university-research metrological research in which scientific research institutions are included in universities (Zhuang and Wu, 2013), this paper divides cooperative agencies into four categories: university, research institute, enterprise and governmental agencies by the institutional attributes of applicants. For example, the applicants whose unit information includes local academies of sciences, design institutes, research centers, research institutes, research institutions, *etc*. are classified as scientific research institutes, those whose unit information includes some colleges or universities are classified as universities, those whose unit information includes some companies, plants, cooperatives, *etc*. are classified as enterprises, and whose unit information includes local sectors, departments or bureaus are classified as governments. For application for patents in China, government-driven hybrid organizations (like technology popularization stations, technical evaluation stations, epidemic prevention stations, protection stations, rural technical service centers, county-level technical service stations, *etc.*) instead of governments are often listed as authors in most cases. To emphasize the leading role of governments in hybrid organizations and for the convenience of narration, hybrid organizations are classified as governmental agencies. To analyze the temporal-spatial evolution characteristics of each patent and process the cooperation information of organizations obtained, the data of each cooperative patent is used to make relation matrixes, including cooperation matrix of same cities and cooperation matrix of different cities, and point out the spatial locations on Chinese map based on the applicants' cities (prefecture-level city), *etc*. After that, Ucinet, ArcGIS, Photoshop and other software are used to design the topological structure diagram and spatial distribution map of China's agricultural sci-tech knowledge network at the urban level and analyze its network structural relationship, spatial evolution characteristics and influencing factors. It is important to note that this paper takes the agricultural patent as data source and has some statistical limitations: 1) due to patent application costs, more medium and large enterprises, colleges & universities and researches have applied for the patents. Therefore, it fails to reflect the innovative activities of small and individual enterprises; 2) the agricultural innovative activities that are hard to be turned into patents are beyond description. However, it can reflect the evolution of government-industry-university-research cooperative innovation network of China's agriculture to some extent.

2.2 Social network analysis

The government-industry-university-research cooperative innovation network serves as a knowledge network and organizational network, as well as a social and dynamic network. As a network analysis tool, social network analysis (SNA) (Wasserman and Faust, 1994) helps clearly observe the interaction between the subjects of social network and the structural characteristics of its cooperative network. SNA covers a global network structure at macro level and an ego network at micro level. The global network is described mainly by network size, total number of relations, network density and network centralization, while the ego network is analyzed mainly by individual centrality (degree centrality) and betweeness. The degree centrality refers to the number of relations gathered on a specific action-taker. In general, a specific action-taker who gathers more relations will have higher centrality and play a more important role in the network. The betweenness is used to measure the potential ability of a behavior (as a broker or gatekeeper) to control other behaviors, as well as the power of a subject (Wasserman and Faust, 1994). The average path length refers to the average shortest path length of network nodes. The Ucinet developed by Borgatti, Everett and Freeman provides a useful tool to analyze the characteristics of network structure indicators (Borgatti et al., 2002). However, the social network analysis is only a static analysis method, and a more thorough analysis requires an insight into the implication of social relations behind the phenomenon (Li et al., 2011). This method is relatively weak in problem analysis and dynamic analysis. In view of the drawbacks above, this paper dynamically analyzes the structure and evolution characteristics of government-industry-university-research cooperative innovation network of China's agriculture at an urban level with the help of Arcgis, Coreldraw and Photoshop. In detail, it collects reference data from the agricultural cooperative patents in 1985–2014, uses the relation data in time series, and combines SNA with spatial econometric analysis.

3 Structure and Evolution Analysis of Cooperative Innovation Network of Agricultural Patents

The evolution characteristics of China's agricultural cooperative innovation network and its organizational and spatial structure can be revealed by analyzing the agricultural patents of CNKI: Patent Full-text Database in 1985–2014.

3.1 Overall evolution of China's agricultural patents

(1) Over the past 30 years, China has made great improvement in the innovation of agricultural science and technology and the technology content in patents. The number of patents in agricultural science and technology granted in 2000–2014 (244 559) was 11 times more than that in 1985–1999 (21 263). Since the 21st century, a rapidly increasing number of agricultural sci-tech patents are published in China, growing by more than 15 times from 2000 to 2014. It can be seen from Fig. 1 that

the patents for inventions and utility model patents with high technology content are dominant. The number of patents for inventions accounts for 52.6% of the total, followed by utility model patents (43.2%) and design patents (4.2%), indicating that the technology content in agricultural sci-tech patents is increasing year by year

(2) The cooperative innovation network is less developed and, patent cooperation is dominated by cooperativepublishing by the same units. As shown in Fig. 1 and Table 1, although the cooperation frequency among different organizations is increasing year by year, the cooperation rate (only 2.13% in 2014) and the network development degree remain low compared with the total number of patents. In 2000–2012, the number of patents published by independent authors accounted for 23% of the total, followed by patents jointly published by authors of the same unit (73%) and patents jointly published by authors from different units (4%, 1127). The patents jointly published by Chinese and foreign authors are very limited. It can be drawn from above data that there is little communication about China's agricultural sci-tech knowledge from the perspective of space and patent cooperation is dominated by cooperation of the same unit, but the cooperation among different units is being strengthened.

3.2 Evolution of patent cooperative organization network

(1) The single helix network structure is evolving into double helix network structure, and the triple helix period is yet to come. It can be seen from Fig. 1 and Table 1 that the macro-evolution of China's agricultural patents can be divided into three phases: slow-growth single helix period (1985–2000), relatively fast growing double helix period (2000–2010) and fast growing double helix period (2010–2015). In the first phase, the number of patents was increasing slowly, and the total number of patent cooperation was also increasing in volatility (never equal to or over 50 times). That is to say, agricultural innovation is published basically by

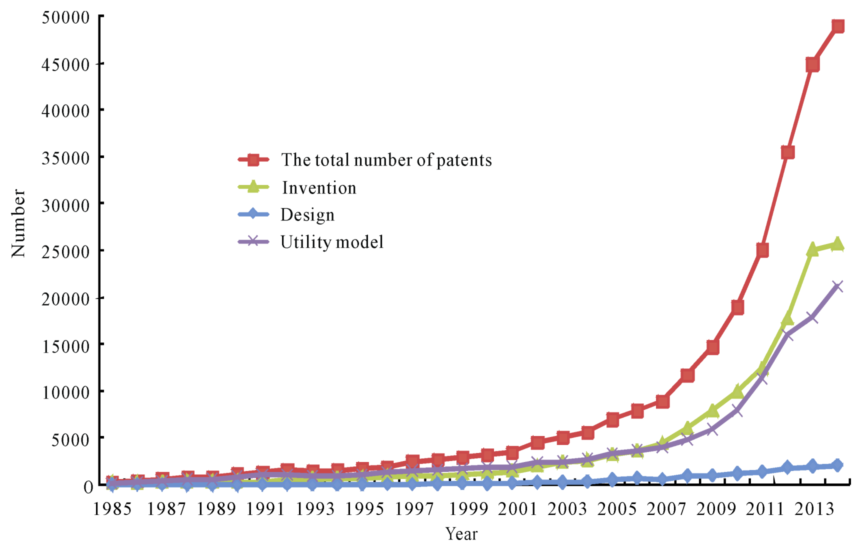


Fig. 1 Agricultural patents granted in China, 1985–2014

Table 1 Number of cooperation patents in agricultural technology among different units

Year	U-U	P-P	F-F	G-G	U-P	U-F	U-G	P-F	P-G	F-G	U-P-F	U-P-G	U-F-G	Total
1985	1	0	0	0	1	1	0	0	0	1	0	0	0	4
1990	0	3	3	0	1	1	1	13	0	2	0	0	0	24
1995	0	2	0	2	1	1	1	6	0	1	0	0	0	14
2000	2	7	5	1	4	4	1	8	1	5	3	1	0	42
2005	0	10	5	3	20	18	2	19	0	1	3	0	0	81
2010	16	39	73	3	33	115	3	161	5	9	5	4	1	467
2014	10	15	360	16	48	221	5	314	22	2	19	5	1	1038

Notes: U represents University; P represents Public Research Institute, F represents Firm; G represents the Government and Total represents total cooperation individuals (by individual or cooperation with authors of the same unit); in the second phase, the total number of patents and number of patent cooperation between two units were increasing steadily, but there is little cooperation with third parties; in the third phase, the total number of patents, number of patent cooperation between two units and among three units were increasing significantly. The reason is, the right of private enterprises to apply for patents was limited before 2000. On August 25, 2000, the Standing Committee of the 9^{th} National People's Congress approved the *Decision on Amending the Patent Law of the People's Republic of China* at its 17th meeting, which gives non-state-owned enterprises the same right to apply for patents as state-owned enterprises, national research institutions, *etc*. and accelerates the application for patents by individuals and private enterprises. During the Eleventh Five-Year Plan period, the National Development and Reform Commission introduced a series of policies to promote agricultural science and technology development, including *The Outline of the National Intellectual Property Strategy*, *Agricultural Science and Technology Development Plan (2006–2010)*, *Key Project 'Science and Technology Project for Food Production' in the National Science & Technology Pillar Program During the Eleventh Five-Year Plan Period*, *etc*., which have driven and promoted the development of agricultural sci-tech patents.

(2) Different types of organizations participate much more actively in innovative cooperation, and cooperative innovation among enterprises is dominant. The total number of cooperative patents by organizations rose from 4 in 1985 to 1038 in 2014 (Table 1), of which, the cooperation among enterprises increased most rapidly (360 times), followed by cooperation between enterprises and public research institutes, and cooperation with hybrid organizations (51 times). Over the past 30 years, China's agricultural cooperative innovation was dominated by cooperation among enterprises. In 2012, 720 organizations were involved in agricultural cooperative patents, of which, the number of enterprises, public research institutes, universities and governmental agencies accounted for 60.83%, 20.97%, 14.44% and 11% of the total respectively. That is to say, the new technology research and development, and S&T achievements transformation and application of China's agriculture were disjointed. This may be attributed to the long-term teaching-oriented policy of Chinese universities. In addition, enterprises laid more emphasis on the application of agricultural technology, but colleges & universities and public research institutes gave priority to theoretical research and have weak consciousness of achievements industrialization, thus resulting inlong-time disjunction of China's industry-university-research.

(3) The function of governments and government-driven hybrid organizations is insignificant. Over the past 30 years, the industry-university-research cooperation has been gradually strengthened, but governments still played an insignificant role. In 2014, governments and hybrid organizations participated in industry-university-research cooperation 35 times, which only accounted for 3.4% of the total. This indicated that the industry-university-research cooperative innovation remained at a low level, and it was extremely urgent to establish a third party - hybrid organization to promote industry-university-research cooperation. In the 18th National Congress of the Communist Party of China held at the end of 2012, 'Speeding up the transformation of technological achievements and establishing the market-orientated industry-university-research innovation system dominated by enterprises' was clearly proposed as a policy in response to these questions.

(4) Subjects that participate in agricultural patent cooperation in different periods are different, and universities have begun to play their roles. Before 2000, the agricultural patent cooperation was dominated by internal cooperative of enterprises, public research institutes or colleges & universities, and cooperative innovation was seldom jointly made by different subjects. After 2000, the innovation cooperation among different subjects was increasing gradually, and the agricultural patent cooperation began to be dominated by enterprises. The cooperation between enterprises and public research institutes, as well as cooperation between enterprises and colleges & universities accounted for more than 50% of the cooperation among different subjects. In 2014, enterprises were involved in agricultural patent collaboration 917 times, which accounted for more than 88% of the total (Fig. 2). For participation of different organizations in patent cooperation, China's innovative cooperation was dominated by enterprises, and a growing decrease in the participation of public research institutes in patent collaboration was shown. It meant that independent innovation and cooperative innovation of

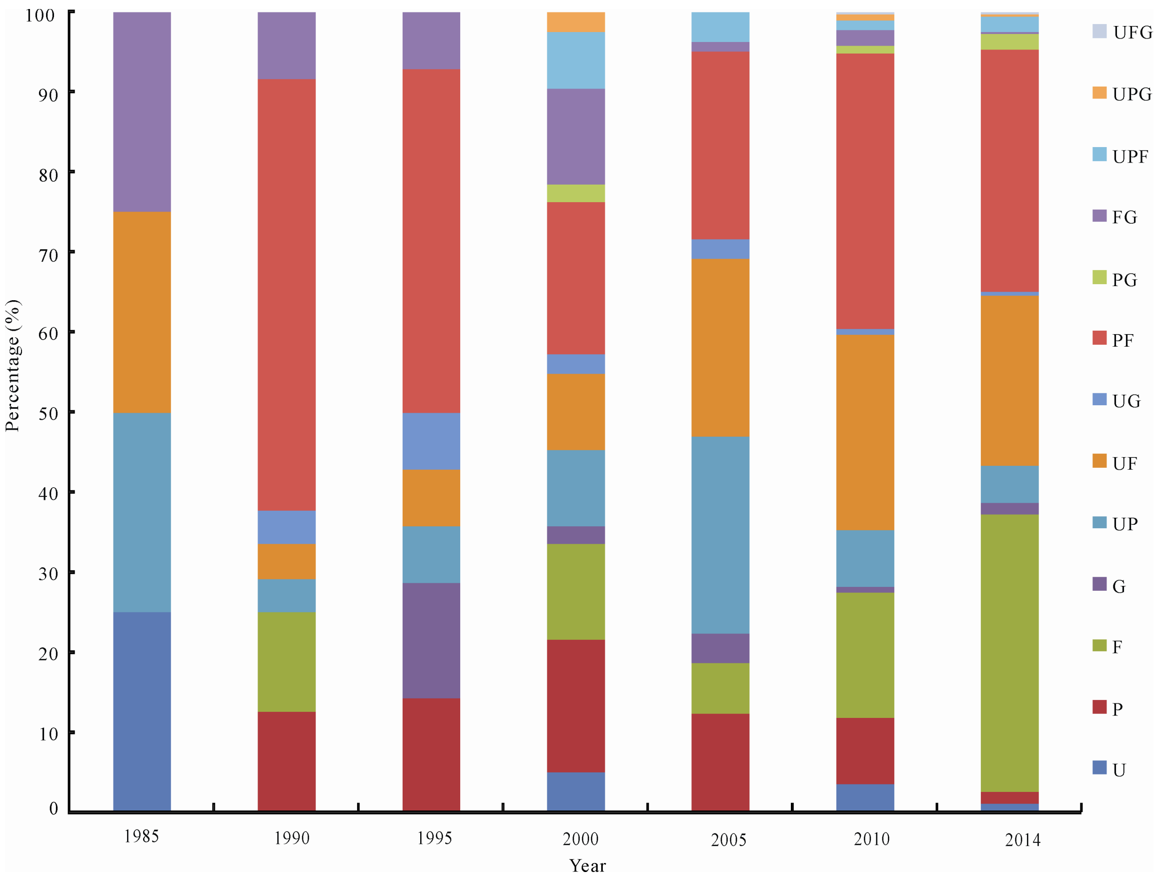


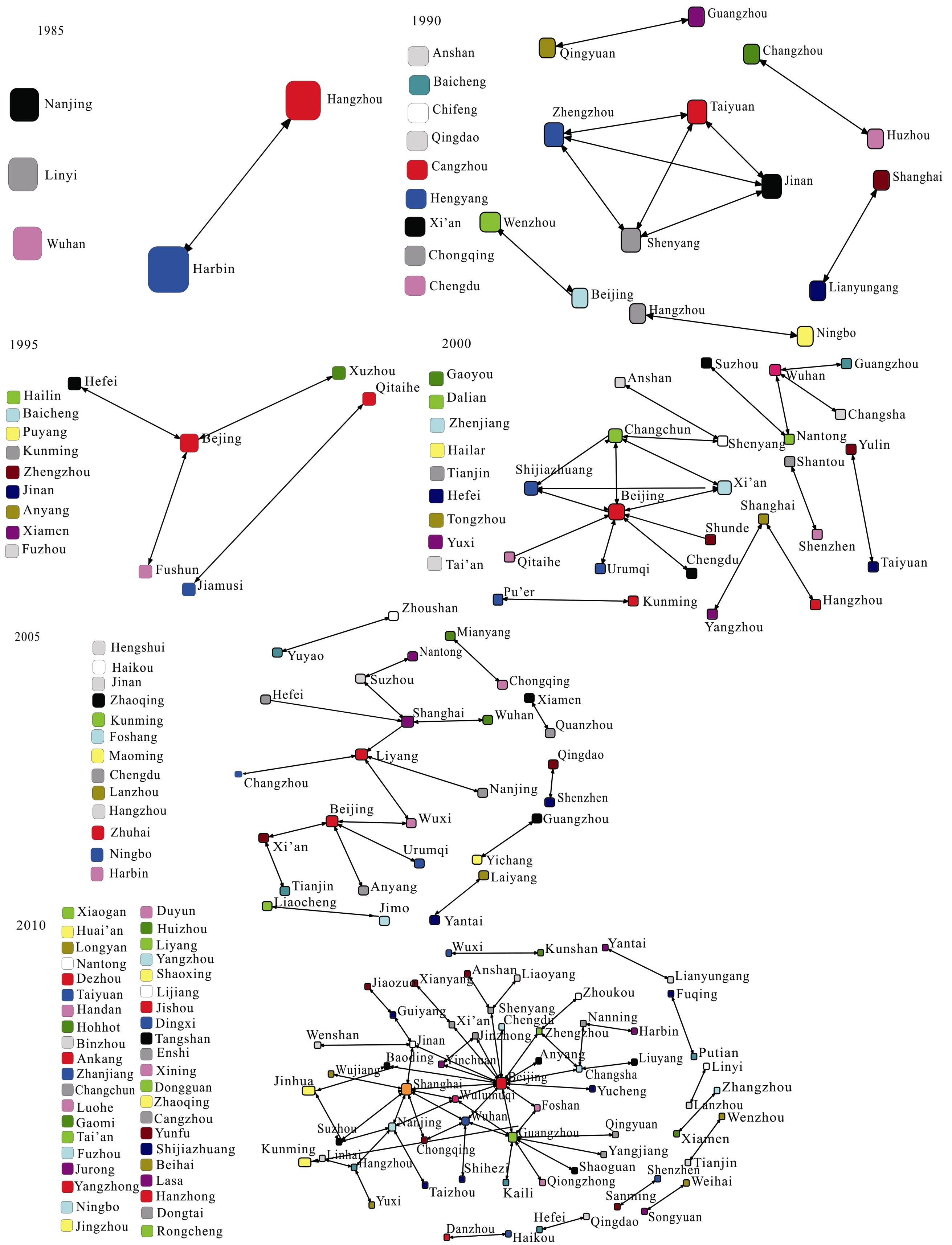
Fig. 2 Structure of agricultural patent cooperation in 1985–2014. The letter 'U' stands for University, the 'P' for Public research institute, the 'F' for Firm and the 'G' for Government)

enterprises were being strengthened. Besides, universities were participating in agricultural cooperation more and more frequently and contributing more and more to patent cooperation.

3.3 Evolution of spatial network structure of patent cooperation

The space structure and evolution characteristics of agricultural cooperative innovation network were analyzed with respect to agricultural patent collaboration by authors from different units. The core node of topological network was determined through core-periphery structure analysis in Ucinet; the core node of spatial network was determined by adding the ratio of network size of each network node computed to the entire network size and the ratio of total connections of the node with other nodes to the total connection among all nodes within the entire network. The intercity cooperation data matrix ('1' is assigned for connected nodes, otherwise '0' will be assigned) was developed according to agricultural patent cooperation by different units, and the topological structure diagram of agricultural cooperative innovation network was drawn (2000–2012) (Fig. 3). After that, the spatial structure diagram of agricultural cooperative innovation network (1985–2014) (Fig. 4) was drawn using the multi-value matrix for intercity and intracity cooperation (0 and 1 were used to indicate whether there was connection. In addition to that, line thickness also referred to the strength of relation of internal provinces or between nodes by Arcgis, Coreldraw and Photoshop software.

(1) Innovation cooperation is dominated by provincial and urban cooperation. The frequency of provincial and urban cooperation was significantly higher than that of inter-province and inter-city cooperation (Fig. 5), but the development of provincial intercity cooperation had gradually exceeded the development of urban cooperation. It indicated that geographical proximity (Boschma, 2005; Boschma and Frenken, 2010; Balland et al., 2015) played a significant role in cooperative innovation of agricultural technology, but its effect on cooperative innovation was gradually weakened. Geographical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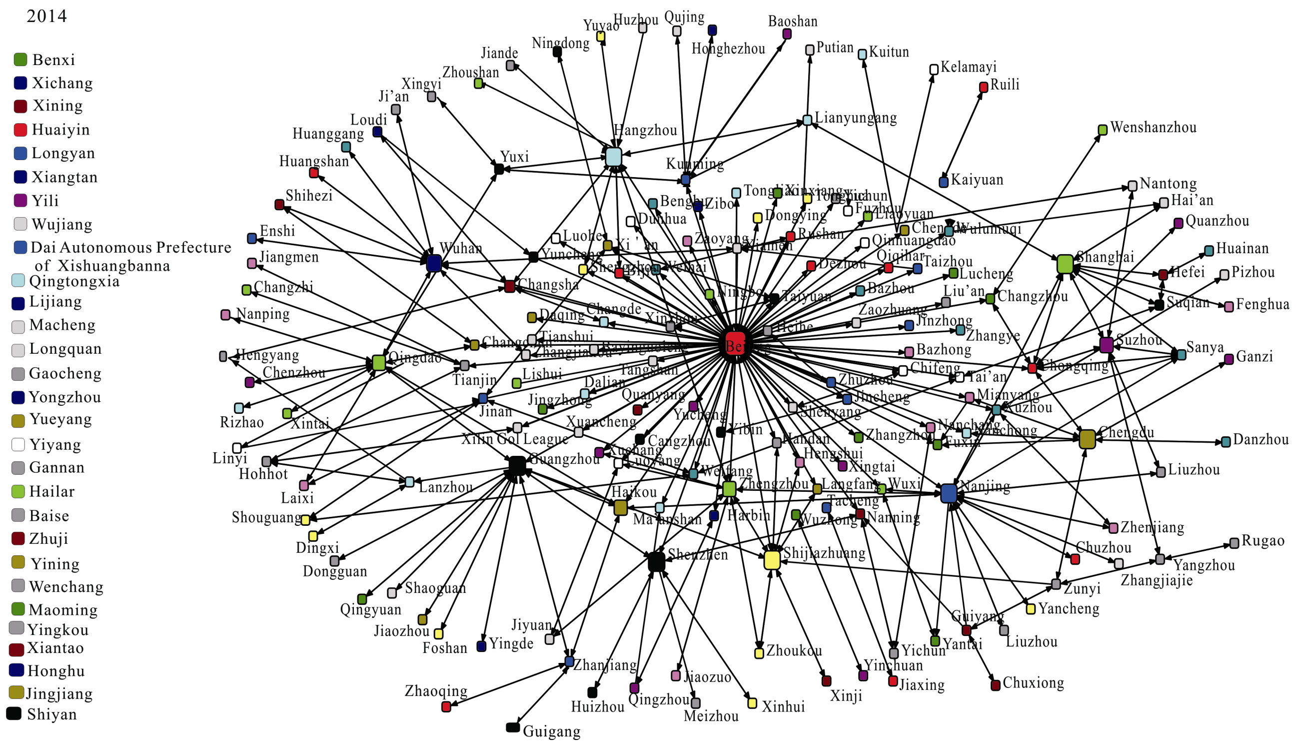

Fig. 3 Agricultural patents network topology structure in 1985–2014

proximity can facilitate interactive learning, most likely by strengthening the other four dimensions of proximity, that is, cognitive proximity, organizational proximity, social proximity and institutional proximity (Boschma, 2005).

(2) Innovative cooperation differs greatly by region. Among China's four sub-regions, the eastern region is characterized by fastest development and most internal cooperation (512 times in 2014), and the northeastern region has the least cooperation (21 times in 2014). The eastern region made more cooperation with the western region and the central region, and the western region and the northeastern region had the least cooperation (The eastern region includes Beijing, Tianjin, Shanghai, Hebei, Shandong, Jiangsu, Zhejiang, Fujian, Guangdong and Hainan provinces. The western region includes Inner Mongolia, Ningxia, Shaanxi, Gansu, Qinghai, Xinjiang, Tibet, Yunnan, Guizhou, Sichuan, Chongqing and Guangxi provinces. The central region includes Shanxi, Henan, Hubei, Anhui, Hunan and Jiangxi provinces. The northeastern region includes Heilongjiang, Jilin and Liaoning provinces) (Fig. 6). It is closely related to the education and technology resources in each region. According to the China City Statistical Yearbook (The department of urban social and economic surveys of NBS, 2015), there are 980 colleges & universities and 2 061 000 scientific researchers and teachers in the eastern region (2014), followed by 627 colleges & universities and 925 000 scientific researchers and teachers in the western region, 668 colleges & universities and 669 000 scientific researchers and teachers in the central region and 254 colleges & universities and 363 000 scientific researchers and teachers in the northeast region. A multi-pole growth pattern (including Beijing-Tianjin-Tangshan, Yangtze River Delta, Pearl River Delta, Yunnan, Xinjiang, *etc.*) has been established. In 2014, Beijing, Guangzhou and Nanjing have become the concentrated areas of cooperative innovation for China's agricultural technology (Fig. 4).

(3) Dominant organizations differ in different cities and regions. As an agricultural innovation center, Beijing has long been taking the lead in agricultural patent cooperation. It can be found from the cooperation history that agricultural patent cooperation in Beijing is dominated by scientific research institutes. Patent cooperation in Nanjing is dominated by enterprises, and that in Guangzhou is dominated by colleges & universities. In Kunming and Urumqi, research is mainly conducted on special agriculture for its special natural climate. In Xinjiang, scientific research institutes are the main

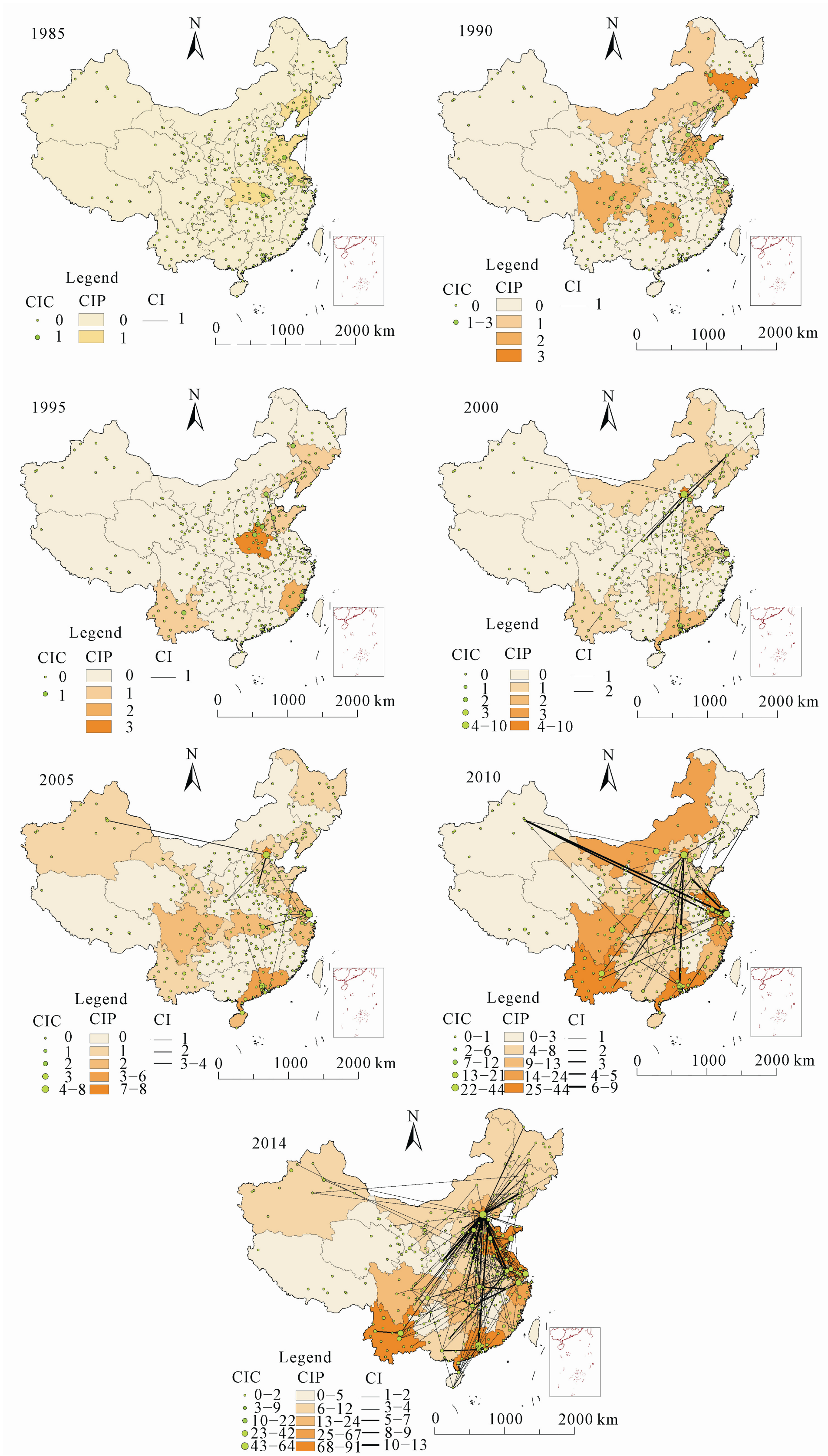

Fig. 4 Evolution of spatial structure of agricultural patent cooperation network in 1985–2014. CIC refers to the size of cooperation inside city; CIP refers to the size of cooperation inside province; CI refers to the intensity of cooperation inter-city

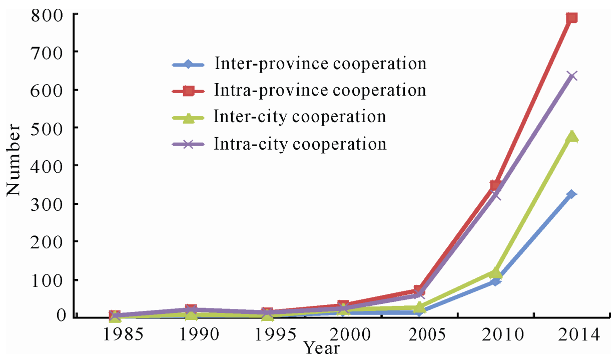

Fig. 5 Agricultural patent cooperation in provincial and city level, 1985–2014

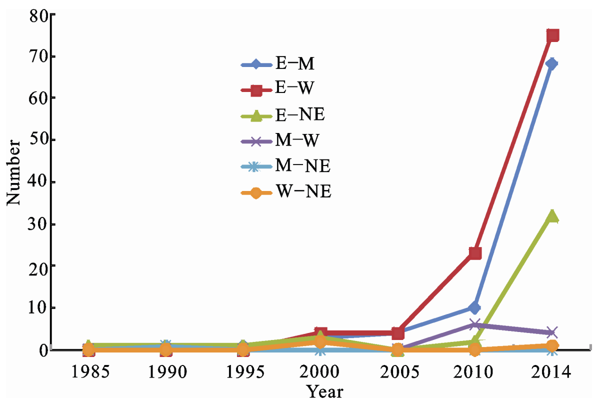

Fig. 6 The agricultural patent cooperation in regional level, 1985–2014. The letter 'E' stands for the eastern region, 'W' for western region, 'N' for northern region and 'M' for central region

participants of cooperation. The central region is always participating less in agricultural patent cooperation. Take Henan as example, as a major agricultural province and main production area of wheat, Henan has a favorable agriculture production environment and base, but participates less in agricultural patent innovation cooperation in recent 30 years, which may be attributed to the limited number of agricultural enterprises and scientific research institutes in Henan.

(4) The spatial structure of agricultural cooperative innovation network differs by period and co-evolves with its organizational structure. It can be found from Fig. 3 and Fig. 4 that the spatial structure of agricultural cooperative innovation network and the organization network structure have the same characteristics of three phases.

① Single helix empty-to-single core period (1985–2000)

It can be seen from the organization network analysis that the cooperative innovation network in 1985–2000 was in slow-growth single helix period and agricultural innovation was basically published by single subjects (individuals or authors of the same unit). The cooperation network is small and few cities were involved in cooperation. In 1985–2000, the network size was under 50, and most cities throughout the country remained isolated. In addition, the knowledge transmission of urban nodes was also limited. Although there was little cooperation, few patents also led to not-so-low network density (0.22 in 1995), as shown in Table 2. It can be seen from Fig. 6 that nodes were distributed dispersively, no topological core node and obvious regional difference was shown, and cities in the eastern region mainly participated in agricultural patent cooperation (dominated by internal cooperation). After 1995, Beijing gradually became the core of network (Table 3, Table 4). In 1995–2000, most node cities were distributed in the eastern coastal regions and key capital cities, and the cooperation between node cities showed strong regional characteristics (less cross-large-region communication), indicating that the agricultural patent knowledge diffusion was dominated by contagious diffusion.

Table 2 Topological structure of global network

Year	Total number of nodes (*)	Density	Average path length	Clustering coefficient	Total number of relations
1985	5 (3)	0.10	1.00	1.00	4
1990	14 (0)	0.11	1.00	1.00	24
1995	6 (0)	0.22	1.43	0.00	14
2000	33 (10)	0.07	1.91	0.66	42
2005	41 (10)	0.05	2.76	0.00	81
2010	104 (34)	0.06	3.12	0.70	467
2014	203 (29)	0.04	3.09	1.27	1038

Note: * represents quantity of nodes which only have internal relations

Table 3 Degree centrality of the core nodes of the ego-network

Year	Core nodes
1985	None
1990	None
1995	Beijing (3)
2000	Beijing (10), Changchun (7), Shijiazhuang (6), Xi'an (6), Wuhan (3), Shenyang (2), Nantong (2) and Shanghai (2)
2005	Beijing (5), Shanghai (5), Urumqi (2), Wuxi (2), Xi'an (2), Suzhou (2) and Wuhan (2)
2010	Beijing (51), Shanghai (38), Urumqi (23), Jinan (22), Guangzhou (15), Wuhan (9), Nanjing (8), Suzhou (7), Changsha (7) and Xi'an (6)
2014	Beijing (218), Nanjing (38), Changsha (32), Guangzhou (30), Hangzhou (30), Tianjin (29), Kunming (26), Wuhan (25), Zhengzhou (23), Shanghai (15) and Changde (15)

Table 4 Betweenness of core nodes of ego-network

Year	Core nodes
1985	None
1990	None
1995	Beijing (3)
2000	Beijing (44), Changchun (26), Shenyang (15), Wuhan (10), Nantong (6) and Shanghai (2)
2005	Beijing (62), Wuxi (55), Shanghai (43), Xi'an (19) and Suzhou (14)
2010	Beijing (599), Shanghai (217), Guangzhou (199), Nanjing (157), Changsha (119), Jinan (119), Urumqi (86), Shenyang (81), Hangzhou (81) and Wuhan (64)
2014	Beijing (22554), Guangzhou (3092), Nanjing (3070), Chongqing (1960), Wuhan (1878), Qingdao (1849), Hangzhou (1752), Kunming (1290), Shanghai (1252), Chengdu (1123)

② Double-helix multi-core period (2000–2010)

The cooperative innovation network was in a relatively fast growing double-helix period characterized by fast increase in network size (Table 2), total number of relations, cities participating in cooperation and cooperation frequency. In 2010, Beijing and Shanghai became network poles (Table 3), followed by Nanjing and Guangzhou, and the network diffusion effect began to emerge. The multi-core structure appeared due to an increasing number of core nodes of network topology, and other capital cities like Changsha, Jinan, Urumqi, etc. had their degree centrality in the front row. The sub-network structure emerged, and the dense connection remained between core nodes. In addition, the core nodes began to have more connection with edge nodes.

③ Double-helix complex network period (2010–2014)

In 2014, the number of patents achieved by intercity cooperation was more than that achieved by different units of the same city and accounted for 62.44% of the total. The number of nodes increased quickly to 203, and that of relations increased to 1038 (Table 2), resulting in a more complex network. However, the large number of cooperative patents also resulted in reduced network density (0.04). Cooperation nodes were distributed dispersively and characterized by obvious hierarchy. Beijing remained a national cooperative innovation pole with degree centrality of 218 and betweenness of 22 554 (Table 2, Table 3), which far exceeded that of other cities. Nanjing and Guangzhou were among secondary core nodes, and key capital cities like Chongqing, Wuhan, Qingdao, Hangzhou, Kunming, Shanghai, Chengdu, *etc*. became third core nodes. Especially in Shanghai, more intra-city cooperation and less intercity cooperation caused a decline in its position in cooperative innovation. In this period, the hierarchical diffusion of agricultural patent knowledge occurred.

The intra-city cooperation of agricultural patent remained dominant. In addition, geographical proximity and organizational proximity remained essential factors for technical exchange. It can be seen from Fig. 3 that intra-city cooperation was always followed by inter-city cooperation, and the patent knowledge flow was significantly influenced by the amount of urban internal information resources as well as the development level of communications. For example, more than 20 organizations in Beijing made intra-city cooperation 57 times in 2014. In addition, Shanghai, Nanjing, Kunming, Tianjin, Hangzhou, *etc*. also achieved more intra-city cooperation.

4 Influencing Factors of Agricultural Cooperative Innovation

The government-industry-university-research cooperation of cities is established following the principle of reciprocity according to the Triple Helix Theory (Etzkowitz, 2008). Each subject must make its efforts to achieve cooperative innovation. Therefore, each subject's participation in cooperative innovation is related to its efforts, like government's investment in knowledge infrastructure, industry development scale, talent training in universities and R&D investment of scientific research institutes. So, many factors are involved with respect to whether an innovative subject makes innovative cooperation with other units and how much cooperation may be achieved, such as knowledge infrastructure level, industrial development size, human capital accumulation and science and education inputs at the city level.

Knowledge infrastructure: the innovation in knowledge flow is an essential mode of knowledge innovation (Tu and Gu, 2013), and knowledge infrastructure serves as an important soft environment determining the knowledge flow and innovation ability of a region. The number of mobile phone users and internet users of each city is selected as indicators to measure the knowledge infrastructure.

Industrial development size: the external absorption capability and diffusion ability of a region are often affected by industrial development size and economic development (Liu and Shi, 2009). The technical demand for agricultural innovation depends on agricultural development. This paper selects the per capita GDP, fixed-asset investment and gross output value of agriculture of each city as indicators to measure the industrial development size of each region.

Human capital accumulation: it is the basis of innovative cooperation. In this paper, the size of urban population, number of school teachers, number of school students and number of scientific research and service technicians are selected to measure human capital.

Sci-tech & education development: Cohen and Klepper (1992) pointed out that scientific research and development is an important source of knowledge innovation. As the distribution center of national scientific knowledge, colleges & universities and scientific research institutes are important subjects of patent cooperative innovation. The gross science & technology expenditure, gross education expenditure and collection of books of public libraries are selected as important influencing indicators of soft environment of technical innovation.

In summary, this paper selects 12 indicators as independent variables, including gross expenditure on science & technology, gross education expenditure, fixed-asset investment, per capita GDP, number of mobile phone users, number of internet users, number of school teachers, number of school students, number of collections of public libraries, gross output value of agriculture, population size, number of scientific research and service technicians of each city. Since few cities participate in cooperative innovation in some years, this paper selects the year 2014 to analyze the influencing factors on China's urban government-industry-university-research innovative cooperation. Relevant data is derived from the *China City Statistical Yearbook*.

Since the 12 independent variables are closely related to each other, this paper first extracts principal components from the 12 independent variables using the SPSS19.0 principal component analysis (PCA). Four principal components are extracted and the contribution rate is 90.48%. The first principal component (Component1) is highly correlated to the expenditure on science & technology, number of collections books of public libraries, gross education expenditure, etc., and has a variance contribution rate of 61.976%, reflecting the urban science & education investment. The second principal component (Component2) has a strong correlation with number of school teachers, number of colleges & universities, number of scientific research and service technicians, etc., and has a variance contribution rate of 15.249%, reflecting the number of urban scientific researchers and teachers. The third principal component (Component3) has a variance contribution rate of 7.244%, reflecting the agricultural development. The fourth principal component (Component4) has a variance contribution rate of 6.011%, reflecting the urban economic development (Table 5). Next, multiple linear regression is conducted by replacing 12 previous independent variables with the scores of 4 principal components of each city, and taking the degree of government-industry-university-research cooperative innovation

Table 5 Rotated component matrix

Indicators	Component1	Component2	Component3	Component4
Science & technology expenditure	0.907	0.245		0.283
Collection of books of public libraries	0.845	0.332		0.290
Gross education expenditure	0.765	0.291	0.469	0.201
Number of school teachers	0.259	0.910	0.218	0.151
Number of school students	0.273	0.881	0.240	0.176
Number of scientific research and service technicians	0.602	0.639		
Fixed-asset investment	0.291	0.589	0.568	0.324
Number of mobile phone users	0.535	0.560	0.323	0.464
Number of internet users	0.458	0.498	0.365	0.479
Gross output value of agriculture		0.105	0.939	
Population size	0.327	0.272	0.862	
Per capita GDP (RMB)	0.283	–0.141	0.147	0.906

(measured by degree centrality of each city in the agricultural cooperative innovation network) as the dependent variable.

The result shows that $R^2 = 0.718$, $F = 90.967$ and $P < 0.005$, which means that the regression model is significant. In addition, all independent variables have undergone t test (Table 6) at the significance level of 0.05. It can be seen from Table 6 that agricultural cooperative innovation is primarily influenced by urban science & education investment (Component1), with a standardized coefficient of 0.645; the number of scientific researchers and teachers (Component2) also has significant impacts on agricultural cooperative innovation, with a standardized coefficient of 0.527. It should be noted that the agricultural development level (Component3) and economic development level (Component4) may exert slightly negative effects on agricultural cooperative innovation. The standardized coefficients of them are respectively –0.091 and–0.122, which means that, on one hand, traditional agricultural regions (like the central region and northeastern region) and high per capita GDP resource-based cities (petroleum cities like Karamay, Dongying, Daqing, *etc*.) are not active in agricultural cooperative innovation (for lack of education and technology resources), and on the other hand, in economically-developed industrialized or service cities, agricultural innovation is mainly achieved by actors of the same unit, but not the cooperation between different units.

Table 6 Coefficients of the regression

Model	Unstandardized coefficients		Standardized coefficients	t	Sig.
	B	SE	Beta		
Constant	6.669	0.831		8.025	0
Component1	12.117	0.834	0.645	14.532	0
Component2	9.901	0.834	0.527	11.874	0
Component3	–1.711	0.834	–0.091	–2.052	0.032
Component4	–2.283	0.834	–0.122	–2.738	0.007

5 Conclusions

It is drawn from the above analysis that:

(1) Over the past 30 years, China has made great improvement in the innovation of agricultural science and technology, but the development degree of cooperative innovation network remains low and patent collaboration is dominated by cooperation of the same unit. Therefore, it is extremely urgent to promote the government-industry-university-research cooperation in China.

(2) Different from the industry-university-research innovation network of equipment manufacturing industry dominated by colleges & universities, enterprises are always dominant in agricultural cooperative innovation at the organizational level, but are not active in government-industry-university-research cooperation in general. The organizations driving patent cooperation differ in different regions. The cooperation between scientific research institutes is the main driving force in Bei-

jing-Tianjin-Tangshan, Xinjiang, *etc*., and enterprises are the driving forces in Yangtze River Delta region. In Pearl River Delta, Yunnan and other regions, a balanced growth of different organizations appears. However, the effects of governments and hybrid organizations driven by governments are not significant. Therefore, it is very necessary to give full play to the role of hybrid organizations (like incubators, technical advice stations, technical evaluation stations, epidemic prevention stations, protection stations, rural technical service centers, county-level technical service stations, etc.) in promoting government-industry-university-research cooperation.

(3) Provincial and urban cooperative innovation is dominant at the spatial level, and a multi-pole growth pattern including Beijing-Tianjin-Tangshan, Yangtze River Delta, Pearl River Delta, Yunnan, Xinjiang, etc. has been established. The single-helix empty-core cooperative innovation network structure has evolved into double helix multi-core network structure, but the triple helix period is yet to come. The knowledge diffusion previously dominated by contagious diffusion is gradually dominated by hierarchical diffusion. Geographical proximity has some effects on cooperative innovation, but its effects are gradually declining. Establishing a national ordered agricultural innovation system has become an effective way to improve agricultural innovation efficiency.

(4) The urban science & technology capital investment and staff investment are the most crucial factors for agricultural cooperative innovation. However, the urban agricultural and economic development level may have slightly negative effects on agricultural cooperative innovation. That is to say, traditional agricultural regions with strongerdemand for agricultural innovation are not so active in agricultural cooperative innovation for lack of education and technology resources. Therefore, there is a spatial mismatch in the supply and demand of cooperative innovation for China's agricultural technology, and an immediate investment in science and education of agricultural provinces is imperative.

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