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Research Article

Spatial Pattern and Evolution of Global Innovation Network from 2000 to 2019: Global Patent Dataset Perspective

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In the era of the knowledge economy, the improvement of national innovation systems is playing a significant role in the global entrepreneurship ecosystem. Entrepreneurs are accelerating international intellectual property applications to be competitive. What remains to be explored is the evolution of international intellectual property network in the globe. With the application of social network analysis and intellectual property application database, the global innovation network structure from 2000 to 2019 is explored. Results showed that (1) in the period 2000–2019, the global innovation network has been expanding rapidly from a sparse network to a dense and complex one. (2) Patent application is unevenly distributed in the globe. Countries such as the US, China, and Canada have been the top countries flowing in, while Japan, Korea, EU, and Switzerland have been the main countries flowing out. (3) Global innovation network shows an obvious "core-periphery" pattern. The distribution pattern presents a quadrilateral structure with the four core regions of "US, Japan, EU, and China" as the apex. This analysis contributes to the visualization of the global layout of intellectual property and the evolution trend by analyzing intellectual property application networks. This can provide important experience reference for enterprises to study the global entrepreneurship ecosystem.

1. Introduction

Innovation is becoming the key driver for the survival and growth of firms in emerging and developed countries. With the continuous development of technology and the deep division of the global value chain, the development strategy of enterprises is entering an era in which growth is driven by knowledge innovation. For nations, innovation is far more important than land, physical capital, or labor in a knowledge-based economy, and is the dominating factor affecting different economic growth and development. As a result, the effective management of knowledge and innovation has gained increasing interest in the public debate, calling upon the contribution of scholars and practitioners [1]. One of the important views is that innovations never occur in isolation but on the contrary generated by networks of interacting actors (e.g., organisations, multinational enterprises, and individuals) [2]. For instance, multinational enterprises engage in overseas innovation for adapting products to meet the unique requirements in foreign markets [3]. Thus, inbound and outbound flows of knowledge activated by the stakeholders' interactions within a country make today's innovation ecosystem is highly globally interlinked [4].

In the era of the knowledge economy, intellectual property has become the core innovation factor, infiltrating into all fields of international trade. The identification of the main actors involved in regions has been revised across the years by, most recently, including the emerging markets [5, 6]. The concept of an innovation network was first proposed by Ernst [7] after he studied the internal relationship between regional production and global production. Since then, increasing studies have started related research, such as topological properties [8–10], spatial pattern [11], evolution process [12, 13], and mechanisms. The previous studies generally revealed the characteristics of innovation network, such as scale-free [8, 9], hierarchical [8, 9], and spatial agglomeration [12, 13]. It is also widely verified that cognitive proximity, social proximity, organizational proximity, institutional proximity, and geographic proximity are important factors affecting the evolution of innovation networks [14–18]. However, in view of the research scale, these studies have been conducted on either country or region scale because of the data availability [19, 20]. As the importance of interactions between different national innovation systems, the question arises that how nations perform in the global innovation network. Understanding knowledge network from a global view and monitoring the network evolution change in a global scale is necessary for enhancing innovation capability.

The intellectual property is an important driving force to encourage entrepreneurship, and an important means to maintain entrepreneurial achievements and promote the sustainable development of enterprises [21]. The intellectual property network has gradually become the main way to study regional knowledge spillover, innovation and technology diffusion, regional development path, innovation cluster, and other practical problems. The improvement of international intellectual property system, which is led by World Intellectual Property Organization (WIPO), is playing a significant role in the construction of global entrepreneurship ecosystem. WIPO provides us with a novel approach to obtaining innovation flows in global scale. Thus, the aim of this study is to explore how the structure of globalization of technology via intellectual property networks has changed longitudinally. The identification of the main countries in the global innovation network can not only describe the innovation performance and development strategy of each country but also can help to figure out the trend of global economy.

The rest content is divided into four sections. The first section briefly describes the data collection and method applied in this analysis. The results of properties, "core-periphery" pattern of global innovation network during 2000–2019 will be presented in the third section. The fourth section discusses the main findings and potential limitations outlined in this section. Following this section, an overview of potential avenues for further research is presented. This analysis will contribute to current studies by visualizing the global layout of intellectual property, which provides references for enterprises to study the global entrepreneurship ecosystem.

2. Methodology

2.1. Data Source and Network Generation. In this study, we use a comprehensive dataset from WIPO to investigate the structure and dynamics of global innovation network from 2000 to 2019. Innovation has been the primary driving force for development in the past decades. In the twenty-first century, especially, globalization, information and intelligent development, which are inseparable from technological innovation, have provided large support for the world economy. In order to explore the evolution of global innovation since the 21th century, the year 2000 is chosen as the starting year while the year 2019 is chosen as the ending year due to the emergence of COVID-19 in 2020.

WIPO, which manages the international application system and the global intellectual property system, is an intellectual property management agency affiliated with the United Nations. Compared with other intellectual property databases, it has a long history (since 1967) with a large volume of data (more than 55 million patent records) and a large number of member countries (193 member countries). It provides free intellectual property information as well as patents from the African Regional Intellectual Property Organization (ARIPO), the Eurasian Patent Organization (EAPO), and the European Patent Office (EPO) and regional patent office's records. Furthermore, the WIPO dataset can provide the information on filing office and application's origin which is basic for constructing networks in our analysis. Therefore, the dataset of the WIPO Intellectual Property Statistics Data Center (https://www3.wipo.int/ipstats) is applied in this analysis. Based on the availability and reliability of data, this analysis selects 203 countries and regions as the research objects. The gross domestic product (GDP) and patent applications of these countries and regions account for more than 90% of the global value, which can represent the basic situation of the global innovation cooperation network.

In the process of data collection, this analysis selects the "total number of patent applications (direct application and entry into the PCT national phase)" instead of granted applications. Due to the complicated process of application and differences between countries, the approval process of one patent might take years. For this reason, the number of granted applications cannot reflect the latest technological development and changes in the field of innovation. The report type selection is counted by the filing office and the origin of the applicant. In order to analyze the evolution of the global innovation cooperation network, data from 2000 to 2019 are collected and applied in this analysis. Besides, there are some missing data in individual countries in some years. To minimize the impact of missing data, the processing method of this analysis is (1) to supplement the missing data with interpolation; (2) to average all the data every five years. In addition, this analysis merges the countries that joined the European Union (EU, hereafter) that year into the EU. Finally, this analysis constructs a patent data matrix for four periods: 2000–2004, 2005–2009, 2010–2014, and 2015–2019. According to the selected countries identified above, there were 185 nodes in the global innovation network in 2000–2004, 175 nodes in 2005–2009, 173 nodes in 2010–2014, and 172 nodes in 2015–2019. The change in the number of nodes is due to the accession of some countries to the EU during the study period. Thus, directed adjacent matrices of $185 * 185$, $175 * 175$, $173 * 173$, and $172 * 172$ were constructed based on the strength of patent edges (Figure 1). The values in the matrix represent the number of patents between the two countries, and the matrix is directed.

2.2. Indicators of Network Analysis. By constructing a weighted network, we explore the direction and strength of the connection between countries. This analysis adopts a

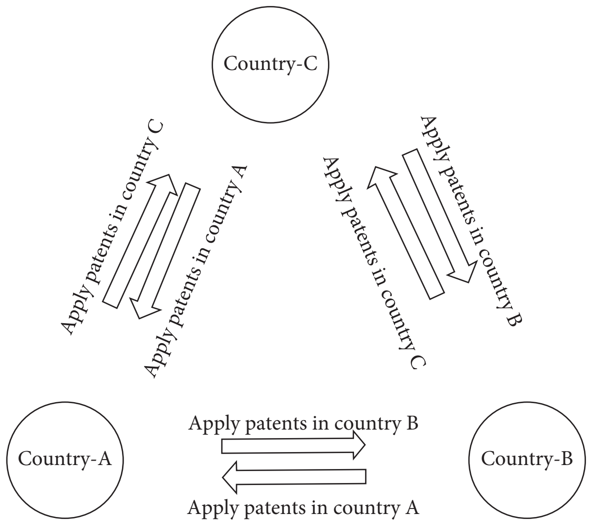

Figure 1: Construction of innovation network with patent.

directed weighted network, which can reasonably evaluate the spatial structure characteristics of innovation network.

2.2.1. Key Indicators. This analysis aims to analyze the network structure and evolution of the global intellectual property network (GIPN) from network scale, small-world property, scale-free property, centrality properties' views. In general, $G = (V, E)$ stands for a directed network, V is the set of nodes while E is the set of edges. Density and network diameter are used to indicate the scale of the GIPN. The value of density refers to the ratio of the number of actual network relationships to the maximum number of possible relationships. The network diameter is the longest path of any two nodes in the entire network. The specific calculation formulas are

$$D = \frac{2M}{N(N-1)},$$
$$R = \max_{\forall v_i, v_j \epsilon V}\left(r\left(v_i, v_j\right)\right), \tag{1}$$

where D refers to the network density, R refers to the network diameter, M refers to the number of relationships existing in the actual network, and N represents the number of nodes in the network. v_i, $v_j \in V$, $r(v_i, v_j)$ represents the longest path between nodes i and j.

The average clustering coefficient and average path length are used to analyze small-world properties of the GIPN. The average cluster coefficient is the mean of the clustering coefficient of all nodes. The cluster coefficient of a node is the density of its open neighborhood [22]. The neighborhood (N_i) of node v_i is the set of its adjacent nodes. N_i is defined as

$$N_i = \left\{v_j\colon e_{ij} \epsilon E \vee e_{ji} \epsilon E\right\}. \tag{2}$$

Cluster coefficient is calculated by means of the following formula:

$$C_i = \frac{\left|\left\{e_{jk}\colon v_j, v_k \epsilon N_i, e_{jk} \epsilon E\right\}\right|}{N(N-1)}, \tag{3}$$

where C_i refers to the cluster coefficient of v_i. Average clustering coefficient (C) is calculated as

$$C = \frac{1}{N}\sum_{i=1}^{n} C_i. \tag{4}$$

The average path length is the average number of edges along the shortest path for all possible pairs of nodes.

$$L = \frac{1}{N(N-1)}\sum_{i,j} d\left(v_i, v_j\right), \tag{5}$$

where L refers to the average path length and $d(v_i, v_j)$ represents the shortest path between nodes i and j.

Centrality measurements are used to identify nodes that are most critical and central in networks. Among which, degree, betweenness, and closeness centralities are the most widely used indexes. Degree centrality is calculated by means of the following formula:

$$DC_i = \sum_{j=1}^{N} w_{ij}. \tag{6}$$

The degree centrality can be calculated according to weighted network data or binary network data. In this analysis, weighted data are used to calculate the degree centrality of each node. w_{ij} is the number of patents between country i and j.

Closeness centrality refers to the mean geodesic path between nodes in networks. Here, the geodesic path is defined as the number of edges traversed from node i to j. Thus, a node with a high closeness centrality indicates a short communication edge to other nodes in networks. In general, geodesic paths are not unique, as there can be several paths between two given nodes with the same shortest length. However, at least one geodesic path always exists between any two nodes in the same connected component of a network. The mean geodesic distance between i and all other nodes in the network is given by

$$g_i = \frac{1}{N}\sum_{j=1}^{n} \gamma_{ij}. \tag{7}$$

Here, γ_{ij} refers to the number of edges traversed from node i to j. Then, the closeness centrality CC_i of node i is defined as follows:

$$CC_i = \frac{1}{g_i} = \frac{N}{\sum_{j=1}^{n} \gamma_{ij}}. \tag{8}$$

Another notion of centrality is betweenness centrality, which measures the number of short paths between nodes while they pass through a given node. Thus, we define

$$v_i(s,t) = \begin{pmatrix} 1, & \text{if } i \text{ lies on the geodesic path from } s \text{ to } t \\ 0, & \text{otherwise,} \end{pmatrix}. \tag{9}$$

Then, the betweenness centrality BC_i of node i is

$$BC_i = \sum_{s,t\in N} v_i(s,t). \tag{10}$$

DC_i and CC_i analyze the properties of nodes. Graph centrality is used when the focus is on the whole network. This analysis uses graph degree centrality and graph betweenness centrality to analyze the centrality trend of the whole network [23]. The specific calculation formulas are

$$\begin{aligned} DC &= \frac{\sum_{i=1}^{N}\left(DC_{\max} - DC_i\right)}{N^2 - 3N + 2}, \\ BC &= \frac{\sum_{i=1}^{N}\left(BC_{\max} - BC_i\right)}{N^3 - 4N^2 + 5N - 2}, \end{aligned} \tag{11}$$

where DC and BC refer to the graph degree centrality and graph betweenness centrality, and $DC_{\max}$ and $BC_{\max}$ represent the maximum value of DC_i and BC_i.2.2.2. In-Out Flow

The in-out flow is calculated based on out-flow and in-flow. The out-flow is defined as

$$O_i = \sum_{i\neq j}^{n} S_{ij}, \tag{12}$$

where S_{ij} refers to the number of patents flowing from country i to country j. O_i refers to the number of patents flowing out of country i. The in-flow is defined as

$$I_i = \sum_{i\neq j}^{n} S_{ij}', \tag{13}$$

where S_{ij}' refers to the number of patents filed by country i in country j. I_i refers to the total number of patents filed by country i. Then, we compare the out-flow and in-flow, which is referred as in-out flow.

$$\text{In} - \text{out flow}_i = I_i - O_i. \tag{14}$$

There are two possible results: (i) $\text{In} - \text{out flow}_i > 0$, which presents country i has more in-flow than out-flow, indicating the number of patents flowing into country i is higher than the number of patents flowing out. (ii) $\text{In} - \text{out flow}_i < 0$, which presents country i has more in-flow than out-flow, indicating that the number of patents flowing out from country i is higher than the number of patents flowing in.

2.3. Coreness. There is often a core edge structure in the network, so the coreness is introduced to quantitatively study the status of each node in the network, and have a quantitative understanding of where the node is (core, semicore, and periphery). When calculating the coreness, each node needs to be given a coreness c_i. The coreness is calculated by the following steps:

$$\delta_{ij} = c.c^T. \tag{15}$$

δ_{ij} is the pattern matrix of the network data matrix W_{ij} to be analyzed. c is the eigenvector, and c^T is its transpose vector. The core-periphery analysis method finds the eigenvector c, which can make the correlation coefficient maximum between the actual matrix W_{ij} and the pattern matrix δ_{ij}. The element c_i in eigenvector c is the coreness of each node in the network. This indicator is achieved by the Ucinet platform.

In order to construct a continuous core-periphery model, nodes in the GIPN are divided into the following four layers: nodes with a coreness greater than 0.2 belong to core layer; nodes with a core degree between 0.01 and 0.2 are semicore countries, nodes with a coreness between 0 and 0.01 are semicore countries, and countries with zero coreness are considered as peripheral nodes.

3. Results

3.1. Key Indicators. Table 1 presents the summary statistics of complexity of the GIPN from 2000 to 2019. The following observations can be gained.

(1) The density and the number of edges increase, and the network becomes denser. From 2000 to 2014, the scale of the GIPN expanded rapidly, and the number of nodes in the network declined. This is due to the increasing number of EU countries in the sample. At the same time, the number of edges expanded rapidly, from 1772 in 2000–2004 to 3070 in 2015–2019. The network density increased rapidly from 0.0521 to 0.1044, indicating that the global urban innovation network has gradually grown from a sparse network to a dense and complex network.

(2) In view of the centrality indicators, the weighted degree centrality increased from 8.14 to 15.08. The average intermediary centrality of the GIPN has gradually increased, indicating that some countries have gradually increased their ability to control and deliver innovation. Besides, closeness centrality increased from 2.87 to 7.23, indicating that the relationship between countries and the core countries of the innovation network is getting closer.

(3) Both degree centrality and betweenness centrality have large Gini coefficients and coefficients of variation, and the nodes in the network are very polarized. The Gini coefficient of degree centrality is relatively large, remaining above 0.88, indicating that the GIPN exhibits a strong discrete trend and extremely unbalanced characteristics.

(4) In view of the evolution over the years, the coefficient of variation of degree and betweenness centrality shows a downward trend, indicating that the discrete trend of the GIPN has declined.

3.2. Global Distribution. In this section, the topological relationship is converted to spatial connections with the application of the ArcGIS platform. The difference between in-flow and out-flow in 2000–2019 is visualized in Figure 2, and three observations were gained.

Table 1: Complexity statistics of global intellectual property network from 2000 to 2019.

Statistical characterstics	Index	2000–2004	2005–2009	2010–2014	2015–2019
Network scale	Number of nodes	185	175	173	172
	Number of edges	1772	1791	2650	3070
	Density	0.0521	0.0588	0.0891	0.1044
	Diameter	4	3	3	4
Small-word property	Average clustering coefficient	0.76	0.785	0.752	0.757
	Average path length	1.918	1.828	1.823	1.804
	Power law fitting of degree centrality	$y = 1618.2X^\wedge - 1.313$	$y = 1415.3x^\wedge - 1.271$	$y = 1965.8x^\wedge - 1.246$	$y = 1972.7x^\wedge - 1.216$
Scale-free property	$R2$	0.7984	0.7871	0.7405	0.7262
	Exponential fitting of degree centrality	$y = 88.082e^\wedge - 0.031x$	$y = 90.871e^\wedge - 0.032x$	$y = 125.85e^\wedge - 0.029x$	$y = 138.6e^\wedge - 0.029x$
	$R2$	0.9895	0.9847	0.983	0.9807
Degree centrality	Average degree centrality	8.143	9.051	13.503	15.028
	Graph degree centrality	0.539	0.577	0.61	0.641
	Coefficient of variation	1.487	1.443	1.19	1.135
	Gini coefficient	0.961	0.96	0.955	0.954
Betweenness centrality	Average betweenness centrality	0.369	0.379	0.473	0.458
	Graph betweenness centrality	0.143	0.144	0.138	0.157
	Coefficient of variation	4.615	4.403	3.677	3.852
	Gini coefficient	0.887	0.941	0.916	0.91
Closeness centrality	Average closeness centrality	2.872	2.049	7.213	7.23
	Coefficient of variation	0.0063	0.0066	0.0177	0.0177
	Gini coefficient	0.003	0.004	0.01	0.01

First, in view of the overall distribution pattern of the GIPN, countries that were most deeply embedded in GIPN include the US, China, Korea, Japan, EU, Switzerland, and Canada, as shown in Figure 2. Specifically, the US, China, and Canada have been the top countries with large in-flow patent and small out-flow patents during 2000–2004. Since then, China and the US have jointly occupied important positions in the GIPN. Besides, Japan, Korea, EU, and Switzerland have been the top countries with large out-flow patents and small in-flow patents. Second, the transferring direction has been concentrated among these top cities. For instance, the in-flow and out-flow patents among the USA, Japan, China, and Korea occupied more than 60% of the total. Besides, the transferring direction of patented technology is mainly east-west in the northern hemisphere. Third, increasing in-flows in Asian countries can be observed. These Asian countries include Viet Nam, Thailand, Malaysia, Singapore, and Indonesia.

3.3. In-Out Flow of the Global Intellectual Property Network. For our interests in the positions of a country, the countries' position is overlaid by differencing in-flow and out-flow. The analysis of ranking countries in the GIPN was conducted in the last 20 years periods from 2000 to 2019. In view of the in-flow, our results point to the evolution of countries' positions in the GIPN (Figure 3). The first point to make here is that the primary three countries, including the US, Japan, and China (Figure 3, dark lines), have remained the top three positions in the past years. Specifically, the total in-flow in the three countries share more than 52% of the total volume. Moreover, the concentration of in-flow in the three countries has been increasing. Specifically, the in-flow volume accounts for 52.2% during 2000–2014 while the percentage has increased to 63.6% during 2015–2019. This indicates that the three countries possess high position relative to their economic and innovation potential in the GIPN. The second point is that some countries have raised their position largely. These countries include Korea, India, and Indonesia reflecting the trend from the low rank to the high rank in the GIPN. The third point is that some countries, including Canada, EU, and Brazil, rank from higher to lower positions.

In view of the out-flow, our results point to the evolution of countries' positions in the GIPN (Figure 4). The first point to make here is that the primary three countries, including EU, Japan, and the US, have remained in the top three positions in the past years. Specifically, the total in-flow in the three countries shares more than 49% of the total volume. The concentration of the out-flow in the three countries has been decreasing. Specifically, the out-flow volume account for 51.7% during 2000–2014 while the percentage has decreased to 49.6% during 2015–2019. This

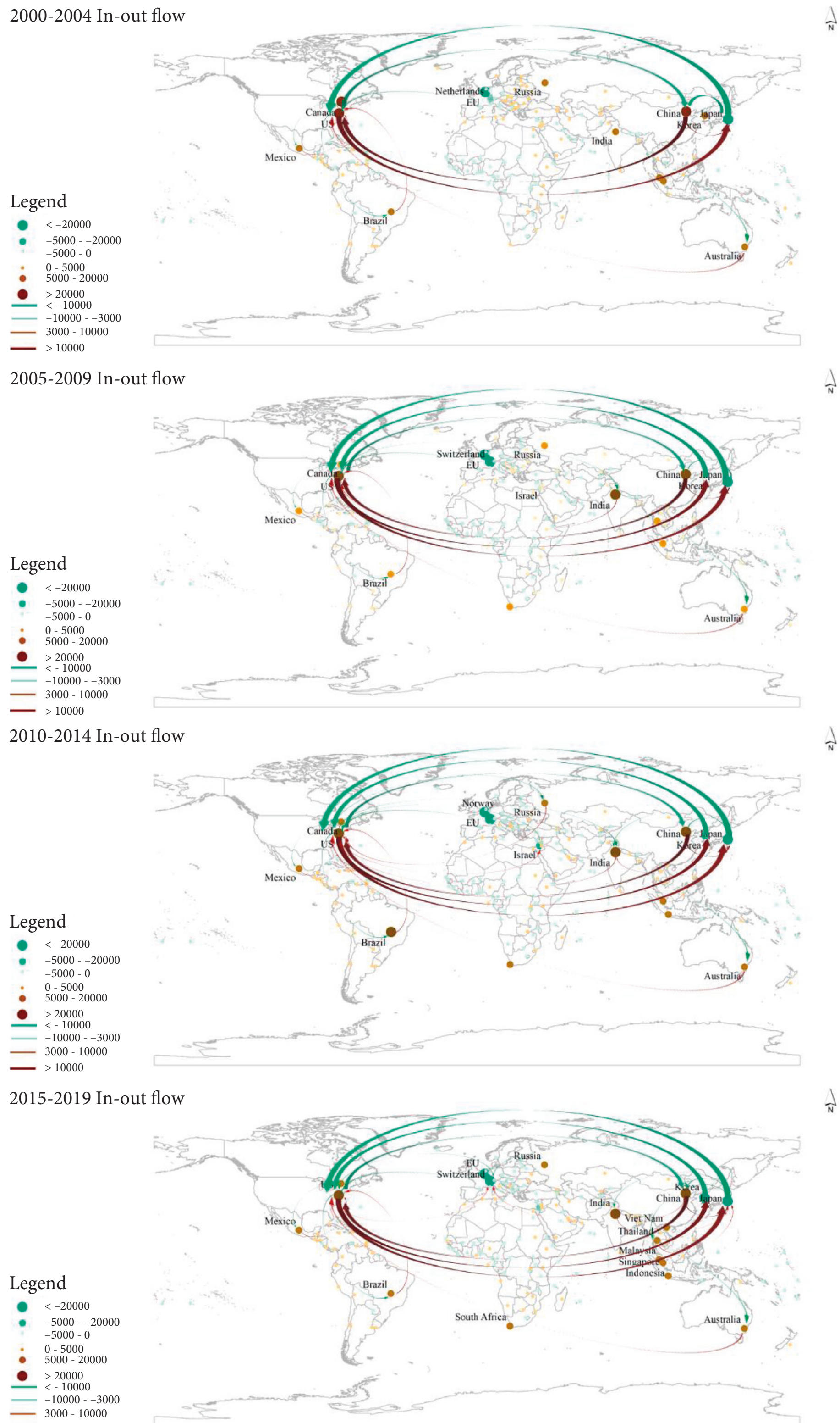

FIGURE 2: In-out flows of countries in 2000–2019.

indicates that the three countries possess high positions relative to their economic and innovation potential in the GIPN. The second point is that some countries have raised their position largely. These countries include China, India, Singapore, and Kazakhstan, reflecting the trend from the low rank to the high rank in the GIPN. The third point is that some countries, including Switzerland, Canada, and New Zealand, rank from higher to lower positions.

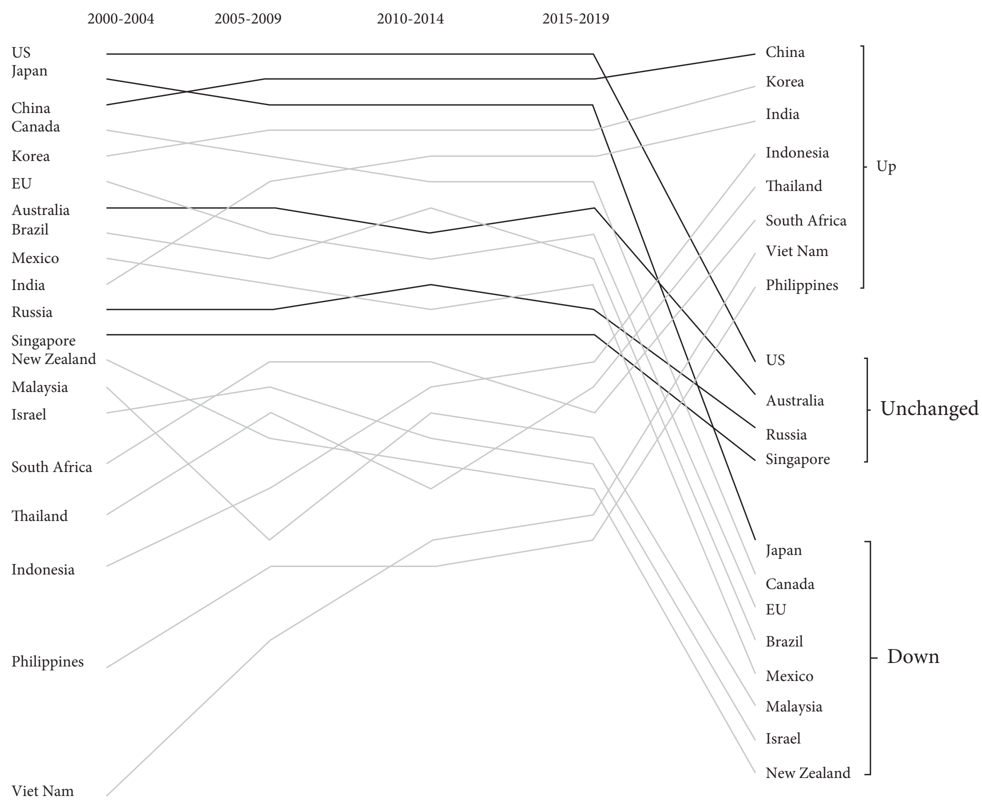

Figure 3: Positions of countries in in-flow.

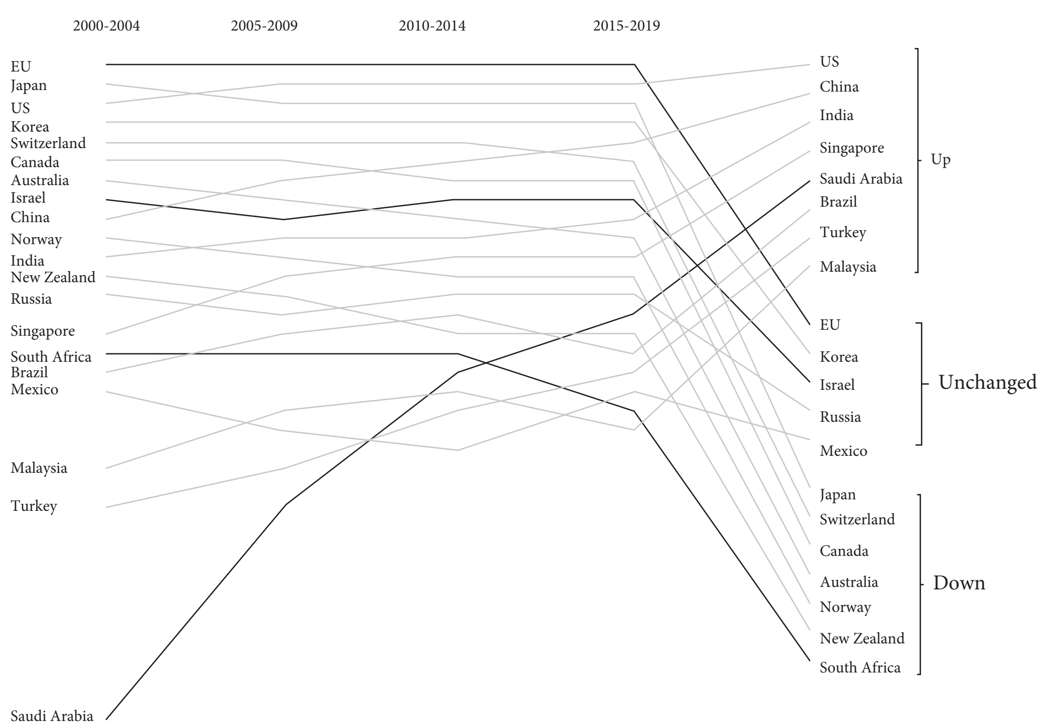

Figure 4: Positions of countries in-out flow.

3.4. Core and Periphery of the Global Intellectual Property Network. The centrality is an important indicator to measure the degree of centralization of the entire network. From 2000 to 2019, the degree centralization of the GIPN was basically maintained at about 0.6, and the closeness centralization was basically maintained at about 0.65, indicating that the entire network has a relatively obvious direction, indicating a significant core-periphery structure with hierarchies in the GIPN (Figure 5). In sum, the following three observations can be gained.

(1) In the core layer, the GIPN gradually developed from a triangular structure to a quadrilateral pattern. Specifically, the coreness of the four periods from 2006 to 2010 has always been higher than 0.8, becoming the absolute core of the network. EU and Japan have far lower patent transfers than the US. As a result, the core countries from 2000 to 2009 are the US, Japan, and the EU. China has performed well, and its core degree has always increased, from 0.105 in 2000–2004 to 0.262 in 2015–2019, further narrowing the gap with the EU. As a result, China ranks among the core countries of the innovation network.

(2) In the semicore (second) layer, it has maintained a relatively stable state. Specifically, Australia, Brazil, Canada, China, India, Israel, Mexico, Korea, Russia, Singapore, and Switzerland have stayed in the semicore layer.

(3) The innovation network presents an obvious phenomenon of cooperation aggregation-technical cooperation within core countries, between core and semicore countries, is intensive, while the participation of peripheral countries in the GIPN is limited.

In view of the patent transfer among layers, three observations can be observed (Table 2). First, in sum, patent within the core layer and between the core and semicore layer occupies more than 87% of the total patent. Second, the transfer of patents at the core layer is more concentrated. In the two phases of 2000–2004 and 2005–2009, the proportion of patent transfers at the core layer composed of the US, EU, and Japan was 39.45% and 34.34%, respectively, which decreased somewhat. From 2010 to 2019, due to China's entry into the core layer, the proportion has increased sharply to 49.76% and 50.03%, respectively. Third, the technology spillover effect from core layer to semicore is obvious, manifesting in the increment in patent transfer from 10.07% to 15%. The technology transfer from semicore to core layer has dropped significantly, and the number of patent transfers has increased from 39.56% to 22.4%.

4. Discussion

The 21st century has seen rapid development and wide application of various emerging technologies such as the Internet, big data, cloud computing, artificial intelligence, and blockchain. The production, search, dissemination, and application of knowledge have effectively broken through the limitations of geographical distance. Innovation activities have expanded from within the organization to cross-organizational and cross-regional networks, and gradually evolved into a global network. As a result, the scale of the GIPN expanded rapidly from a sparse network to a dense and complex network. As the number of global patent cooperation increase continually, the patent cooperation network shows obvious small-world characteristic, and the integration of countries is high, which helps to obtain new information and new resources, and strengthen patent cooperation and innovation among countries.

Our results also suggest some important implications. First, the patents dataset is useful for exploring the global trends of technological diffusion. The strength of network analysis is that it describes the relationships among countries. In this study, network analysis presented not only which countries have higher technological capabilities but also how countries are mutually connected for technological collaboration or transfer. Since 2000, the GIPN has gradually lost its scale-free feature, and the small-world feature has been continuously strengthened [24].

Second, intellectual property is an important indicator to forecast global investment flow and entrepreneurial environment. As innovation shows the property of clustering, which provides an important driving force and encouragement for entrepreneurship [25]. In a long term, the pattern of the GIPN has presented a triangle structure with the three core regions of "US-EU-Japan." The triangle structure accumulated a large number of patents. Since 2005, the pattern of the GIPN has presented a diamond structure with the four core regions of the US, EU, Japan, and China, as the apex. Although the US, EU, and Japan have been the core of the GIPN, Asian countries have gradually improved their status in the cooperative innovation network and gradually entered the core layer [26, 27]. Patent plays a key role in transferring innovations and changing the social, economic, and political system on a global level. Through innovative production and technological cooperation, countries gained chances to surpass their original innovative production network system and achieve a certain degree of leapfrog development. Existing studies have shown that emerging marketing countries' positions in the GIPN have been raised gradually [27–29].

Third, the GIPN has been structured as a core-peripheral structure. During the period of 2000–2009, the US has been the absolute core in the GIPN. Our analysis also presents an interesting observation that the countries' positions in the GIPN have been relatively stable. Specifically, the US, EU, Japan, China, Australia, Brazil, Canada, China, India, Israel, Mexico, Korea, Russia, Singapore, and Switzerland have remained in the top positions in the GIPN. Enterprises, especially multinational companies, are the mainstay of innovation. Multinational companies transfer innovation to various countries through R&D alliances, cooperation agreements, subsidiaries, and affiliates. Therefore, the GIPN is an extension of the global production network [30]. In the GIPN, information technology and industry are combined to form a useful supplement to the internal innovation activities of enterprises and their core competitiveness. However, even so, in the industrial value chain, the innovation function is the most difficult to transfer. In comparison, patent greatly influences global technology collaboration among well-developed or major economically powerful countries while less developed countries have less potential to participate in the process of global technology transfer. In other words, the division of labor in the global

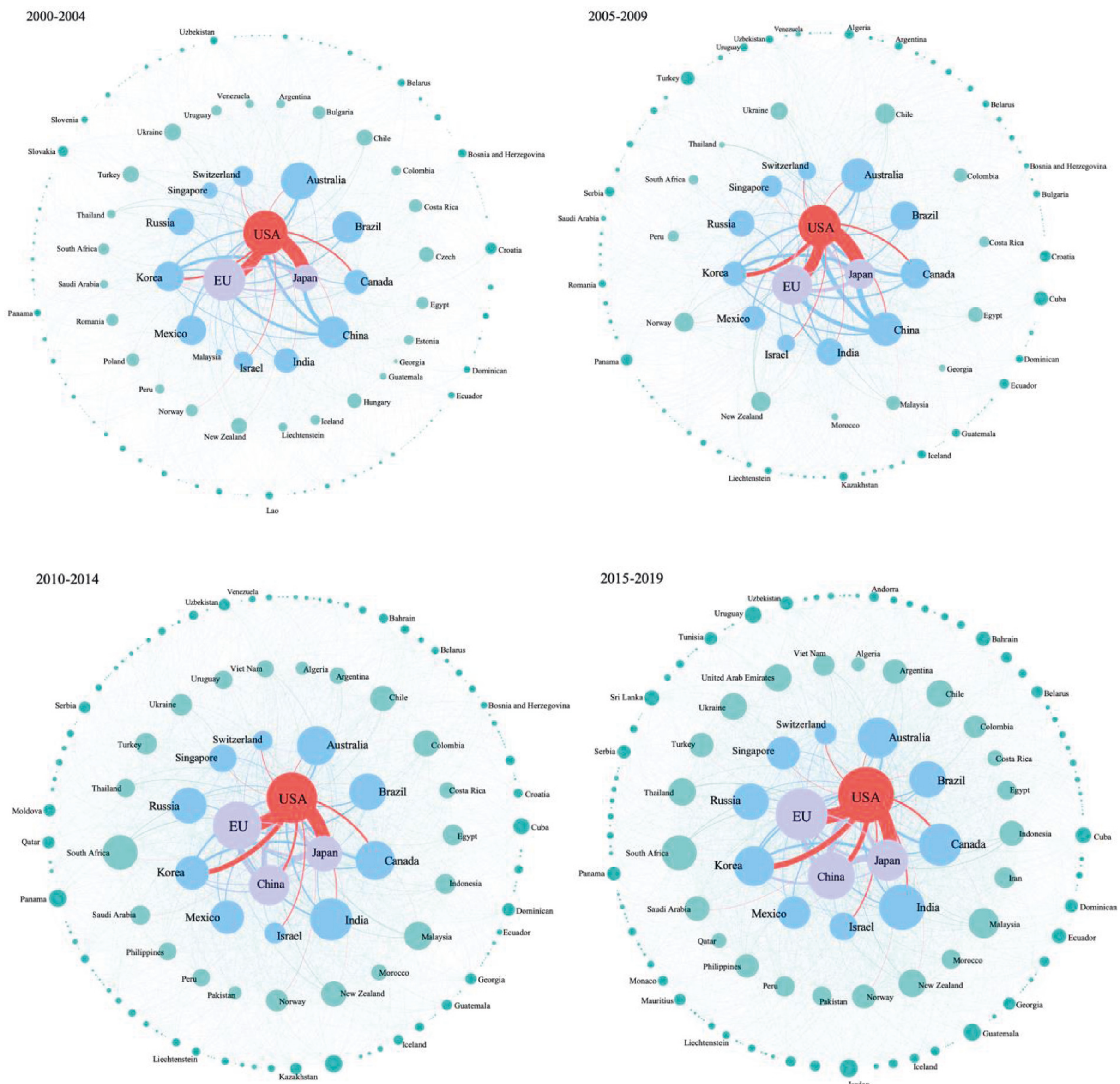

Figure 5: Core-periphery structure in the GIPN.

Table 2: The percentage of patents among layers in GIPN.

Layer	Percentage (%)			
	2000–2004	2005–2009	2010–2014	2015–2019
Core-core	39.45	34.34	49.76	50.03
Core-semicore	10.07	11.82	14.17	15.00
Core-semiperiphery	0.70	0.48	0.83	1.04
Core-periphery	0.07	0.26	0.26	0.22
Semicore-core	39.56	41.91	24.59	22.40
Semicore-semicore	4.40	5.94	2.87	2.64
Semicore-semiperiphery	0.56	0.47	0.42	0.40
Semicore-periphery	0.13	0.27	0.14	0.11
Semiperiphery-core	3.90	3.42	5.26	6.19
Semiperiphery-semicore	0.52	0.53	1.07	1.27
Semiperiphery-semiperiphery	0.08	0.04	0.12	0.15
Semiperiphery-periphery	0.03	0.03	0.05	0.05
Periphery-core	0.43	0.39	0.35	0.37
Periphery-semicore	0.07	0.08	0.09	0.10
Periphery-semiperiphery	0.02	0.01	0.01	0.02
Periphery-periphery	0.00	0.01	0.01	0.01
Sum	100	100	100	100

industrial value chain is still difficult to change. Therefore, similar to the global production network, only several countries determine the global innovation division of labor and the direction of technological development [31]. In addition, another point of view explaining this phenomenon is that the multilateral intellectual property system under the WTO is rooted in neoliberalism, which is the main economic ideology of western industrial capitalism. Although neoliberalism supports the use of multilateral rules and policies (such as proprietary intellectual property) as tools to promote technology transfer and commodities, empirical results show that the impact of such support is very limited [32].

5. Conclusion

This analysis explored the structure and evolution characteristics from both static and dynamic aspects. Static analysis reveals the overall distribution characteristics of the GIPN, while dynamic evolution analysis effectively identifies the evolution characteristics and development trends of the GIPN.

This analysis has aimed to explore the structural characteristics and evolution of the GIPN with the application of the patent dataset. Results gained from our analysis show that (1) in the period 2000–2019, the scale of the GIPN is expanding rapidly, gradually growing from a sparse network to a dense and complex network. (2) Patent application is unevenly distributed in the globe. The US, China, and Canada have been the top countries flowing in while Japan, Korea, EU, and Switzerland has been the main countries flowing out. (3) Some Asian countries have raised their position largely in the GIPN. These Asian countries include Viet Nam, Thailand, Malaysia, Singapore, and Indonesia. (4) The GIPN shows an obvious "core-periphery" pattern. The distribution pattern is unevenly distributed in space and presents a quadrilateral structure with the four core regions of "US, Japan, EU, and China" as the apex.

This analysis contributed to providing new insights both methodologically and theoretically. From the methodological view, based on the dynamic and static analysis of the GIPN, this analysis enriches network characteristics at the global scale and deepens the understanding of the global intellectual property transfer mechanism. From a theoretical view, given that the core of the GIPN is still distributed in a small number of core countries, countries are maintaining cooperation with core countries. The country at the key connection point can control and promote the technical exchange of nodes in the network. By linking different technologies together, technical barriers can be overcome, and the integration and innovation of different technologies can be accelerated. In addition, a deepening cooperation with countries in the core layer is also proposed in the future.

6. Limitations and Future Research

The analysis suffers from limitations in both methodological and dataset perspectives. First, the analysis suffers from limitations in a dataset perspective since we fail to distinguish the types of innovative areas, which may loss the shifting knowledge of intellectual property among the various fields. Second, we use the data of application rather than completed and approved. As in recent years, countries have become more and more strict about the protection of high-tech products and the term from application to approval is almost two years or more. The long application cycle may cause delays in changes in the GIPN. Third, this analysis did not focus on countries which have low rankings in the GIPN, paying little attention to the development of marginal countries in the GIPN. The overall goal of this analysis was to estimate the evolution structure of the GIPN. From the information collected from WIPO, we found that all the main country which occupy the main positions in global economy have been included. Thus, we believe the above effect to be of minor relevance. Future studies may consider the GIPN's changes in the turbulent year of 2020. At the same time, the GIPN will focus on various industries [33], consider the deep reasons for the evolution of innovation networks, and explore the deep relationship between the world innovation pattern, transnational knowledge capital flow and international economic background.

Data Availability

The data collected during the study are freely available from the World Intellectual Property Organization (https://www.wipo.int/portal/en/index.html).

Conflicts of Interest

The authors declare no conflict of interest.

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References

[1] C.-Y. Tseng, "Technological innovation and knowledge network in asia: evidence from comparison of information and communication technologies among six countries," *Technological Forecasting and Social Change*, vol. 76, no. 5, pp. 654–663, 2009.

[2] R. M. Grant and C. Baden-Fuller, "A knowledge accessing theory of strategic alliances," *Journal of Management Studies*, vol. 41, no. 1, 2004.

[3] J. Cantwell and R. Mudambi, "Mnes competence creating subsidiaries mandates," *Strategic Management Journal*, vol. 12, pp. 155–172, 2005.

[4] N. M. Coe and T. G. Bunnell, "Spatializing' knowledge communities: towards a conceptualization of transnational innovation networks," *Global Networks*, vol. 3, no. 4, pp. 437–456, 2003.

[5] X. Bai and Y. Liu, "Exploring the Asian innovation networks (AINs) characteristics," *Information Development*, vol. 35, no. 1, pp. 21–35, 2019.

[6] C. Zhang and X. Wang, "The influence of ict-driven innovation: a comparative study on national innovation efficiency between developed and emerging countries," *Behaviour & Information Technology*, vol. 38, no. 1, pp. 1–11, 2019.

[7] D. Ernst, "A new geography of knowledge in the electronics industry? Asia's role in global innovation networks." *Policy Studies*, vol. 54, 2009.

[8] D. Li, Y. D. Wei, and T. Wang, "Spatial and temporal evolution of urban innovation network in China," *Habitat International*, vol. 49, pp. 484–496, 2015.

[9] F. Peng, Q. Zhang, Z. Han, Y. Ding, and N. Fu, "Evolution characteristics of government-industry-university cooperative innovation network of electronic information industry in liaoning province, China," *Chinese Geographical Science*, vol. 29, no. 3, pp. 528–540, 2019.

[10] L. Zhang, Y. Zhao, D. Chen, and X. Zhang, "Analysis of network robustness in weighted and unweighted approaches: a case study of the air transport network in the belt and road region," *Journal of Advanced Transportation*, vol. 2021, pp. 1–13, Article ID 8810254, 2021.

[11] J. Li, Y. Wang, and Y. Cheng, "Study of the collaborative innovation and operation mechanism in regional innovation network," *Science & Technology Progress and Policy*, vol. 29, no. 13, pp. 32–36, 2012, (In Chinese).

[12] T. Buchmann and A. Pyka, "The evolution of innovation networks: the case of a publicly funded German automotive network," *Economics of Innovation and New Technology*, vol. 24, no. 1-2, pp. 114–139, 2015.

[13] S. Valverde, R. V. Solé, M. A. Bedau, and N. Packard, "Topology and evolution of technology innovation networks," *Physical Review E - Statistical, Nonlinear and Soft Matter Physics*, vol. 2, Article ID 056118, 2006.

[14] H. Chen and F. Xie, "How technological proximity affect collaborative innovation? An empirical study of China's beijing–tianjin–hebei region," *Journal of Management Analytics*, vol. 5, pp. 1–22, 2018.

[15] L. Lazzeretti and F. Capone, "How proximity matters in innovation networks dynamics along the cluster evolution. A study of the high technology applied to cultural goods," *Journal of Business Research*, vol. 69, no. 12, pp. 5855–5865, 2016, Journal of Business Research.

[16] E. Marrocu, R. Paci, and S. Usai, "Proximity, networks and knowledge production in europe," *Working Paper Crenos*, vol. 80, 2011.

[17] M. Steinmo and E. Rasmussen, "How firms collaborate with public research organizations: the evolution of proximity dimensions in successful innovation projects," *Journal of Business Research*, vol. 69, no. 3, pp. 1250–1259, 2016.

[18] L. Zhang, Y. Zhao, B. Dessein, and P. De Maeyer, "Determinants of intercity air-passenger flows in the "belt and road" region," *Complexity*, vol. 2021, pp. 1–14, Article ID 5514135, 2021.

[19] Y. Sun, "The structure and dynamics of intra- and inter-regional research collaborative networks: the case of China (1985-2008)," *Technological Forecasting and Social Change*, vol. 108, pp. 70–82, 2016.

[20] L. Yao, J. Li, and J. Li, "Urban innovation and intercity patent collaboration: a network analysis of China's national innovation system," *Technological Forecasting and Social Change*, vol. 160, Article ID 120185, 2020.

[21] M. Dost, Y. F. Badir, Z. Ali, and A. Tariq, "The impact of intellectual capital on innovation generation and adoption," *Journal of Intellectual Capital*, vol. 17, no. 4, pp. 675–695, 2016.

[22] D. J. Watts and S. H. Strogatz, "Collective dynamics of 'small-world' networks," *Nature*, vol. 393, no. 6684, pp. 440–442, 1998.

[23] L. C. Freeman, "Centrality in social networks conceptual clarification," *Social Networks*, vol. 1, no. 3, pp. 215–239, 1978.

[24] G. Morrison, E. Giovanis, F. Pammolli, and M. Riccaboni, "Border sensitive centrality in global patent citation networks," *Journal of Complex Networks*, vol. 2, no. 4, pp. 518–536, 2014.

[25] D. Reis, F. Moura, and I. Aragão, "Entrepreneurship, intellectual property and innovation ecosystems," *International Journal for Innovation Education and Research*, vol. 9, no. 2, pp. 108–134, 2021.

[26] X. Pan, M. L. Song, J. Zhang, and G. Zhou, "Innovation network, technological learning and innovation performance of high-tech cluster enterprises," *Journal of Knowledge Management*, vol. 23, no. 9, pp. 1729–1746, 2019.

[27] Z. Org, "Innovation offshoring:asia's emerging role in global innovation networks," *Economics Study Area Special Reports*, vol. 10, 2006.

[28] J. Wu, C. Wang, J. Hong, P. Piperopoulos, S. Zhuo, and E. Shuaihe Zhuo, "Internationalization and innovation performance of emerging market enterprises: the role of host-country institutional development," *Journal of World Business*, vol. 51, no. 2, pp. 251–263, 2016.

[29] Y. Qiu and Y. Fan, "Rethinking global innovation strategy: emerging market perspectives," *Business and Management Research*, vol. 2, no. 3, 2013.

[30] L. Ju, "Exploring the interplay, differences, and commonalities between global production networks and global innovation networks of two multinational companies," *Papers in Innovation Studies*, 2014.

[31] L. Zhang, H. Du, Y. Zhao, P. De Maeyer, B. Dessein, and X. Zhang, "Drawing topological properties from a multi-layered network: the case of an air transport network in "the Belt and Road" region," *Habitat International*, vol. 93, Article ID 102044, 2019.

[32] C. May, *The Global Political Economy of Intellectual Property Rights: The New Enclosures?*Taylor & Francis, 2013.

[33] T. Van der Valk, M. M. H. Chappin, and G. W. Gijsbers, "Evaluating innovation networks in emerging technologies," *Technological Forecasting and Social Change*, vol. 78, no. 1, pp. 25–39, 2011.