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The Structure of Global Innovation Network: Evidence from Chinese Cities

Tangwei Teng, Jiayi Chen and Xianzhong Cao

The Center for Chinese Modern City Studies, East China Normal University, Shanghai, 200062, China

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ABSTRACT The process of deep globalization and open innovation is deeply shaping the global innovation geography, which drives the evolution of global innovation network simultaneously. Based on the innovative service value matrix of city-by-inventor's R&D activities, the paper employs the complex network analysis and GIS to illustrate the internal and external features of global innovation networks. The global innovation map reveals the status and function of Chinese cities represented by Shanghai in the network. Meanwhile, this paper reveals the signification of urban agglomeration for corresponding cities to integrate into global innovation network, such as Yangtze River Delta Urban Agglomeration, to leverage and rise within the global innovation network. This research concludes potential scenery of Chinese characteristic model for innovation development and its transformation in the coming days.

INTRODUCTION

In the information era, economic globalization continuously amplifies the width and depth of the mobility of innovation resources such as knowledge, talent, and information. According to the relational turn in the Economic Geography (Bathelt and Glückler 2003; Boggs and Rantisi 2003; Hudson 2004; Yeung 2005; Sunley 2008; Bathelt and Glückler 2011), and the shift of open innovation paradigm (Chesbrough et al. 2006), it is very important to access and leverage the external innovation resources for the regional economic performance. Innovation is no longer confined within the border of firms, regions, and nations, the open innovation widely using resources inside and outside regions has become a sustainable way of innovation development. The accessibility of innovation networks promotes the integration of the local innovation activities and external environment. It indicates that a multi-level feature of innovation networks in the geographic space, which is not only showed as local innovation networks, but also extended to national and global levels.

The world enters into an open innovation era characterized by global mobility of innovation elements as an essential feature. As a leading force in globalization, multinational corporations achieve global innovation and optimal allocation of resources by the layout of R&D institutions and the establishment of R&D networks across the world. The global technology innovation networks of multinational corporations are coupled and merged by the global knowledge innovation networks among universities, as well as the local innovation systems worldwide, interweaving into an integrated and sophisticated global network of innovation. In this global innovation networks (GINs), a number of cites with international superior geographic location, better industrial foundation and innovation environment are able to gather broader global innovation flows, becoming nodes in the innovation networks.

Under this background, the role of global innovation networks is more significant than global production networks, becoming a powerful force of reshaping economic geography. Different from the costs oriented, raw materials oriented and market oriented location choices of production activities, innovative activities are more sensitive to location and have more complex requirements. It suggests global spatial pattern of innovation presented as a spikey world (Florida 2008), which further reshapes global economic geography profoundly. As the core supporter of the global movement of innovation resources and the spatial concentration, global innovation networks has become a significant issue of human-economic geography under hot debates (Hervas-Oliver et al. 2015).

Address for correspondence:
Xianzhong Cao
E-mail: xzcao@geo.ecnu.edu.cn

Depending on the focal point of researchers, the existing research of GINs in the field of human-economic geography can be summarized into four categories. The first one is the enterprises-based study of global innovation networks by Organization for Economic Co-operation and Development (OECD). OECD (2008) pointed out that enterprises develop R&D activities outside of their home locations in order to get close to the enormous and growing market, get access to engineers and researchers, and approach the location of manufacturing, marketing and other activities. In this process, innovation development will be open to external partners, which may be affected by geographical proximity, market demands, the pursuit of excellence, and other factors and motivations. The amount of cross-organizational innovative activities has significantly increased, forming global networks of innovation. OECD claims that innovation is about collaboration, and collaboration involves all types of firms by R&D status. Policies that stimulate collaboration and networks initiatives will have an impact on the entire spectrum of innovative firms.

The second branch focuses on the R&D outsourcing of the flagship enterprise represented by Ernst (2002). By the means of increasing vertical specialization of knowledge, multinational enterprises penetrated into emerging markets and constructed the global innovation networks. The GINs integrate separate projects, productions, and research activities across corporate boundaries and geographical boundaries, promoting interdependence relationship of national economies and innovation system into an unprecedented level. In the case of ICT industry, Ernst (2009) identified four levels of innovation locations within the GINs, including global centers of excellence in the United States, Japan, and the EU; advanced locations (Israel, Ireland, Taiwan, and Korea); catching-up locations (Beijing, the Yangtze River Delta, and the Pearl River Delta in China, and Bangalore, Chennai, Hyderabad, and Delhi in India); new frontier locations (lower-tier cities in China and India plus Romania, Armenia, Bulgaria, Vietnam, and others). Along with the development of GINs, Asia plays an increasingly significant role (Ernst 2008).

Thirdly, Coe and Bunnell (2003) put forward the theory of transnational innovation networks based on the concepts of practical communities, knowledge communities, and international communities, which surpass the traditional research prospective of enterprises and institutions. They stress that the GINs also have specific social networks and transnational communities in addition to the internal relationships of enterprises and relationships among enterprises.

The last research focuses on the analysis of global cluster networks. Bathelt and Li (2014) detected the network of formal linkages (FDI) between organizations yet primarily focused on a specific industrial cluster or a dyad of locations. Built upon the knowledge-based cluster and global value chains literatures Turkina et al. (2016) suggested an overall network to evolve from a geographically localized structure to a translocal hierarchical structure that is stratified along value chain stages. The global cluster network provides effective attempts of cross-regional knowledge transfer and sharing. However, the quantitative descriptions of the GINs contained in the global cluster networks still need more investigation.

The GINs is the extension of GPNs. Similar to the analysis of GPNs, mostly researches characterize global innovation networks of specific industrial sectors based on innovative subjects, lacking of a panoramic analysis. This limitation is increasingly evident in the cross-border (discipline, department, region, etc.) collaborative innovation under the background of open innovation. This paper argues that global innovation networks are the combination of innovation actors and spatial carriers. Transnational enterprises and countries are two of the main characters (Dicken 2007) shaping the long-term and potential changing process of the global economy. The global distribution of multinational enterprises' R&D institutions becomes a key factor driving the formation of global innovation network. R&D institutions can act as the catalyst of innovation centers' activities of learning new knowledge and developing innovative capacity (Enrst 2008). In the post-crisis era, compared to the role of national governments in global production networks, cities play increasingly important roles in building global innovation networks. New York, London, Tokyo, Paris, Singapore and other global cities have considered technological innovation as strategic initiatives to reconstruct the competitive advantages of cities, and strive to become core nodes in global innovation networks, which clearly affect the reshaping of the global innovation geography.

As the world's factory, China has been actively implementing the independent innovation strategy since setting innovative country as the goal of 2020 in 2006. As the result, the rate of scientific and technological progress contribution increased from thirty percent in 2000 to 55.3 percent in 2015.The target of China's innovative country is largely conducted through the implementation of Self-dependent Innovation Demonstration Area in urban regions. From 2009 to the first half of 2016, 14 National Innovation Demonstration Zones have been set up covering 24 cities in mainland China, promoting cities' agglomeration of innovation factors and innovation capacity through institutional reform and policy motivation. Supported by the central government, Beijing (Zhongguancun National Innovation Demonstration Zone) and Shanghai have set the establishment of global science and technology innovation centers as their targets since 2013. Cities in mainland China have been becoming new participators in the global innovation competition. Shanghai, Beijing, Guangzhou, Shenzhen, Tianjin, Chengdu, Qingdao, Hangzhou, Nanjing, Dalian and other cities take positions among 2014 GaWC world city system. Especially, Shanghai and Beijing are ranked in the 5th and the 10th places. In the Global Power City Index 2015, Beijing and Shanghai from mainland China are ranked in the 17th and 18th places. In Australia's "2thinknow" Innovation Cities ™ Index 2015, Shanghai, Beijing and Shenzhen from the Chinese mainland are ranked in the 20th, 40th, and 75th places, compared respectively to previous year's rank of 35th, 50th, and 74th. Besides the rapid rise in this rank and more and more Chinese cities emerging in it, Shanghai and Beijing have been ranked among the first class as NEXUS cities worldwide. The innovation-driven development of Chinese cities is restructuring the global innovation networks. To depict global innovation networks based on innovation actors and the main cities and to specify the status and function of Chinese cities in the global innovation networks is a new proposal worth exploring. The GINs acted as the channels and conduits of knowledge and other innovation factors flow. Compared to previous research, from the dual actors-cities perspective to investigate the structure and function, GINs has advantage to reveal the main gathering places of the R&D institutions of leading innovators worldwide. Accordingly, it could enable the researchers to describe the status of Chinese cities in the GINs and their potential to access and make use of global innovation elements, and to absorb external knowledge to translate into endogenous innovation capability.

The paper starts with a conceptualization of GINs. In subsequent sections, the researchers present the research design and methods, explore the characteristics of Global Innovation Network, and discover the status of Chinese cities in the GINs. In the final section, the researchers discuss the academic and policy implications of this study.

METHODOLOGY

Data Sources

The data adopted in this paper is from the Thomson Reuters Top 100 Global Innovators released in 2014. Thomson Reuter is an information firm well-known in the world and the major information provider of business information for professional corporations, financial institutions and consumers. It was created since the Thomson Corporation's purchase of British-based Reuters Group. Thomson Reuters releases yearly the list of Top 100 Global Innovators since 2011, which becomes one of the most widely recognized rank of innovators in the world. The innovators are selected through the Thomson Reuters Derwent World Patents Index, Derwent Patents Citation Index, Quadrilateral Patent Index and Thomson Innovation, a collaborative research platform of intellectual property and intelligence. The financial reports of these innovators are from the Thomson Reuters financial information platform. The specific indicators include the total number of patents, rate of successful patent licensing, global reach of patent portfolio and citation-based influence of patents. Generally, the Thomson Reuters Top 100 Global Innovators is scientific and representative. The researchers further collected the location, size and function of these innovators through news, the official website of the innovators, reports and other documents for the following analysis of inter-city innovation linkages.

The researchers' research approach draws on the analysis from the GaWC on the world city networks and the global production networks. According to the GaWC, global enterprises more often locate their offices in world cities, which promoted the agglomeration and development of advanced producer services (APS). Hence the basis framework of the world city networks can be constructed by an analysis on the global offices network of world leading APS firms. For building an APS firm-based global city network, an interlocking network model have been used (Taylor et al. 2010, 2011, 2014). The modelling consists of two steps. First is to quantify the service value of each city in which there offices are. Then is to set up a spatial interaction model referenced to quantify the connectivity between cities and grade the integration of the cities in global city network which reveals the global status of the city. The researchers' modelling for GINs is similar to that: assuming that the R&D departments of global innovators mainly agglomerate in cities that have a relatively richer innovation resources, better innovation endowments and prospects for development, hence implying their potential to improve their innovation capability in the future based on global R&D network of global innovators, to describe and portray the global innovation network in which cities are as nodes and the intercity connectivity (innovation factors flowing, knowledge exchange and transfer, and cooperation among different R&D institutes belong to the same inventor) as channels.

Quantitative Characterization of the GINs

Complex network is a reflection of the network in the form of complex systems, which is the theoretical basis for the researchers' global innovation network analysis. As a complex giant system, global innovation network covers the flow of innovation resource flows, innovators (such as firms and R&D institutes, etc.), and innovation environment. Cities have been treated as the node of GINs, and the interactions among different R&D institutions within the innovators as lines of the network. GINs can be quantitatively characterized by using a two-dimensional model. Meanwhile, different from the general complex network, GINs also has a sense of spatial distribution due to the geographical attribute of a particular city. Specifically, to describe GINs includes the following three steps:

- The first step is to abstract the global innovation activities as an innovation network model which consists of three layers: network layer, node layer, and sub node layer.

a) Sub node layer: Sub node layer is composed of 2014 Top 100 Global Innovators released by Thomson Reuters.

b) Node layer: Node layer consists of major cities (node), which are from the locations of 2014 Top 100 Global Innovators' R&D institutions. Statistical research indicates that the R&D institutions locational distribution of 2014 Top 100 Global Innovators is in 424 cities located in US, Europe, East Asia and Southeast Asia (see Fig. 1).

c) Network Layer: Network layer is a mesh layer arising from the flow of innovative activities, also known as the final global innovation network map. Innovative flow means innovative connections among different cities which is calculated based on R&D activities of 2014 Top 100 Global Innovators (specific measurement method will be mentioned below).

- The second step is to construct matrix V_{ij} of innovation (service) value.

Based on the collection of information on each innovator's all R&D institutions and their corresponding locations with particular size and functions in different cities worldwide, that is, based on each inventor's R&D institution network, the city-by-inventor matrix V_{ij} of innovation (service) value could be obtained. V_{ij} is the "innovation service value" of city *i* to innovator *j*. This service value is a standardized measure of the importance of a city to an innovator's R&D institution network, which depends on the size and functions of an innovator's R&D institution(s) in a city. The size and functions of an innovator's R&D institution(s) in a city are quantified into five levels (scored as 1-5) (Table 1).

Table 1: Quantitative standard of R&D institutions

Size and function	*Score*
Global R&D headquarter	5
Large regional R&D institution	4
National R&D institution	3
Regional R&D institution	2
Only office/ small scale institute	1

On the basis of innovation value (service) matrix V_{ij}, further calculations of innovation connectivity degree between cities R_{a-j} can be implemented. R_{a-j} measures connectivity of inno-

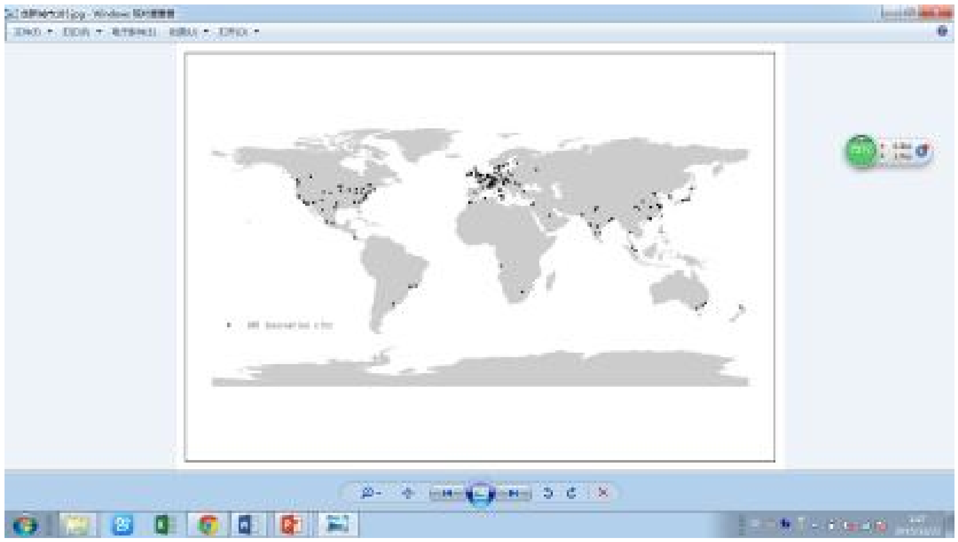

Fig. 1. Distribution of R&D centers in cities worldwide
Source: Author

vation factors exchanges such as knowledge flow between city *a* and city *j*. Finally, GINa, indicator measuring the importance of city *a* in the GINs, could be calculated, which shows the position of city *a* in the GINs.

According to the levels of GINs construction, the degree of innovation connectivity between cities $R_{a\text{-}j}$ and the indicator of importance of city GINa represent weight values of mesh layer and node respectively. The calculation formulas are as follows:

$$R_{a-j} = \sum_{j} v_{a,j} \times v_{i,j} \quad (a \neq i) \tag{1}$$

$$GIN_a = \sum_{i} R_{a-i} \quad (a \neq i) \tag{2}$$

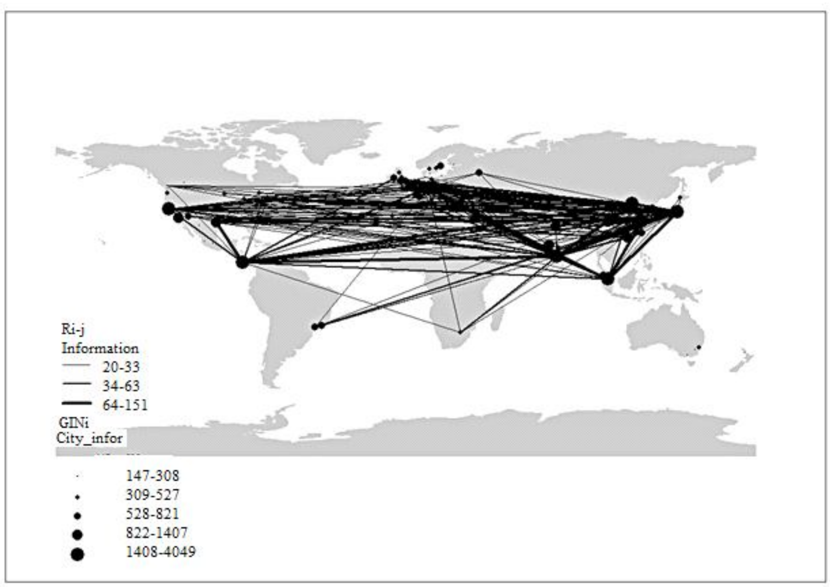

Fig. 2. City-centered global innovation network
Source: Author

⇒ *a* represents the city where the innovator's R&D institution located, *j* represents a city other than city *a*

⇒ *j* represents innovator, V_j represents the level of sixe and functions of each R&D institutions established by the innovator

⇒ $R_{a\text{-}j}$ represents that degree of innovation connectivity between cities, GINa represents the importance of city in the GINs.

⇒ V_{ij} represents the level of size and functions of innovators *f's* R&D institution in city *i* the *i*.

- The third step is to draw GINs.

According to the city's geographical location, $R_{a\text{-}j}$ and GNa, GINs shown n Figure 2 can bedrawn by tehe means of Aregis.

Each line in Figure 2 represents innovative connection between the two cities. The thicker is the line connected between the cities, the greater the weight of the communication and innovative (service) value is, and thus the more closely is the innovative connection between the two cities. Points represent the node cities in GIN, and dot size represents the importance of the city in the innovation network. Pursuant to network diagram, the center of gravity of the whole Figure is on the right, and East Asia has the highest density network.

The Specific Characteristics of GIN

External Characteristics of Global Innovation Network

As shown in Figure 2, the center of gravity of GINs is in the Northern Hemisphere, and the highest density area of GINs is in East Asia, indicating that the status of East Asia in the global R&D systems is becoming increasingly important.

According to global innovation networks node city ranking conducted by GINa (Table 2), most cities of the top 10 cities are located in Asia. Several cities from the developing countries such as China and India substantially increase their innovative connectivity. These cities have advantage to attract the top innovators to establish R&D institutions, which enable them to access external knowledge and talent.

The above analysis shows that traditional R&D institutions agglomeration structure has changed obviously. Shanghai ranked first in the global innovation network node cities, besides Shanghai, Beijing, Shenzhen and other Chinese cities also being listed in the top 100 nodes (Table 2).

Table 3 selected five countries, which have the highest proportion of cities where R&D institutions of 2014 Global 100 Innovators are located, and counted the number of cities in GINs. The study involved a total number of 424 cities. US have 115 cities that have R&D institutions of 2014 Global 100 Innovators, more than one quarter of the total. There are 61 cities in Japan, accounting for 14.4 percent of the total. On the contrary, cities, such as Shanghai and Bangalore, have the most innovative connectivity, however, their corresponding countries, China and India accounted for relatively small innovative connectivity. This Figure indicates that global giant innovators have relatively balanced

Table 3: The number of node cities in GINs in particular countries

Country	*Number of node cities*
China	23
India	15
Japan	61
German	24
USA	115

Table 2: Rank of global/Chinese innovation network node city ranking

Country	*City*	*Rank*	*Country*	*City*	*Rank*
China	Shanghai	1	China	Shanghai	1
India	Bangalore	2	China	Beijing	3
China	Beijing	3	China	Shenzhen	9
Japan	Tokyo	4	China	Chengdu	16
USA	San Jose	5	China	Taipei	20
Singapore	Singapore	6	China	Nanjing	21
German	Munich	7	China	Tianjin	45
Japan	Yokohama	8	China	Hong Kong	46
China	Shenzhen	9	China	Guangzhou	50
USA	Santa Clara	10	China	Xian	53

R&D institutions layout in developed countries, and conversely, R&D layout in developing countries is more concentrated. To some extent, the Figure reflects that the overall strength of innovation is much stronger in developed countries, only a few cities in developing countries have stronger attractiveness for innovative enterprises and institutions. Developing countries are still in the stage of transferring technology from developed countries, and have deficiencies in deepening localization of technique. Also, developing countries seek more opportunities to cooperate with global research and development.

Internal Structure of the GINs

The GINs is a complex giant system, the GINs diagram (Fig. 2) reveals more agglomeration of innovative flow trends and innovative activities, but it cannot reveal the internal structure of the GINs. Complex network analysis can transfer the relationship between the elements and each element into a network of nodes and edges, describing the relationship between the various parts of the real system through network format and emphasizing the topological properties of the system structure. In addition to vast majority of characteristics of complex weighted network, global innovation network, as space network, also has features that are different from abstract network. These features determine the topological nature of the city connection network. To summarize: 1) the node of global innovation networks is present in the two-dimensional geographic space, and have a clear position; 2) the side of global innovation networks has practical meanings, which is not simply the relationship defined in the abstract space; 3) Remote connection among the nodes of global innovation networks requires a certain cost, and this feature directly affects the possibility of the emergence of small-world behavior, which is featured as short path and optimum distance. Therefore, using complex network analysis can reveal the structure and the essential characteristics of innovation systems.

Centrality Analysis of GINs

Centrality indexes include degree centrality, Closeness centrality, Betweenness centrality (Freeman 1977). In the graph theory, degree k_i of node *i* is defined as the number of other nodes connected to the node *i*, indicating the importance of node city in global innovation network. Large k_i indicates hub node cities in global innovation network, and meanwhile these cities have a high degree of connectivity. This is a weighted complex network, and the weight need to be involved in the calculation to get the strength of node.

Degree focuses on a single node, but betweenness reflects the role and influence of the nodes or edges. If there are different B pieces of the shortest path between a pair of nodes, and there are b pieces pass through node *i*, then the contribution of node *i* to the betweenness of the pair of nodes is b/B. Betweenness of node *i* can be calculated by adding up contributions of node *i* to all pairs of nodes and then dividing by the total number of pair of nodes. The greater the betweenness is, the more the shortest paths that pass through the node are. In the process of innovation flow, the more the innovation flow that passes through the city node, the easier the innovation spillovers can happen.

Figure 3 visualizes the degree and the betweenness of GINs. In the Figure 3, the color represents the degree, while the node size reflects the betweenness. Similarly, the darker the color between the two cities nodes is, the more closer is the innovation connection between the two cities. The color from dark to light of the city node means that the city has more connections with other cities, indicating that the city obtains more innovative flow. Based on the Figure, Shanghai, Bangalore, Beijing, Noida, and San Jose have large degree of centralization and have more city nodes that have innovation connection with them. Also, Shanghai, Bangalore, Beijing, Singapore, and Munich have larger size of city nodes and the larger betweenness, indicating that these cities are situated in the communication and exchange paths of lots of network nodes, showing the ability to control the innovation connections happening among other nodes.

Distribution of node degree is an important geometric property of the network: Delta distribution shows the nodes have the same values of degree in regular network; distribution of the degree of the nodes in random network can be approximately described by the Poisson distribution; the degree distribution of power-law forms exists in scale-free networks. From the perspective of distribution of node degree, the global innovation network is more closed to scale-free network (Fig. 4).

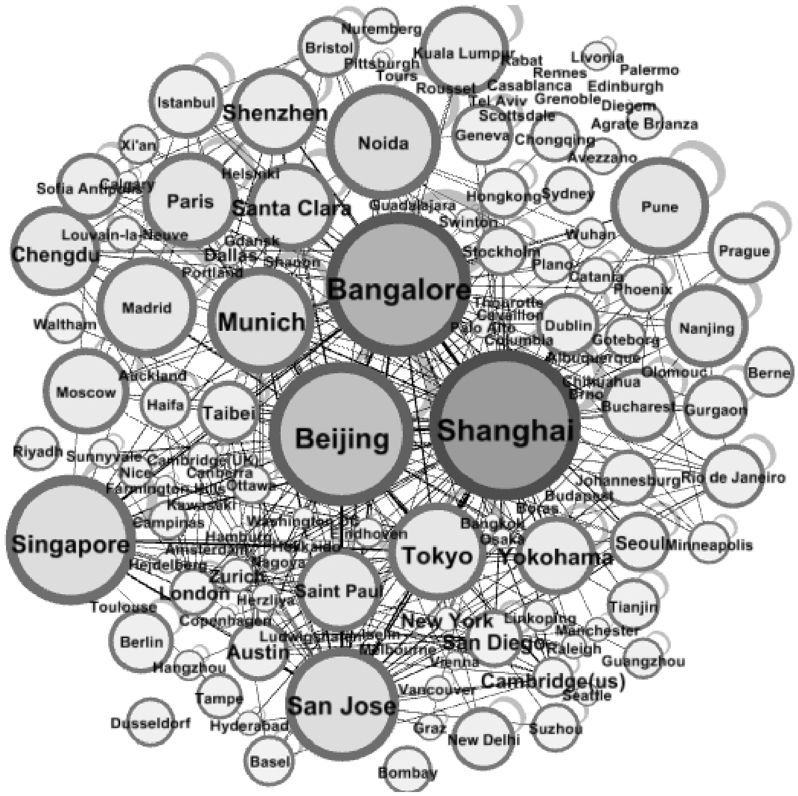

Fig. 3. Concentration analysis of degree and betweenness
Source: Author

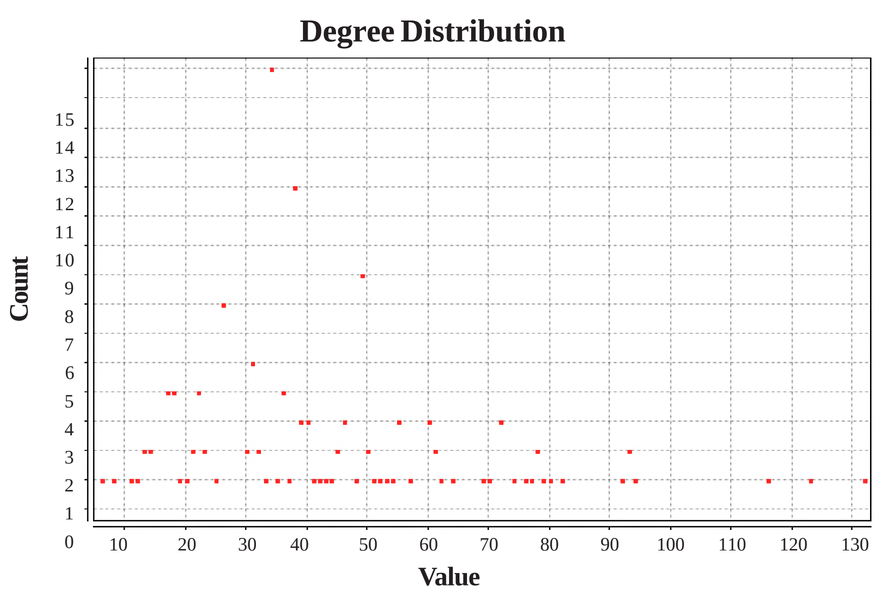

Fig. 4. The distribution of degree in GINs
Source: Author

Barabási and Albert (1999) proposed model of scale-free network, and suggested that growth and cherry-picked encouraged the generation of so many scale-free networks in reality. In this model, growth often starts at a small population of nodes, and adds new nodes at each time interval. After that the new node is connected to the existed node in the system. Selecting a connection point of the new node is conducted by cherry-picked mechanism, and probability depends on the degree of node. In global innovation networks, there are relatively small amounts of nodes with greater degree, and relatively large amount of nodes with smaller degree, showing distribution of power-law to some extent. Global innovation networks expands mainly through adding new nodes, and the new established city node connects with cities, which have larger degree of nodes, in other words, connects with important city nodes. That is to say, the original birth place of R&D institution(s) and major R&D center(s) are relatively centralized. Thereafter research and development activities will contact with the edge innovative cities, and these activities research gradually expands to sub level cities.

By the means of concentration analysis of degree and betweenness, the analysis of distribution of degree in GINs, the GINs has obvious structure characteristics of Core-Periphery structure. As shown in Table 4, city nodes, such as Shanghai, Bangalore, Beijing, and Munich, are core subsystem in the global innovation network. In this core subsystem, there exists frequent flow of innovation elements and dense innovation activities. Also showed in Table 4, cities, such as Amsterdam, Montel, Atlanta, Bangkok, and Copenhagen, maintain tight connections with each respective core city node but have less connection with each other and less innovation correlation. Thus, these cities form peripheral subsystem of the global innovation network.

The Length of Shortest Path of GINs

The shortest path represents the path that has the least number of edges between two nodes. The length of shortest path is called distance between two points, and represented by d_{ij}. The average distance between all pairs of nodes is the average length of path, called L.

In the global innovation networks model, the average length of shortest path, which reflects the number of intermediate cities needed, is an important index of network accessibility. According to calculations, the average length of shortest path for networks is 1.702, meaning that the flow of innovation from the original city to target city only needs to go through one intermediate city. Despite the enormous number of nodes in the network, the average length of path in the network is very small, showing significant small-world effect. If relation between the increase in the average distance between any two points in the network L and the number of grid points N is logarithmic growth, being described as $L \sim l n N$, and part of structure in the network still has obvious group characteristics, then the network has a small network world effect. Watts and Strogatz (1998) proposed a construction method for small-world network model (WS): connecting all sides of a node in the regular network, and disconnecting one endpoint with a certain probability P, and then re-

Table 4: The result of core-periphery analysis

Core cities	*Periphery cities*
Gdansk Hamburg Manchester Dublin Berlin London Brno Paris Vienna Budapest Graz Ottawa Minneapolis Istanbul Madrid Beijing Tianjin Seoul Tokyo Yokohama Nagoya Osaka Phoenix Dallas Nanjing Shanghai Chengdu Wuhan Hangzhou Chongqing New Delhi Guangzhou Guadalajara Pune Hyderabad Bangalore San Jose Kuala Lumpur Rio de Janeiro Johannesburg Sydney Helsinki Portland Goteborg New York Stockholm Vancouver San Diego Singapore Munich Shenzhen Santa Clara Austin Noida Moscow Cambridge(us) Taipei Saint Paul Bucharest Gurgaon Geneva Sofia Antipolis Bristol Prague Zurich Haifa Basel Louvain-la-Neuve Hongkong Catania Plano Xi'an Farmington Hills Agrate Brianza Avezzano Cambridge(UK) Cavaillon Thourotte Palo Alto Nice Swinton Berne Suzhou Sunnyvale Hokkaido Washington DC Herzliya Eindhoven Linkoping Raleigh Riyadh Campinas Boras Tampe	Amsterdam Warsaw Calgary Montreal Toulouse Buffalo Pittsburgh Kawasaki Atlanta Calcutta Bangkok Canberra Auckland Melbourne Edinburgh Zagreb Bombay Algiers Casablanca Luanda Palermo Rabat Seattle Livonia Dusseldorf Rennes Tel Aviv Grenoble Tours Rousset Diegem Scottsdale Ludwigshafen Waltham Hejdelberg Iselin Copenhagen Olomouc Columbia Albuquerque Chihuahua

connecting to any other node. When reconnecting probability P=0, it means that the network is a regular network; P=1 means the network formed is completely random network. When 0 <P <1, it means the network formed is small-world network. Small-world network not only has clustering characteristics like regular network, but also has shorter length of average path like random network. In other words, small-world network has both large coefficient of clusters and small average shortest distance. GINs obtains both large coefficient of clusters and small average shortest distance, indicating that network has a high degree of clustering, that innovation occurs mainly between several major cities, and that innovative edge of city is often directly associated with higher degree of innovation cities, rather than spreading from the high energy level of innovation city to middle level innovation city, and finally to low level innovation city.

Network Density Analysis of GINs

Network density can be illustrated via two statistical indicators, density of figure and coefficient of clustering. Density of figure measures the integrity of network. The density of a completed figure with all potential connected edges is 1. The coefficient of clustering in the network can identify dense and sparse region to discover the relationship between the global schema and relation among data. If a node i in the network connected with other nodes k_i, then nodes k_i can be viewed as neighbors of node i. These k_i nodes can only have up to $k_i(k_i-1)/2$ pieces of edge. E_i represents pieces of edge that actually exist. The coefficient of clustering of node i can be calculated by using $k_i(k_i-1)/2$ divided by E_i.

$$C_i = \frac{2E_i}{k_i(k_i-1)} \quad (3)$$

C represents the average value of all nodes' coefficient of clustering

Gi represents all nodes i

$$C = \frac{1}{N}\sum_{i\in G} G_i \quad (4)$$

Coefficient of clustering of a node researches the degree of connection density between node and its neighbors. Higher coefficient of clustering means the node is a leading role in the node network. The range of coefficient of clustering is from 0 to 1. When C = 0, all nodes in the network are isolated point; when C = 1, each node has edge to connect with other nodes. The larger the coefficient of clustering of city node, the easier the innovation can flow in the city. The more coefficient of clustering in the network, the higher density of connection between one node and its neighbors is. In other words, innovation network focuses on areas that have frequent innovative flow frequent. On the contrary, the higher density of figure, the more connections in global innovation and the more balanced distribution of innovative flow are. The calculated global innovation network coefficient of clustering is 0.753, and the density of figure is 0.315. Relatively high coefficient of clustering of network and low density of figure indicate that the network concentrates in certain areas, suggesting that this complex global innovation network is not completely random, and that innovative flow has significant clustering effect.

Chinese Cities as Important Nodes of GINs

As Table 2 showed, there are 8 cities of China mainland, along with Taipei and Hong Kong which ranked in the top 100 node cities of GINs. Among them, Shanghai, Beijing, Shenzhen, Chengdu, and Nanjing ranked No 1, 3, 9, 16, 21 and 45. Shanghai has become the most important node of GINs, and established innovation linkage with the vast majority of nodes distributed in each continent (Fig. 5). Shanghai has deeply integrated into the GINs.

Hakanson and Nobel (1993) treated geographical and psychological distance as an important factor affecting the Multi-National Corporation's overseas R&D investment location. The research of this paper shows that the innovation activity of innovative enterprises is becoming more and more globalized, and it has the tendency to transfer from the developed countries to the developing countries, especially to the Asian countries. The significant position of Chinese cities in GINs would be thanks to the foreign R&D activities, human capital, closeness to the excellence center of R&D, regional innovation center and the expanding agglomeration economies of scale (Siedschlag et al. 2013). In terms of Shanghai, on the one hand, Shanghai has advantageous conditions of development: the biggest comprehensive economic center of China, with rich resources endowment of science and technology, Shanghai culture environment, broad market hinterland, superior traffic

Fig. 5. The innovation linkage of Shanghai to other node cities in GINs
Source: Author

conditions, but also a new round of reform and opening up the frontier (FTA). On the other hand, Shanghai is China's largest integrated center city, superior location, the high ranking in the world city system, etc. Therefore, it is one of the most preferred destinations for enterprises R&D institutions in China. By the end of 2014, foreign R&D center in Shanghai has reached 366, accounting for 1/4th of the country. There are more than 70 multinational corporations in Shanghai to set up a global and regional R&D center. General Electric, Dow Chemical and other world famous multinational companies in Shanghai R&D center in the business functions and scale have been with North America and the European R&D center to keep pace. From this perspective, China is transforming from so called world factory to world lab with factory. Currently, most of the Top 100 Global Innovators released by Thomson Reuters are from USA, Japan, German, and France. The GINs are still dominated by transnational corporations' FDI, Chinese cities' innovation fates, including Shanghai, Beijing, etc. which are chained to the West to a large extent (Ma and Assche 2013).

Moreover, except for the city's own endowments, located in an advanced and sophisticated urban agglomeration is vital for particular city integrated into the GINs. Shanghai is the leading city of Yangtze River Delta Urban Agglomeration, which is the sixth urban agglomeration in the world. Other member cities such as Nanjing, Hangzhou, and Suzhou are also important nodes among the GINs, which are connected with Shanghai closely and deeply.

DISCUSSION

Innovation and venture are more and more city-based or even metropolitan-based phenomenon. The concept of the innovation as a networked city-based phenomenon (2thinknow

2006) has been widely accepted. City-by-innovator based GNIs analysis has clear advantage to describe and characterize the GINs, to reveal the main innovation locations in the world and global flow of innovative resources.

Chinese cities are rising as important nodes in the GINs. There are 23 Chinese cities in total that have become the worldwide network nodes. This is helpful for China to access, acquire and deploy the global highly mobile innovation resources effectively. It is surprising that Shanghai occupies the first place in the GINs, and Beijing as the third, and Shenzhen as the ninth node, etc. Chinese cities would reshape the global innovation geography, because more and more Chinese enterprises are expected to rank in Global top 100 innovators during the process of China's indigenous innovation development and the construction of Self-dependent Innovation Demonstration Zone. As time goes on, more and more Chinese enterprises are expected to grow up to be the global flagship enterprises, not only private enterprises such as Huawei (among the 2015 Top 100 Global Innovators released by Thomson Reuters), but also state-owned enterprises reconstructed and reformed (Sun et al. 2014). These global brands would take the domestic cities as headquarters and adopt a much more proactive approach to go abroad worldwide to set up offshore R&D institutions and affiliates to make full use of innovative resources around the world locally, which would promote the ongoing rise of Chinese cities as key node in the GINs, along with the enhancement to attract global R&D investment from both developed and developing countries.

CONCLUSION

In terms of the internal structure of GINs, it consists of 424 cities as its nodes, and presents distinguished core-periphery feature. The United States, Japan, Germany are in the leading position of the GINs with the United States having the most innovative networks nodes. The global innovation networks node in the developed countries of the space layout is relatively even. Meanwhile, the center of gravity of the GINs is showing a clear trend towards Asia, where the network density is the largest. In a sense, it partially resulted from the offshore R&D outsourcing activities and global distribution of R&D institutions of transnational corporations from developed countries to highly selected cities in developing countries, representing the functional upgrading along the global value chain in cities of emerging economies. Again, FDI from the north to the south still matters as key drive force for the innovative local-globalization process.

Shanghai, Bangalore, Beijing, Noida, and San Jose have large degree of centralization and have more city nodes that have innovation connection. Also, Shanghai, Bangalore, Beijing, Singapore, and Munich have larger size of city nodes and the higher betweenness, indicating that these cities are in many network nodes of communication paths, showing the ability to control innovation connections with other nodes. The GNIs obtains both large coefficient of clusters and small average shortest distance, indicating that network has a high degree of clustering, that innovation occurs mainly between several major cities, and that innovative edge of city is often directly associated with higher degree of innovation cities, rather than spreading from the high energy level of innovation city to middle level innovation city, and finally to low level innovation city. The GINs is not completely random, and the innovative flow has significant clustering effect.

RECOMMENDATIONS

The researchers' analysis also reveals an important phenomenon that cities with multi-industry and comprehensive industrial structure have advantage to attract top innovators to set up R&D institutions. It needs to be stressed that the GINs primarily act as the platform and channel for global innovation factor flow. The importance of the node cities in the GINs represents its capabilities in innovation resources agglomeration and its connection with other innovation location, but not the actual innovation ability. As a result, the complex effect of GINs on the innovation and development performance of node cities especially Chinese cities is a new field for further research.

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