Spatio-temporal evolution of technology flows in China: patent licensing networks 2000–2017

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Abstract

Technology transfer has become a vital pipeline for acquiring external knowledge. In this study, we propose new evidence on Chinese knowledge flows at a provincial scale based on patent licensing data at the China National Intellectual Property Administration, involving 31 Chinese provinces and all foreign entities. For temporal features, licensing frequencies, the type of patent licensors, the distribution and transfer speed by technical fields were first present. Then, topological structures and centrality rankings, spatial evolution and reciprocity, and blockmodeling were performed in sequence for network analysis. The major findings are: (1) foreign technology played an important role in China and is still an important knowledge source; (2) individuals and enterprises dominate the technology output, and the role of universities and research institutes as innovation engines has not been fully realized; (3) the technical fields of performing, operations, and transporting have extremely active market performance and are favored by market players; (4) patent licensing networks present clear small-world phenomenon, and there is a conspicuous regional hierarchical structure for patent-expanding capabilities in various provinces; (5) an integrally compact, locally dispersed, and multi-core structure centered on Guangdong, Zhejiang, Jiangsu, and Beijing is being formed in the networks; (6) three blocks that play different roles in the patent licensing network are distinguished: source, absorber and beginner. This paper provides important implications for considering the impacts of technology transfer policies implemented so far, and can be useful for making evidence-based policies to establish a more effective national technology transfer system.

Keywords Knowledge flow · Technology transfer · Patent license · Social network analysis · China

JEL Classification O18 · O33 · O38 · R11 · R12

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1 Introduction

The contemporary growth theory indicates that technological progress is the main driving force for national economic growth (Mowery and Rosenberg 1991; Sala-i-Martin and Barro 1995). Although endogenous growth theory highlights the importance of original innovation capabilities, recent research has demonstrated that the capacity to exploit the economical potential and opportunities of inventions is regarded as the real impetus for a region's economic growth (Coe and Helpman 1995; Young and Lan 1997; Lin 2003; Audretsch and Keilbach 2008; Sonn and Park 2011; Seck 2012). Like a "bridge" connecting technology with economy, technology diffusion becomes an important way to realize the cross-region spreading and sharing of innovative resources and to promote technological progress and economic growth in underdeveloped regions (Farris 2007).

As a heterogeneous post-developing country, China faces a host of problems, such as complex industrial characteristics, significant differences in regional economic development, and uneven distribution of regional science and technology resources. China has fallen behind other industrialized countries for the inefficiency and ineffectiveness of industrial R&D in the 1980s and 1990s (Wang et al. 2015). Although the economic production process of China still relies heavily on the introduction of foreign technologies (Yu 2010), many new technologies with proprietary intellectual property rights are springing up (Zheng et al. 2011). Meanwhile, the uneven distribution of innovative activities among regions has given rise to the universal phenomena of technology transferring from R&D resource-intensive areas to industrialized areas (Zhang et al. 2016a). For example, a large number of technologies invented in Beijing, recognized center for technological innovation and diffusion with powerful scientific, economic, and political strength, have been transferred to other industrialized provinces, such as Zhejiang, Jiangsu, and Guangdong (Lu and Huang 2012). In addition, the enhancement of reverse engineering enables more inventions in auxiliary and peripheral technologies, which further promotes the technical transfer from laboratory to industry (Lan and Young 1996; Yang and Maskus 2009).

So far, limited attention has been paid to knowledge flow networks or technology transfer networks within a country. From the perspective of patent licensing, little data has been published on the characteristics of intraregional technology transfer in terms of the subjects and the objects. Meanwhile, macro- and micro-scale research focuses mostly on the relationships between technology transfer and regional economic growth (Zhou and Xin 2003; Lin et al. 2011; Seck 2012) or innovation capability (Chen et al. 2010; Huang et al. 2012; Jian and Liu 2012), while the law of cross-regional technology diffusion with provinces as the nodes is ignored to some extent.

Since there is a lack of previous studies analyzing technology flows in a country by using patent licensing information, it is very difficult to know what statistical characteristics it would show. For this paper, we acquired the patent licensing data of China National Intellectual Property Administration (CNIPA) during 2000–2017, which enabled us to examine the temporal changes of the subjects and the objects of patent licenses. Do certain region pairs dominate in technology flows based on patent licenses? What would be the concentrated knowledge sources for these specializations, namely, are the most easily transferred patents university-based, corporate-based, or R&D institutions-based? What would be the specific types of scientific knowledge embodied in these licensed patents? Would it be easier and faster to transfer certain types of discoveries? To answer these questions, we divide the patent licenses into two parts: the subjects and the objects. The former relates to both licensors and licensees to the patent licensing contracts, and the latter to the

patent document itself. In addition, combined with the provincial address information, we are able to further trace the spatial knowledge flows with the help of social network analysis (SNA). By such a network we are referring to patent transaction relationships formed by 31 Chinese provinces[1] and foreign entities. We focus on three important aspects: (1) the overall topological structure of technology flow networks, region importance by centrality and strength analysis; (2) the spatial evolution of the patent licensing networks and the closest bilateral technology flows by employing adapted Jaccard index; (3) the pattern of relationships among the Chinese provinces, with the help of blockmodeling analysis.

The remainder of this paper is organized as follows. Section 2 reviews the literature on the brief history of China's technology transfer system, patent license as a measure of technology flow, and SNA theory. Section 3 describes the research design, data resources and network construction. Section 4 analyses the temporal changes of subjects and objects of patent licensing data. Section 5 explores the spatial evolution of provincial technology flow networks. Section 6 sums up the major findings and offers implications.

2 Literature review

2.1 Brief history of China's technology transfer system

In the nearly four decades, China has achieved remarkable technological progress and strong economic development today. During the process, the Chinese government believes that technology transfer plays a very important role in converting its economic structure from labor-intensive manufacturing to knowledge-intensive industries, and instituted a package of measures regarding technology transfer. The framework of technology transfer in China is mainly defined by legal system, regulations, and policies (Yu 2010).

Historically, when China began implementing the reform and open-door policy in 1978, its economy, industrial and technological capabilities were devastated by the "Cultural Revolution". China urgently needs to introduce Western equipment and technologies. In December 1981, the "Economic Contract Law" was enacted in order to regulate the relevant rights and obligations of equal trading entities in the market. Article 8 of the law listed science and technology cooperation contracts (including technology transfer) as one of the top ten economic contracts. In May 1985, the "Regulations on Administration of Technology Import Contracts" was then issued by the State Council for the purpose of promoting the introduction and absorption of foreign technology. Meanwhile, in order to ensure that intellectual property rights of foreign entities are not infringed in China and encourage them to transfer technology, the "Patent Law" was promulgated in March 1984, which guarantees the security and protection required for technology transfer. According to this law, any unit or individual that implements another person's patent must sign a written license contract with the patentee and pay the royalty. With the deepening of reform and opening up and the implementation of the policy of "opening the technology market and implementing the commercialization of scientific and technological achievements", the "Technical Contract Law" was enacted in June 1987, which systematically stipulated

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[1] Taiwan, Hong Kong and Macau have their own independent intellectual property systems and are therefore handled part of the foreign region for following analysis, which does not mean that the authors agree with their independence in national sovereignty. Besides the three regions, there are 31 provincial administrative regions in China, including 22 provinces, 4 municipalities and 5 autonomous regions.

technology transfer. In March 1999, China promulgated the three-in-one "Contract Law" based on the "Economic Contract Law", the "Technical Contract Law" and the "Foreign Economic Contract Law", and since then the legal norms of technology transfer rose to the basic law of the state.

Since 2000, China National Intellectual Property Administration (CNIPA) has been responsible for the filing formalities of domestic patent licensing contracts (Wang et al. 2014). According to the "Measures for the Filing of Patent Exploitation License Contracts" enacted in December 2001, the parties to a patent exploitation license contract are called for the filing formalities within 3 months from the effective date of the contract (CNIPA 2011). Although the patent implementation license contract is not premised on filing, it has several advantages, such as pre-litigation prohibition, being a standard of infringement compensation, and the hi-tech enterprise certification, thus greatly improving the transparency of patent technology transfer.

Before 2008, most inward patented technologies come from foreign organizations in China (Cai 2018). To reverse this situation, the "National Medium- and Long-Term Science and Technology Development Plan (2006–2020)" was published in February 2006, as the main blueprint for China's independent innovation and technologically catch-up strategy, which sets the target for China to limit reliance on foreign technology from 50% in 2006 to 30% or less by 2020 (State Council 2006). In September 2007, the "Implementation Plan on National Technology Transfer Promotion Action" was instituted to establish a sound mechanism for knowledge flow and technology transfer (MOST, MOE, & CAS 2007).

In June 2008, the "Outline of the National Intellectual Property Strategy" was implemented by the Chinese government with a view to enhancing creation, utilization, protection and management capabilities of China's intellectual property rights (State Council 2008). In terms of technology transfer, the outline is expected to achieve the purpose of promoting commercialization and industrialization of technological innovation, and guiding enterprises to realize the market value of patented technologies by means of patent transfer, license, and pledge. Besides the outline, the "Measures for the Administration of the Recognition of Hi-tech Enterprises" was revised in April 2008. According to this measure, the acquisition of intellectual property rights by an firm through exclusive licenses for more than 5 years can be used as a condition for the identification of a high-tech enterprise (MOST, MOF, & SAT 2008). Although this measure played an important role in the development of the Chinese patent market, it also triggered a serious issue, that is, some firms obtain a high-tech enterprise certification to obtain tax benefits by signing false patent license agreements. In view of this situation, the "Measures for the Administration of the Recognition of Hi-tech Enterprises" was again revised in January 2016 (MOST, MOF, & SAT 2016). The newly promulgated measures abolish the conditions for obtaining independent intellectual property rights through exclusive licenses for more than 5 years. The Chinese patent trading market has thus gained a more benign environment.

In April 2016, the "Action Plan to Promote the Transfer of Scientific and Technological Achievements" was issued to promote the transformation of scientific and technological achievements into practical productivity (General Office of the State Council 2016). The main goals for 2016–2020 is to: (1) build 100 national technology transfer demonstration institutions; (2) build 10 demonstration zones for transformation of scientific and technological achievements; (3) train 10,000 technology transfer specialists; (4) strive to reach 2 trillion yuan of technology transaction turnover in the whole country.

In summary, the Chinese governmental policies for technology transfer can be characterized as follows. First, China's technology transfer policy is a complex but relatively

independent system, involving many laws and regulations. Second, those policies aimed at facilitating the transformation of scientific and technological achievements were implemented. After 2006, China implemented indigenous innovation strategy to technologically catch up with forerunner countries, and there was an increase in national supports to build an efficient technology trading market. Third, China must, rather paradoxically, partially rely on foreign technology in order to meet its indigenous innovation goals. Therefore, China is actively building a favorable business environment for foreign-funded companies. For example, the "Foreign Investment Law" was enacted in March 2019 in order to expand opening up and promote foreign investment. Fourth, due to the implementation of the filing system, patent license is regarded as the main measurable form of technology transfer in China.

2.2 Patent license as a measure of technology flow

Knowledge is divided into two types: tacit and explicit. Due to the unmeasurable nature of tacit knowledge, scholars often rely on explicit approach to trace knowledge flow, such as technology transactions (Buenstorf and Geissler 2012), personnel mobility (Almeida and Kogut 1999; Trippl 2013), R&D cooperation (Cassiman and Veugelers 2002; Ponds et al. 2009), international commodity trade and foreign investment (Saggi 2002; Keller 2002). In the case of potential commercialization (whether self-enforcing or licensed to others), intellectual capital of firms would be protected by filing patents to maintain their competitive advantages (Blind et al. 2009). Thus, many of the existing studies on technology flows, including learning and diffusion, are based on the analysis of patented technology transfer (Schmoch 1993; Guellec et al. 2001; Alcacer and Gittelman 2006; Dechezleprêtre et al. 2013).

Two branches of the literature based on patent linkages have progressed on separate avenues in the analysis of knowledge flow. One branch of the literature deals with the analysis of patent citation records (Tijssen 2001; Hu and Jaffe 2003; Alcacer and Gittelman 2006; AlAzzawi 2011; Ribeiro et al. 2014; Ye et al. 2015; Sharma and Tripathi 2017). Patent citations provide interesting information tracking knowledge flows, and they can be used to assess the direction (since the cited patent is the origin of the technology and the citing patent its destination) and intensity of knowledge flows. They have also been used as a proxy for patent value or importance (Harhoff et al. 1999; Hu et al. 2012). However, the value of citations is limited by the fact that citing is a low-cost activity. Citations only capture knowledge flows that result in a novel, patentable technology. They cannot help us make inferences about learning via imitation or reverse engineering, or other knowledge flows that do not always result in a patent (Duguet and MacGarvie 2005). In addition, Patent citations cannot distinguish important knowledge flows from related prior patents that may or may not have affected the invention of the citing patent (Vernon Henderson 2007). The other branch widely used measure of knowledge flow is the patent co-inventorships or co-ownerships (Breschi and Lissoni 2009; Gao et al. 2011; Xiang et al. 2013; Li et al. 2014; Wanzenböck et al. 2014; Choe and Lee 2017). A joint patent is highly likely to reflect the real interactions among inventors and patentees compared to the patent citation. However, co-inventorship or co-ownership represents an undirected relationship, and it is thus difficult to monitor the direction of knowledge flow in technology transfer studies. Therefore, joint patent has a lower practical significance. In addition, neither citation nor joint patent show the economic value of the technology.

The use of patent licensing data overcomes all of these problems (Seo and Sonn 2018). First, a licensor transfers the use right of its patent to a licensee for economic value, indicating that both parties make the conscious decision to use this patent. Second, like the citation data, patent licenses clearly reference the source and destination of technology flows. Meanwhile, as in co-inventorship or co-ownership, the licensing records show real technology exchange. Patent licensing data is also flawed. The biggest shortcoming is that official register of patent license is a voluntary behavior, and by doing so it may reveal owner's business intentions and damage its competitiveness. This is why the patent licensing database is difficult to cover the full licensing activities of a country. Despite this, patent licensing data provides meaningful information related to knowledge flows, including economic value, geographical locations and technical fields. Therefore, it is suitable to use patent licensing data to explore China's technology flows.

2.3 Social network analysis

Derived from graph theory, SNA is a set of specifications and methods for characterizing the structure and attributes of the relationships formed by social actors, and it is regarded as a new paradigm in social relations research (Wasserman and Faust 1994; Borgatti et al. 2009). This method quantifies the relationships between actors and their connections rather than relying on the traditional attribute data; furthermore, they can establish a relational model between objects to describe the network characteristics and interactions between actors. Network actors can be individuals (Chen and Guan 2016), institutions (Schilling and Phelps 2007; Lyu et al. 2019), regions (Gao et al. 2011), or even countries (De Prato and Nepelski 2014). The related ideas of network analysis have been extensively employed to study global trade networks (Smith and White 1992; Fagiolo et al. 2008; Maluck and Donner 2015; Zhang et al. 2016b), technological collaboration networks (De Prato and Nepelski 2014), R&D networks (Arranz and de Arroyabe 2007) and interorganizational networks (Knoben et al. 2006; Samaddar et al. 2006).

3 Research design, data resources and network construction

3.1 Analytical framework

Figure 1 presents the analytical framework of this study. We first collected data on patent licenses for China from 2000 to 2017 by setting licensing year as the time truncation. Next, we will examine the temporal changes of the subjects and the objects of patent licenses, and then build provincial patent licensing networks by using the geographic information of the licensors and the licensees. Finally, we will explore the topological structure and node centralities, spatial evolution and reciprocity, and the blockmodels by SNA.
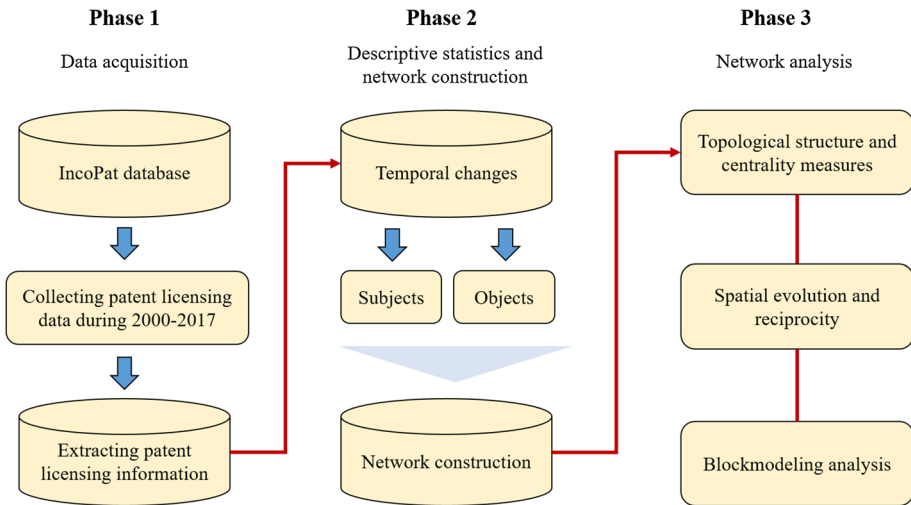
Fig. 1 Research flow chart

3.2 Data resources

In this context, we began our search for licensed patents (only considering invention patents and utility model patents[2]) from the IncoPat (https://www.incopat.com/login?locale=en) pay search services.[3] Each licensing record contains patent application number, application date, licensor, licensee, license type, international patent classification and license date, wherein the licensor refers to patentee, patent applicant, or other right holder involved in the licensing contract, while the licensee refers to the other party involved simultaneously in the contracts. Then, we retrieved the location information of patent licensors and licensees assisted by the data mining software Python on the enterprise data platform Qichacha (https://www.qichacha.com/), followed by manual check to ensure the accuracy of the data.

From 2000 to 2017, the number of licensed patents in China was 110,485. Figure 2 shows the number of all the licensed patents and their growth rate by licensing time. Basic analysis indicates that the number of licensed patents per year varies from 50 to 400 in 2000–2007, and it has soared to 9006 in 2008 and reached a peak of 16,953 in 2011, and then drop to about 3500 in 2016–2017. Due to the surge in 2008, the patent licensing frequency grew by an average annual rate of 195.1%.

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[2] There are three types of patent in China: invention patent, utility model patent, and design patent. According to the definition of Article 2 of China's Patent Law (http://www.gov.cn/flfg/2008-12/28/content_1189755.htm), the design patent is essentially a new design rather than a technical solution. Hence, the results presented below are based on patent licenses of invention patents and utility model patents.

[3] IncoPat is a famous commercial platform for patent information search in China, which contains more than 100 million patents of 102 countries, organizations, and regions. Through comprehensive data integration processing, more than 230 fields can be retrieved, including patent legal status, citation, and licensing information.
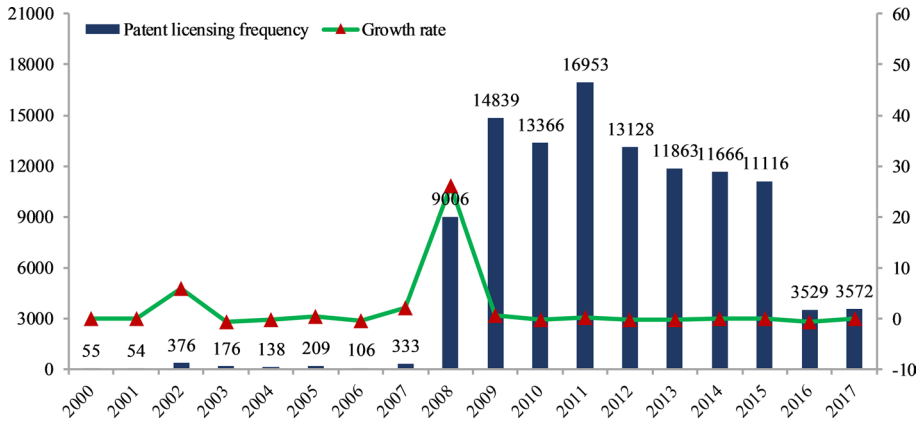
Fig. 2 Patent licensing frequency and growth rate from 2000–2017

3.3 Network construction

Given that the connections between the patent licensor and the licensee are often complex and dynamically change over time spans, the SNA approach is employed. The patent licensing network is a directed and weighted networks and can be abstracted as a graph $G = (N, L)$ consisting of the set of nodes N and set of links L. In the network, node denotes a region and a link denotes the licensing relationship among regions. The network can thus be represented by adjacency matrix[4] $A = (a_{ij})_{N*N}$ and weighted matrix $W = (w_{ij})_{N*N}$, where a_{ij} takes a value in {0, 1} relying on the existence of relationships between node i and node j, and weight w_{ij} represents the patent licensing flows from node i to node j. The value on the diagonal may not be zero due to possible licensing relationships within the region. Accordingly, the characteristics of the patent licensing network can be fully described from the adjacency or weighted perspective.

In order to create contrasts along evolutionary pathways when comparing a later phase with an earlier one, we evenly divided the period (2000–2017) into three phases, marking an interval every 6 years, to construct three subnetworks (2000–2005, 2006–2011 and 2012–2017) and a full network (2000–2017). In the networks, a node denotes a region (including 31 Chinese provinces and other regions) as the origin of a licensee or a licensor, and a link denotes a directed relationship of the patent license from the licensor's region to the licensee's region.

3.4 Measures for network analysis

After the completion of patent licensing network construction, the topological structure and properties of the networks are calculated based on some classic indicators, such as size, link, diameter, density, clustering coefficient and average path length (Wasserman and

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[4] The adjacency matrix represents the edges, and the value of the matrix element in row i, column j, is one if there is an edge between those nodes, and zero if not. For directed networks, the adjacency matrix is unsymmetric.

Faust [1994](#); Fagiolo [2007](#); Borgatti et al. [2009](#)). Then, the concept of centrality proposed by Freeman ([1978](#)) is used to describe how central a node (region) is in the network or how easily an actor obtains or controls resources from any node pairs (region pairs).

Centrality and strength (1) In the directed network, it is feasible to distinguish the degree centrality, including in-degree k_i^{in} and out-degree k_i^{out}, to evaluate the importance of each region in the created patent licensing networks, defined as

$$k_i^{in} = \sum_{j=1}^{N} a_{ji} \ \ \text{and} \ \ k_i^{out} = \sum_{j=1}^{N} a_{ij}.$$

(2) The betweenness centrality measures the potential ability of a node with respect to its role as a broker or a gatekeeper between nodes in the network, defined as

$$C_i = \sum_{j \neq i \neq k} \frac{b_{jk}(i)}{b_{jk}}.$$

Here, b_{jk} is the total number of shortest paths between j and k, while $b_{jk}(i)$ is the number of these paths that include node i. In the context of the patent licensing networks, betweenness centrality indicates the extent to which regions have competitive advantages regarding brokerage opportunities. Regions with higher betweenness centrality are those located at the core of the patent licensing networks. (3) In the directed weighted networks, the node strength s_i considers not only the number of neighbors' nodes but also the weights between the node and its neighbors (Barrat et al. [2004](#)). Foe instance, the node in-strength is defined as the sum of all its incoming link weights:

$$s_i^{in} = \sum_{j=1}^{N} w_{ji}.$$

In addition, due to the existence of self-tie, we also introduce self-strength to characterize the intraprovincial patent licensing flows.

Reciprocity An important aspect of social networks is the reciprocation (or otherwise) of relationships between actors (Garlaschelli and Loffredo [2004](#)). In adjacency matrix, reciprocity characterizes the probability that a randomly chosen link between two nodes also exists in the opposite direction (Maluck and Donner [2015](#)). In this study, however, reciprocity involves the ratio of the reciprocated flows between any pair of regions to all outward flows of the region pairs. We adopt the adapted Jaccard index (Real and Vargas [1996](#); Leydesdorff [2008](#)) to measure the reciprocity of any two regions to recognize the main bilateral patent flows in the networks. Herein, the Jaccard index is defined as

$$J_{ij} = J_{ji} = \frac{s_{ij}}{s_{i\cdot} + s_{\cdot j} - s_{ij}} + \frac{s_{ji}}{s_{j\cdot} + s_{\cdot i} - s_{ji}}, \ \ (i, j = 1, 2, 3, \ldots, N \ and \ i \neq j),$$

where $s_{i\cdot} = \sum_{\substack{j=1 \\ j \neq i}}^{N} s_{ij}$, $s_{\cdot j} = \sum_{\substack{i=1 \\ i \neq j}}^{N} s_{ij}$, $s_{j\cdot} = \sum_{\substack{i=1 \\ i \neq j}}^{N} s_{ji}$, $s_{\cdot i} = \sum_{\substack{j=1 \\ j \neq i}}^{N} s_{ij}$, and $s_{ij}(s_{ji})$ is the strength of patent licensing flows from region i to region j (j to i). Note that self-tie does not contribute to reciprocity, thus the value on the diagonal is zeroed ($J_{ii} = 0$).
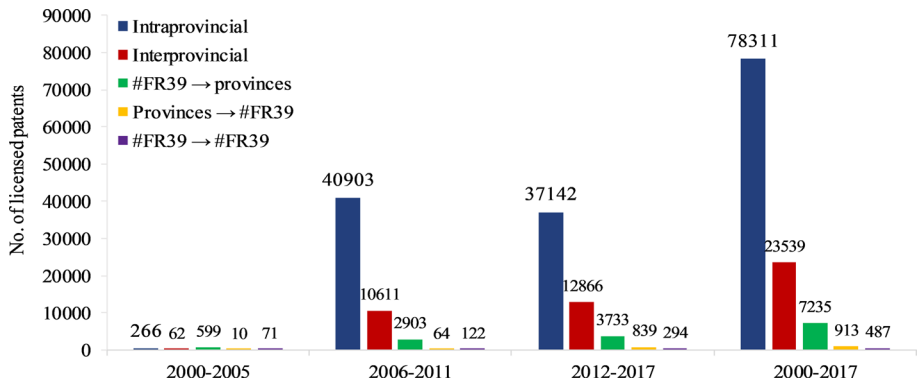
Fig. 3 Cross-region patent licensing frequencies during 2000–2017. Remark: #FR39 represents a collection of 39 foreign regions

Blockmodeling Generally, it is important for sociologists to identify actors that have similar patterns of ties to determine whether they are associated with a particular role or role set or whether actors with similar role sets are involved in characteristic patterns of ties. Actors with similar patterns of ties are said to be relationally equivalent, to constitute an equivalence class, or to occupy equivalent positions in the network (Nooy et al. 2006). Blockmodeling is a classic network technique for identifying these equivalent positions of actors (Lorrain and White 1971). It abstracts individual nodes to blocks through the values derived from structural equivalence analysis or particular indices. In this study, we calculate the dissimilarities between all pairs of nodes, and then cluster nodes which are (nearly) structural equivalent into positions by using hierarchical clustering. The network can thus be divided into several structural equivalence classes for further analysis.

4 Temporal changes in provincial technology flows

4.1 The subjects

As shown in Fig. 3, the patent licensing data is first analyzed according to its cross-region components in the periods considered. #FR39 acts as China's most important source of technology in the first period, accounting for 59.42% of the total number of patent licenses. To reverse this heavy dependence on foreign technology and enhance the ability of independent innovation, the Chinese government promulgated the "National Medium- and Long-Term Science and Technology Development Plan" in 2006 (State Council 2006). With the development of China's innovation strategy and the rapid development of China's patent transaction market, interprovincial technology flows in China have increased period by period, and the proportion of intraprovincial patent trade is fluctuating and rising. Overall, the ratio of intraprovincial technology flows and other technology flows, including the interprovincial, the #FR39→provinces, the provinces→#FR39, and the #FR39→#FR39, are 1:0.3006, 1:0.0924, 1:0.0117, and 1:0.0062, respectively, which indicates that intraprovincial patent transactions dominate Chinese technology flows.

Table 1 The proportional variations of technology sources for patent licenses (%)

Year	Individuals	Enterprises	R&D institutions	Universities and colleges	Govt. and social organizations
2000	50.91	30.91	16.36	1.82	0.00
2001	28.30	64.15	5.66	1.89	0.00
2002	27.93	69.15	1.86	1.06	0.00
2003	20.00	72.57	6.86	0.57	0.00
2004	22.46	75.36	2.17	0.00	0.00
2005	6.31	93.69	0.00	0.00	0.00
2006	26.67	72.38	0.00	0.00	0.95
2007	19.88	77.41	2.11	0.60	0.00
2008	50.32	38.30	4.08	7.13	0.18
2009	51.62	34.75	3.24	10.27	0.12
2010	54.09	32.87	3.29	9.66	0.08
2011	51.38	36.83	4.01	7.64	0.14
2012	45.82	42.34	2.10	9.53	0.22
2013	43.05	46.25	2.11	8.43	0.17
2014	37.89	50.39	3.72	7.78	0.22
2015	34.57	54.62	2.33	8.09	0.40
2016	23.90	57.82	4.01	13.45	0.81
2017	14.91	69.30	2.33	12.78	0.68

Patent licensors and licensees have been classified in function of the following subject types: (1) individuals, (2) enterprises, (3) R&D institutions, (4) universities and colleges and (5) govt. and social organizations. In terms of licensees, enterprises account for more than 95%. Table 1 shows the portion of patent licensors based on the type of subject. From 2001 to 2007, the main type of subject is the enterprise for the patent licensor, representing an average of 74.96%. This high percentage of contributions indicates strong enterprise implantation and market entry. However, during 2008–2012, a decrease in the percentage of enterprise patent licenses in favor of individual patent licenses reflects huge changes in Chinese policy. More specifically, the revised regulations on the determination of hi-tech enterprises in 2008 stipulated that enterprises can acquire exclusive license for more than 5 years to meet the hi-tech enterprise requirement (MOST, MOF, & SAT 2008), which greatly motivated enterprises to obtain low-cost patent licenses from individuals. Owing to the lack of financial, physical, or intellectual resources, it is difficult for individuals to commercialize patented technology through self-enforcing approaches, so they are much willing to monetize their technologies by granting their patents to others. Nevertheless, as the main market players, enterprises once again occupied a large share of licensors after 2013.

In addition, Table 1 also presents that R&D institutions accounted for 2–4% of the licensors over the past decade, while approximately 10% of patent licenses were issued by universities. That universities generally outdid the R&D institutions at technology output quantity indicates a relatively high level of technological marketization of the former. However, as universities and R&D institutions lagged far behind individuals and enterprises at output proportion, the role of universities and research institutes as innovation engines has not been fully realized in China. Information asymmetry is considered as a severe obstacle towards efficient knowledge transfer in the process of industry–university-research

Table 2 Changes in patent licensing types (%)

Year	Non-exclusive license	Exclusive license	Sole license
2002	53.53	17.74	28.73
2003	77.97	14.69	7.34
2004	66.44	28.08	5.47
2005	55.51	37.45	7.04
2006	58.76	33.75	7.49
2007	70.10	20.52	9.38
2008	6.66	91.54	1.80
2009	3.46	95.42	1.11
2010	4.08	94.68	1.24
2011	5.54	93.11	1.35
2012	9.40	88.90	1.70
2013	16.13	82.01	1.86
2014	18.32	80.06	1.62
2015	26.47	70.69	2.83
2016	58.62	34.40	6.98
2017	51.27	39.12	9.61

collaboration (Abramo et al. 2011). Herein, the 1980 Bayh-Dole Act can be referred to as a positive example. The Act reduced the cost of innovation flows and improved the overall efficiency in the entire innovation network, which therefore contributed to a significant growth in university–industry technology transfer and research collaboration throughout the US (Mowery and Sampat 2005). Thankfully, the Chinese government has recently taken a series of promotion measures to transfer the scientific and technological achievements from universities to industry. For example, the *Law of the PRC on Promoting the Transformation of Scientific and Technological Achievements* raises the minimum incentive standard for scientific and technological personnel to 50% from 20%, so as to motivate industrialization of scientific and technological achievements (MOST 2015). China has also established and funded a network of 2000 universities, colleges and technical institutes, coupled with 30 science parks and more than 200 government operated research laboratories (Gross 2013).

Table 2 reveals the annual trend in the proportion of patent licensing types. As shown, non-exclusive license existed as the majority between 2002 and 2007, accounting for approximately 64% on average. However, a proportion over 90% was constantly taken up by exclusive licenses from 2008 to 2012, which did not fall below 70% until 2016. This evidenced the huge impact of hi-tech enterprise recognition on technology trading market. The slow growth of non-exclusive licenses can also be well observed. Comparatively, the utilization of non-exclusive licenses can be more flexible. By signing non-exclusive licensing agreements with multiple licensees, licensors may control the relevant markets effectively and further increase revenues. The increased proportion of non-exclusive licenses also implicates an improved level for patent licensing utilization in China.

Table 3 The proportional variations of the eight sections of the licensed patents (%)

Year	A	B	C	D	E	F	G	H
2000	8.62	13.80	13.80	3.45	29.31	15.51	3.45	12.07
2004	10.80	6.82	15.91	1.14	4.54	3.98	18.75	38.07
2008	9.78	22.65	10.78	3.68	4.70	16.20	12.11	20.11
2012	12.45	22.86	13.68	1.96	5.90	16.73	11.50	14.91
2016	9.72	16.42	12.43	1.00	3.66	7.41	24.29	25.06

Table 4 The variations of patent licensing time-lags by the IPC (years)

Year	A	B	C	D	E	F	G	H
2000	3.48	4.53	8.23	3.83	4.35	4.94	5.75	4.83
2004	7.07	4.70	8.38	4.92	5.30	7.85	7.90	7.37
2008	3.74	3.30	4.59	3.58	3.19	3.17	3.32	3.10
2012	2.58	2.49	4.12	2.77	2.50	2.36	2.73	2.83
2016	3.86	3.31	4.09	4.69	3.46	3.58	8.38	5.90

4.2 The objects

The International Patent Classification (IPC) represents the whole body of knowledge which may be regarded as proper to the field of patents for invention, and be divided into eight sections as the highest level of hierarchy (WIPO 2019). The eight sections are entitled as follows: A (Human Necessities), B (Performing Operations; Transporting), C (Chemistry; Metallurgy), D (Textiles; Paper), E (Fixed Constructions), F (Mechanical Engineering; Lighting; Heating; Weapons; Blasting), G (Physics) and H (Electricity). Based on the IPC, we can examine the technical fields in which these patents belong to identify the most popular type of technology in China. Table 3 presents the proportional variations of the eight sections of the licensed patents by selected year, with the largest proportion of licensed patents in the fields of G and H (together with almost one-half of the licensed patents), followed by the classes B, C, A, F, which together represent another one-half. The classes D and E are the two least active technology fields, accounting for approximately 2% and 4% of the licensed patents, respectively. In addition, a patent may go through different legal states, including application, examination, withdrawal, and expiration. These are different life stages for the patent. It cannot enter directly into the implementation or licensing stage upon application and grant, but undergoes certain time interval between the generation and commercialization of the patent technology. Thus, patents in different technology fields might possess different time-lags at which the patent holders would choose different strategies (i.e., licensing old versus new technology). Table 4 reports the variations of patent licensing time-lags in different technology fields by selected years. The eight sections show remarkable difference in terms of patent licensing time-lags. In 2008 and 2012, the time-lags in all technical domains were relatively low. The classes B, E, and F are the three fastest domains of patents to be transferred, with a time-lag of about three and a half years.

In order to more clearly present what kind of technical field is easier and faster to be transferred, we introduce the matrix with average time-lags and average percentage during 2015–2017 as the lateral and ordinate axes, respectively. It is further divided into four quadrants (I, II, III, and IV) by the mean value line for eight classes, and a scatter diagram
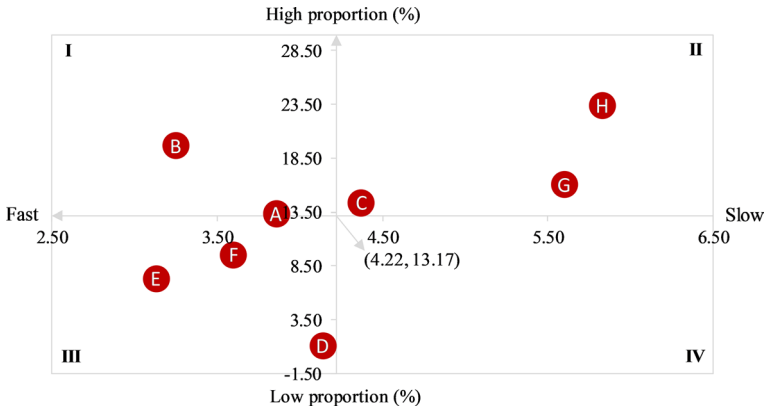
Fig. 4 Technology transfer speed and average percentage by technology field (2015–2017)

Table 5 Topological structure of the patent licensing networks

Indicator	2000–2005	2006–2011	2012–2017
No. of nodes	25	32	32
No. of links	86	627	688
No. of loops	22	30	31
Diameter	5	3	3
Density (loops allowed)	0.138	0.612	0.672
Clustering coefficient (random network)	0.227 (0.130)	0.771 (0.601)	0.767 (0.662)
Average path length (random network)	2.224 (3.025)	1.390 (1.398)	1.341 (1.338)
Average degree (in./out.)	3.44	19.59	21.50
The highest value of in-degree	7	30	30
The highest value of out-degree	16	30	32
Average strength (in./out.)	40.3	1706.3	1714.8
The highest value of in-strength	228	10,567	9467
The highest value of out-strength	670	10,133	8862
Sum of strength (in./out.)	1008	54,603	54,874

is then plotted (Fig. 4). There are significant differences in technology transfer speed and patent licensing probability among eight technology fields, which can be explained as they are quite different in commercialization speed as well as the success rate of technology transfer in the market. Our analysis shows that the first quadrant with the properties of faster transfer speed and higher proportion, contains only the class B; this class has an extremely active market performance and is favored by market players. Although the class H has the highest share, it has the lowest transfer speed in all classes. The other extreme is the class D, which has a medium technology transfer speed while having the lowest transfer success rate. The other classes are in the middle of the above three technology fields.

Table 6 The top 10 variations of node centralities in the networks

Rank	In-degree			Out-degree			Betweenness		
	2000–2005	2006–2011	2012–2017	2000–2005	2006–2011	2012–2017	2000–2005	2006–2011	2012–2017
1	Jiangsu (7)	Jiangsu (30)	Guangdong (30)	#FR22 (16)	Beijing (30)	Guangdong (32)	#FR22 (0.1796)	Jiangsu (0.0521)	Beijing (0.0439)
2	Guangdong (7)	Beijing (29)	Jiangsu (30)	Beijing (12)	Zhejiang (30)	Shanghai (32)	Beijing (0.1187)	Shandong (0.0500)	Guangdong (0.0412)
3	#FR22 (6)	Zhejiang (29)	Beijing (29)	Shanghai (7)	Jiangsu (28)	Beijing (31)	Jiangsu (0.0794)	Beijing (0.0361)	Sichuan (0.0384)
4	Beijing (6)	Guangdong (28)	Zhejiang (28)	Tianjin (6)	Shanghai (27)	Jiangsu (31)	Shanghai (0.0639)	Zhejiang (0.0361)	Jiangsu (0.0344)
5	Liaoning (6)	Shanghai (27)	Sichuan (28)	Jiangsu (5)	Guangdong (27)	Zhejiang (30)	Liaoning (0.0525)	Shanghai (0.0354)	Zhejiang (0.0244)
6	Zhejiang (5)	Shandong (27)	Hubei (28)	Shandong (5)	Shandong (27)	Shandong (29)	Guangdong (0.0515)	Anhui (0.0256)	Shanghai (0.0235)
7	Shanghai (5)	Anhui (27)	Anhui (27)	Liaoning (4)	Shaanxi (26)	#FR36 (28)	Nei Monggol (0.0399)	Shaanxi (0.0228)	Shaanxi (0.0196)
8	Sichuan (4)	Fujian (26)	Hunan (27)	Sichuan (4)	Hunan (26)	Fujian (27)	Zhejiang (0.0257)	Guangdong (0.0179)	Hubei (0.0137)
9	Hebei (3)	Hubei (26)	Guangxi (26)	Guangdong (4)	Sichuan (25)	Tianjin (27)	Sichuan (0.0245)	Heilongjiang (0.016)	Shandong (0.0114)
10	Anhui (3)	Hunan (25)	Shanghai (25)	Jilin (3)	Hubei (25)	Sichuan (26)	Jilin (0.0198)	Hunan (0.015199)	Henan (0.0114)

5 Spatial evolution of provincial technology flow networks

5.1 Topological structure and centrality measures

The patent licensing networks in this study are fully connected in different periods; in each period, the network contains only one giant component and there are paths between regions within this component. It should be noted that we merge all foreign regions into one node with the name #FR, and the number in parentheses after the name represents the number of foreign regions merged. Table 5 reports the topological structure of the patent licensing networks in three periods. We can gain the following information from Table 5.

First, the diameters of the patent licensing networks have remained somewhere between 3 and 5 in three periods, suggesting that the world of patent licenses is quite small. Compared with the corresponding random networks, patent licensing networks have the same level of average path lengths and a higher level of clustering coefficients, implying clear small-world phenomenon. Second, concerning the connectivity level of nodes, the value of the average degree increases from 3.44 in 2000–2005 to 21.50 in 2012–2017, indicating that a region is prone to establish more connections with other regions over time. Comparatively, the growth of average strength is more conspicuous, and the third phase is about 42 times higher than the first phase. Obviously, China's patent transaction market has experienced tremendous growth in the past two decades.

Table 6 reports the top ten regions that occupy the focal positions in the networks regarding in-degree centrality, out-degree centrality, and betweenness centrality. The results show that developed coastal provinces, including Guangdong, Jiangsu, Zhejiang, Beijing, Shandong, Anhui, and Shanghai, possess high in-degree and out-degree and have functioned positively in patent licenses. In terms of technology introduction and supply, the Yangtze River Delta, Pearl River Delta, and Beijing–Tianjin–Hebei area are the three regions where technology flow is most concentrated in China. The Yangtze River Delta formed by Jiangsu, Zhejiang, and Shanghai, is a region with high economic development, strong innovation ability, mature trading market, and reliable commercial environment. The Yangtze River Delta Technological Equity Trading Center is located in Jiangsu Province, and the China Technology Achievements Conversion Trading Center newly established in 2015 sits in the Shanghai Free Trade Zone. These provide unique superiorities for patent licenses, technology transfer, and commercialization regarding geographical and informational distance. The Pearl River Delta region centered on Guangdong is adjacent to Hong Kong and Macao. Such an absolute location advantage in South China conduces to attracting a large quantity of patented technologies and knowledge from all over the country.

5.2 Spatial evolution and reciprocity

Figures 5, 6 and 7 present dynamic patent licensing networks in the period 2000–2017. The sizes of nodes are weighted by their out-strengths. The colors of nodes indicate the strength of the flows. The loops indicate the intraregional patent licensing activities. Figure 5 contains 25 nodes, representing 24 Chinese provinces and #FR22. This diagram depicts a sparsely network structure, showing inactive patent licensing activities. During this period, foreign regions are the main technology exporters, and they create and export technology to provinces where technology is commercialized. Guangdong and Zhejiang are the two main "windows" for undertaking foreign patent technology. While gaining many foreign
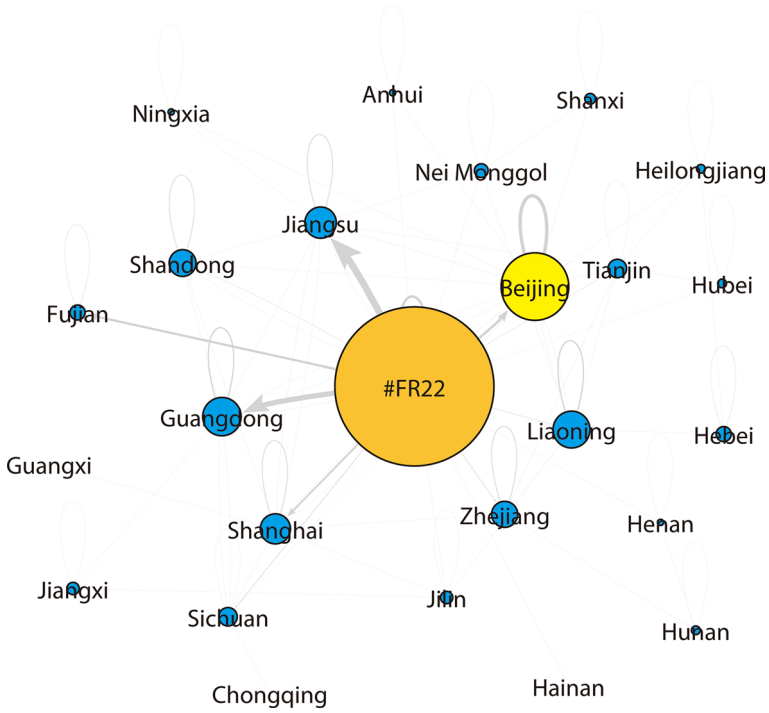
Fig. 5 Patent licensing network, 2000–2005 (Remark: #FR22 represents a node merging 22 foreign regions)
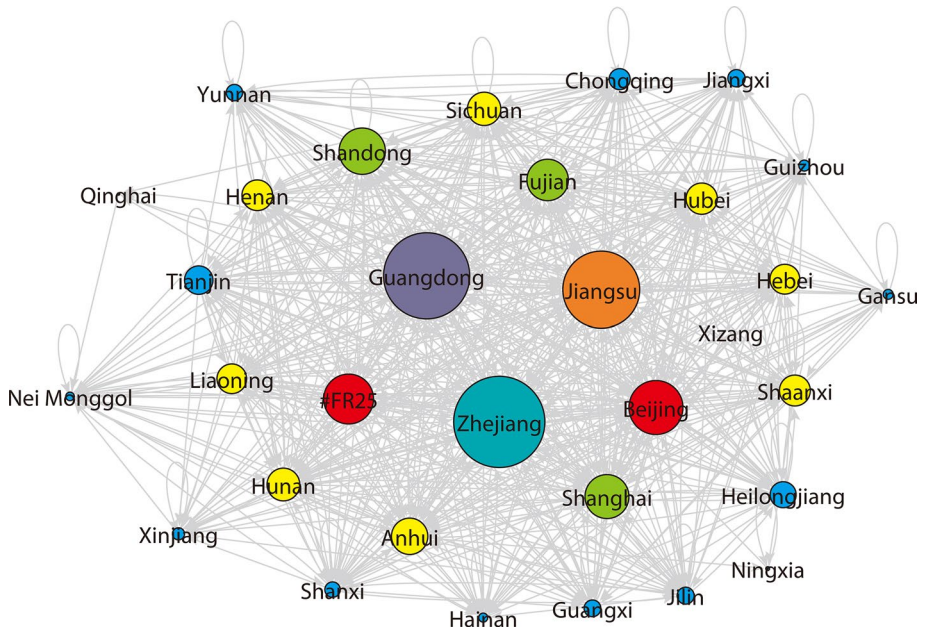

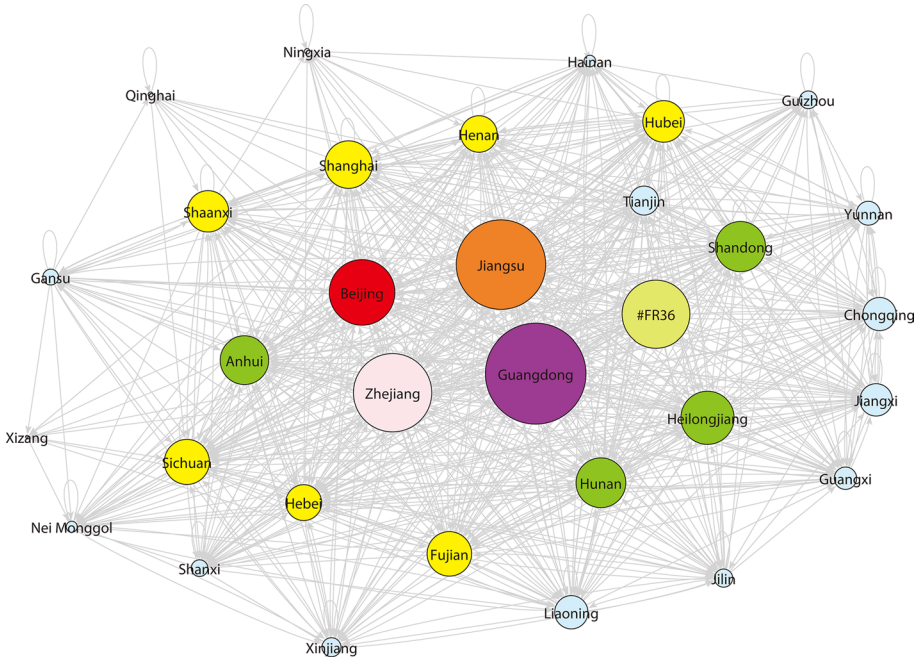**Fig. 6** Patent licensing network, 2006–2011

Fig. 7 Patent licensing network, 2012–2017

patent licenses, Beijing constantly enhances its original accumulation of patented technology. In addition, there are some underdeveloped provinces around the core regions, such as Ningxia, Guangxi, and Jiangxi.
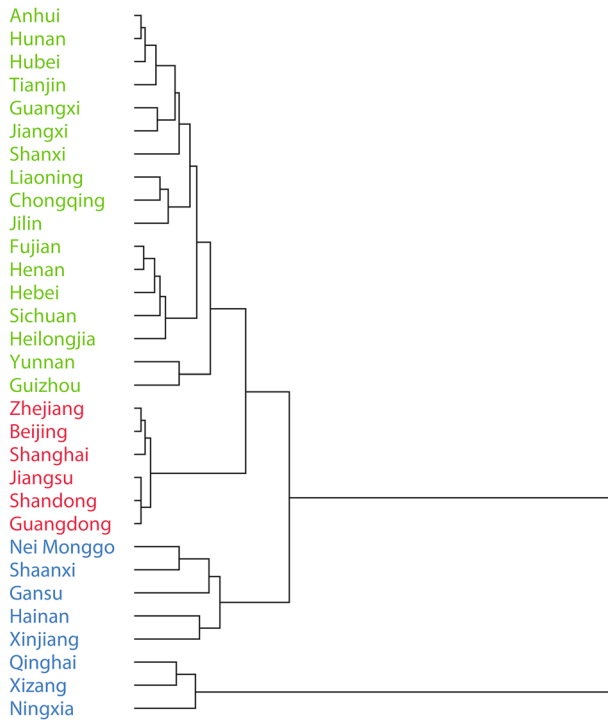
Figure 6 shows the patent licensing network during the period 2006–2011. The network has become denser and the strength of the connections among nodes has increased significantly. Guangdong, Zhejiang and Jiangsu are located in the center and have built up patent transaction relationships with various regions. Beijing also occupies a central position. Besides the four provinces mentioned above, Shandong, Shanghai and Fujian entered the central part of the network, while some provinces, such as Tianjin, Liaoning, Nei Monggol, have been crowded out to the periphery. In addition, foreign regions (#FR25) still play very important role in technology supply. The patent licensing network during the period 2012–2017 is depicted in Fig. 7. Comparing with the period 2006–2011, the most significantly distinguishable characteristic is that some semiperipheral nodes are replaced, such as Shanghai and Fujian relegated, while Anhui, Hunan and Heilongjiang upgraded. The center of the network is still occupied by several developed provinces such as Guangdong, Jiangsu and Zhejiang. Obviously, an integrally compact, locally dispersed, and multi-core structure centered on Guangdong, Zhejiang, Jiangsu, and Beijing is being formed in the patent licensing networks.

Although we have characterized the central nodes in the network through centrality measures, we still know very little about the interaction between any two nodes. Table 7 lists the top 10 bilateral technology flows based on the adapted Jaccard index for three periods. In period one, besides #FR22, the top 10 bilateral technology flows consist of 13 provinces. Among them, #FR22 occupies four bilateral technology flows, and the other half, such as Guangdong, Jiangsu, Beijing and Jilin, act as its important patent trading partners. In addition, Hunan and

Table 7 The top 10 region pairs in the networks

Rank	2000–2005		2006–2011		2012–2017	
	Region pairs	Jaccard index (%)	Region pairs	Jaccard index (%)	Region pairs	Jaccard index (%)
1	Zhejiang–Hunan	100.00	#FR25—Guangdong	20.72	#FR36—Guangdong	56.80
2	Hebei–Heilongjiang	50.00	Shanghai–Zhejiang	20.27	Jiangsu–Shanghai	22.85
3	Hunan–Henan	50.00	#FR25—Jiangsu	19.32	#FR36—Beijing	22.21
4	#FR22—Guangdong	48.53	Shanghai–Jiangsu	15.40	Beijing–Jiangsu	12.22
5	#FR22—Jiangsu	39.36	#FR25—Shanghai	13.52	Hunan–Chongqing	12.12
6	Jilin–Jiangxi	33.33	Beijing–Hebei	13.35	Zhejiang–Shandong	11.77
7	Nei Monggol–Shanxi	25.00	Zhejiang–Jiangsu	13.17	Beijing–Hebei	11.45
8	#FR22—Beijing	22.08	Jiangsu–Anhui	12.50	Zhejiang–Jiangsu	11.06
9	Hebei–Liaoning	20.00	Guangdong–Shaanxi	12.05	Zhejiang–Shanghai	10.73
10	#FR22—Jilin	18.18	Beijing–Jiangsu	11.65	Anhui–Henan	10.72

Fig. 8 Hierarchical Clustering of the patent licensing network in 2000–2017

Anhui
Hunan
Hubei
Tianjin
Guangxi
Jiangxi
Shanxi
Liaoning
Chongqing
Jilin
Fujian
Henan
Hebei
Sichuan
Heilongjia
Yunnan
Guizhou
Zhejiang
Beijing
Shanghai
Jiangsu
Shandong
Guangdong
Nei Monggo
Shaanxi
Gansu
Hainan
Xinjiang
Qinghai
Xizang
Ningxia

Zhejiang form the closest patent licensing relationship with a Jaccard index of 100%. In period two, Heilongjiang, Henan, Hunan, Jiangxi, Jilin, Liaoning, Nei Monggol, and Shanxi departed while Anhui, Shanxi, and Shanghai joined the group. Besides #FR25, the top 10 bilateral technology flows consist of 8 provinces. In this period, bilateral technology flows present higher convergence trends. However, this convergence trend is reversed during the third period.

On the other hand, the results also find that most of region pairs are apparently geographically adjacent. Therefore, geographical distance still constrains majorly the cross-regional technology flow in China despite its dramatic improvement in transportation and information technology. We hold that this observation results largely from the intrinsically incomplete nature of patent licensing contracts, which are commonly accompanied by technical consultants and services. Due to their inaccessibility through documents, faxes, and even phone or e-mail communications, geographic distance would to a large extent affect the subsequent costs. In this case, technology transaction entities with geographic adjacency are more likely to compensate for the additional costs of such imperfections. From a broader perspective, the technology flows in China are mainly confined to and between the four core regions of the Yangtze River Delta (Shanghai–Jiangsu–Zhejiang), the Pearl River Delta (Guangdong), the Beijing–Tianjin–Hebei area, and the central China area (Hubei–Hunan–Henan), implicating a huge imbalance in cross-regional technology flows.

5.3 Blockmodeling analysis

How has the pattern of relationships built up among the Chinese provinces beyond the level of individual region? We carried out a blockmodeling analysis by dividing nodes

Table 8 Block strength (density) matrix in 2000–2017

	Block 1 ($N_1 = 6$)	Block 2 ($N_2 = 17$)	Block 3 ($N_3 = 8$)	P_{thoery}^{intra}	P_{actual}^{intra}	P^{inter}	Position typology
Block 1	56,582 (Density = 1)	6076 (Density = 1)	777 (Density = 0.9375)	0.1935	0.8920	0.0401	Source
Block 2	4797 (Density = 0.9902)	29,315 (Density = 0.9204)	321 (Density = 0.4485)	0.5484	0.8514	− 0.1093	Absorber
Block 3	810 (Density = 0.6875)	298 (Density = 0.3971)	2874 (Density = 0.4531)	0.2581	0.7217	0.0045	Beginner

into three clusters in order to understand the change of licensing relationships among Chinese provinces. The blockmodeling is employed to explore what relationships exist among grouped blocks.

After excluding all foreign regions, we first calculate the dissimilarity of the rows and columns of the provinces in the original patent licensing network. The dendrogram of the network, which is depicted in Fig. 8, shows three very dissimilar clusters of provinces in the patent licensing network: six developed coastal provinces characterized by red, eight underdeveloped provinces characterized by blue, and seventeen medium-developed provinces characterized by green.

Based on hierarchical clustering, three blocks are identified in the patent licensing network, and the reduced block model with regard to the aggregation strength and density matrix is listed in Table 8. The density in the matrix are the ratio of actual ties to theoretical maximum ties from the blocks in the row position to the blocks in the column. To interpret how the individual blocks relate to each other in the reduced block model, we employed descriptive typologies of positions (Wasserman and Faust 1994) to summarize tendencies for blocks to send and receive ties within or outside the block. For intrablock relationships, consider the ties from provinces of block B_i. If there are N_i provinces in block B_i, then there are $N_i \times N_i$ possible ties within this block. In the whole group, there are N provinces; therefore, there are $N_i \times N$ possible ties in total sent by provinces in block B_i. If there is no bias toward (or away from) ties within the block, then we would expect the proportion of a block's total ties within the block:

$$P_{thoery,B_i}^{intra} = \frac{N_i \times N_i}{N_i \times N} = \frac{N_i}{N},$$

where P_{thoery,B_i}^{intra} is the theoretical intrablock spillover index of block B_i. The actual intrablock spillover index (P_{actual,B_i}^{intra}) of block B_i can be easily obtained by calculating the ratio of the actual out-strength within the block and its total out-strength. The index can be used as a baseline for evaluating the tendency toward within-position ties. Additionally, we put forward a new index to measure the interblock spillover as follows:

$$P_{B_i}^{inter} = \frac{\sum_{j=1,j\neq i}^{M} s_{ij} - \sum_{j=1,j\neq i}^{M} s_{ji}}{\sum_{j=1,j\neq i}^{M} s_{ij} + \sum_{j=1,j\neq i}^{M} s_{ji}} \in [-1, 1],$$

where M is the total number of blocks, and $\sum_{j=1,j\neq i}^{M} s_{ij}$ represents the total out-strength from block Bi to other blocks. When $P_{B_i}^{inter} > 0$, block Bi acts as a technology expansionist, and $P_{B_i}^{inter} < 0$ acts as a technology attractor. The closer the index is to 1 (or -1), the stronger the block's technological expansiveness (or attractiveness) capacity.

As shown in Table 8, Block 1 comprises six provinces, i.e., Zhejiang, Beijing, Shanghai, Jiangsu, Shandong, and Guangdong, each of which has high values of degree centrality, betweenness centrality and strength. In addition, the constituent provinces of Block 1 are closely connected to each other (density of Block 1 = 1). This block possesses a high intrablock spillover index and a relatively high positive interblock spillover index; thus, the provinces in this block are strongly capable of licensing their patents both internally and externally. Therefore, we define the role of Block 1 in the network as an extender. The constituent provinces of the extender block have numerous advantages regarding brokerage opportunities compared with other provinces due to their high betweenness centrality.

Fig. 9 Reduced graph of the patent licensing network in 2000–2017
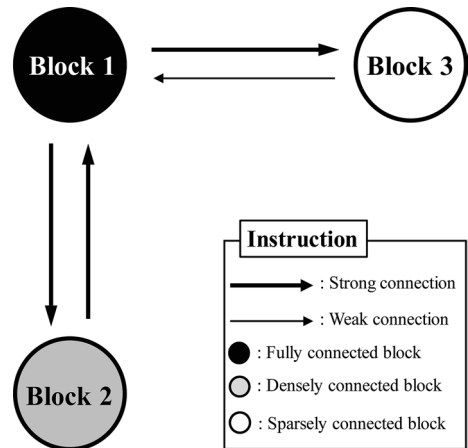
Block 2 contains seventeen provinces, i.e., Hebei, Anhui, Heilongjiang, Liaoning, Fujian, Sichuan, Tianjin, Hunan, Guangxi, Hubei, Henan, Jilin, Shanxi, Jiangxi, Chongqing, Yunnan, and Guizhou, with the second highest value of indicators (such as density of Block $2 = 0.9204$) among the three blocks. The fact that Block 2 has the second highest intrablock spillover index and negative interblock spillover index in the network demonstrates that these provinces in this block have a stronger tendency to obtain patented technologies from other provinces and are just beginning to develop the capability of generating patented technologies themselves. Block 2 can thus be defined as a absorber block. In addition, the constituent provinces of this block contain numerous redundant connections, and their advantages in terms of brokerage opportunities are very limited.

Finally, Block 3 consists of eight provinces, including Nei Monggol, Hainan, Ningxia, Shaanxi, Gansu, Xinjiang, Qinghai, and Xizang. Provinces within this block possess the lowest values of individual indicators and share relatively less mutual connections (density of Block $3 = 0.4531$). The constituent provinces in Block 3 can obtain patent licenses mainly from leading provinces but are unable to generate high-value patents or license patents to other provinces due to their low out-strength. Block 3 can thus be defined as a beginner block. The provinces in Block 3 do not possess any brokerage opportunities due to their low betweenness centrality.

Based on the characteristics of each block, a simplified graph of the patent licensing network can be constructed to show the patterns of intra- and interblock relations. Figure 9 presents the corresponding reduced pattern graph of the network. The constituent provinces of Block 1 having strong connections with Blocks 2 and 3 are the main suppliers of patent licenses to other provinces. Block 2 receives a strong linkage from Block 1 and establish a strong opposite connection with Block 1, indicating a strong reciprocal relationship between them. Moreover, the constituent provinces of Block 3 play a beginner role and have weak outward connections with the provinces in Block 1, showing that the technology flows between the central provinces and their neighboring western provinces are weak.

6 Conclusions and implications

This paper investigated licensed patents at the provincial level in the periods 2000–2017, to depict the profiles of the spatio-temporal evolution of provincial technology flow network in China. It involves all Chinese provinces and foreign entities taking part in CNIPA patent licensing activities. The statistical characteristics of patent licenses are first explored by the subjects and the objects, including cross-region patent licensing frequencies, the type of patent licensors, the distribution and technology transfer speed by technical fields. Then, we study the Chinese knowledge flows through patent licenses in three periods (2000–2005, 2006–2011 and 2012–2017). The network analyses are conducted from several aspects as follows: (1) the overall topological structure of technology flow networks, region importance by centrality and strength; (2) the spatial evolution of the patent licensing networks and the closest bilateral technology flows by employing adapted Jaccard index; (3) the pattern of relationships among the Chinese provinces, with the help of block-modeling analysis. The main findings of this study are summarized below.

First, in terms of the subjects. The intraprovincial patent licenses in 2012–2017 have outpaced the pattern of #FR39→provinces in 2000–2005. Due to the influence of hi-tech enterprise policies, patent transactions between individuals and enterprises are more active. In contrast, as universities and R&D institutions lagged far behind individuals and enterprises at output proportion, the role of universities and research institutes as innovation engines has not been fully realized in China. In 2008–2015, exclusive licenses played a very important role in hi-tech enterprise policies spurred by hi-tech enterprise policies, accounting for more than 90% of the total. However, as policy changes, this high proportion of exclusive licenses has been exceeded by non-exclusive licenses.

Second, regarding the objects. Overall, the class B (Performing Operations; Transporting) has an extremely active market performance and is favored by market players. The classes G (Physics) and H (Electricity) are the two most popular technology domains in Chinese patent trading market. By contrast, the classes D (Textiles; Paper) and E (Fixed Constructions) are the two least active technology fields. In 2008 and 2012, the technology transfer speeds in all technical domains were relatively fast. The classes B (Performing Operations; Transporting), E (Fixed Constructions), and F (Mechanical Engineering; Lighting; Heating; Weapons; Blasting) are the three fastest domains of patents to be transferred, with an average time-lag of about three and a half years.

Third, patent licensing networks present clear small-world phenomenon. Compared with the corresponding random networks, patent licensing networks have the same level of average path lengths and a higher level of clustering coefficients. The upward trend of the average degree indicates that a province in the patent licensing networks is prone to establish more connections with other regions over time. Comparatively, the growth of average strength is more conspicuous, indicating a tremendous growth of China's patent transaction market in the past two decades.

Fourth, patent licensing networks exhibit a highly unevenly distribution of degree centrality. The empirical results show that there is a conspicuous regional hierarchical structure for patent-expanding capabilities in various provinces. The significant coefficient of variation in betweenness centrality also indicates that the distribution of gatekeeper advantage in each province is profoundly unbalanced.

Fifth, spatial evolution results show that an integrally compact, locally dispersed, and multi-core structure centered on Guangdong, Zhejiang, Jiangsu, and Beijing is being formed in the patent licensing networks. The bilateral technology flows further present that

the technology flows in China are mainly confined to and between the four core regions of the Yangtze River Delta (Shanghai–Jiangsu–Zhejiang), the Pearl River Delta (Guangdong), the Beijing–Tianjin–Hebei area, and the central China area (Hubei–Hunan–Henan), implicating a huge imbalance in cross-regional technology flows.

Finally, based on blockmodeling analysis, three blocks that play different roles in the patent licensing network are distinguished: source, absorber and beginner. The source block is characterized by a high intrablock spillover index and a relatively high positive interblock spillover index; thus, the provinces in this block are strongly capable of licensing their patents both internally and externally. The absorber block have a stronger tendency to obtain patented technologies from other provinces and are just beginning to develop the capability of generating patented technologies themselves. In addition, the constituent provinces of this block contain numerous redundant connections, and their advantages in terms of brokerage opportunities are very limited. Provinces in the beginner block obtain patent licenses mainly from leading provinces but are unable to generate high-value patents or license-out patents to other provinces due to their low out-strength. They do not possess any brokerage opportunities due to their low betweenness centrality. Furthermore, the reduced matrix and graph of the network vividly depict the technology transfer patterns of intra- and interblock relations.

These findings have some important implications. First, the use of patent licensing data for network analysis helps explore the structure and evolution of technology flows at a regional scale. Network theory establishes the interpretation of social structures and processes with regard to relation schema. In this paper, network analysis revealed not only which provinces are the stars but also how provinces are connected to each other for the expansion and absorption of patented technologies. Second, the provincial technology flow mechanism in China is mainly characterized by self-absorption and interaction among developed provinces, supplemented by the gradient technology transfer from the eastern provinces and the reflows of the central and western provinces. As the technology sources, the eastern provinces provide a large number of technologies for the central and western provinces. A small number of technologies of the central and western provinces return to the eastern provinces, reflecting a "jumping flow" phenomenon. On the other hand, as a technology transfer station between the eastern and western regions, the brokerage potential of the central provinces remains to be developed. Third, the national system of technology flows in China is constructed as a block hierarchy structure. The blockmodeling analysis shows that there are asymmetric flows of patented technologies and capitals between different blocks. There is a highly positive correlation between the level of economic development and regional activity of patent licenses. The western region is vulnerable for patent licensing with a huge risk of isolation, which will further exacerbate the technology gap between eastern and western regions. A feeble knowledge flow behind patent licenses leads to a powerless impetus for indigenous innovation, thereby weakening the innovation ability and the momentum of sustained economic growth in West China. The importance of technology exchange among provinces has the Chinese government endeavor to balance domestically the technology generation and diffusion through establishing various technology markets (Johnson and Liu 2011).

In conclusion, although this paper uses network analysis to provide a number of valuable insights concerning the spatio-temporal evolution of technology flows in China, it suffers from a few limitations. For example, technology transfer is a complex system process, of which the spatial research should be further divided into industries and categories to reveal the characteristics and scale effects at varied spatial hierarchies. While directly reflected by patent licenses, cross-regional technology transfer involves in the

meantime knowledge cooperation, talent flow, government technology alliances, commodity exchange, and investment. Therefore, it is urgent to understand comprehensively the spatial law of cross-regional technology transfer in such aspects as research papers, project cooperation, high-end talent migration, R&D investment, and commodity exchange. In addition, cross-regional technology transfer is also affected by a serious of geographical factors like subject attributes, location conditions, and regional environment. It is necessary to explore the dynamic mechanism of cross-regional technology transfer from the perspectives of economy, technology, local policy, and geographic distance.

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