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Network Structure and Dynamics of Chinese Regional Incubation

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Abstract
In recent years, the structure of incubation networks has attracted much attention. However, the intricacy of network has limited the discussions on its structure and dynamics. Information theory is employed as a model independent approach, which is capable of overcoming these obstacles. Information flows between different regions are calculated with the help of the transfer entropy methodology. Moreover, corresponding incubation networks are constructed over two periods. Thereafter, local transfer entropy is calculated for analysing how the structure of networks is changing with time. The results obtained are presented as follows. Firstly, the adjacent geographical location is the key factor in the formation of region incubation networks and six region incubation networks are formed in China; Secondly, network-level in different regions exhibits a serious imbalance; Finally, the policy significantly contributes to the dynamics of region incubation networks. The key findings revealed in the paper extend support to the governments and local authorities in shaping their prospective policies for not only the incubation industry, but also the entrepreneurs, and development of the region economy.

Keywords Network structure · Network dynamics · Transfer entropy

1 Introduction

Several studies have suggested that business incubation is an effective business development tool, which requires a modest investment and provides an excellent return on investment to the regional economy (Markley and McNamara 1995; Voisey et al. 2006;

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Liargovas 2013). Both the number and scale of incubators in China have manifested rapid growths following approximately thirty years of developments (Hu and Mathews 2008). The incubator is not only an organization, which performs a series of incubation activities, but also serves as a strategic resource to drive innovation (Mian 2011). A single incubator is unable to meet the complex and diversified needs of enterprises; accordingly, the network development of incubators emerges as a pivotal direction for the incubators (Löfsten and Lindelöf 2005; McAdam and Marlow 2008; Stadler and Rajwani 2014). Regional incubator network is an important component of the innovation system, which is conducive to the integration of innovation resources and promotes the adjustment of industrial structure. Significant effects of regional incubation network are recognized following the analysis of the key causes of social and economic development. Regional incubation networks not only improve the entrepreneurial environment in a physical space, but also support the development of start-ups by means of soft services. Regional incubation networks not only improve the entrepreneurial environment in a physical space, but also support the development of start-ups by means of soft services. Incubation networks not only improve the entrepreneurial environment in the physical space, but also support the development of start-ups with the help of soft services, such as technological level and management support (Smith and Zhang 2012), internal resources (Somsuk and Laosirihongthong 2014) or selection strategies. That is why the incubation network constitutes a trend for the development of future incubators.

Previous research on the regional incubation networks mainly emphasized the formation and operation mechanism of networks and their impact on the entrepreneurial performances. Maraqa and Darmawan (2016) identified the role of incubators and the factors, which influence the success of start-ups and suggested that the network resources provided by the regional incubators are important factors to promote the success of start-ups. Maximization of the business value of start-ups is the primary task of the incubation network, so the start-ups should be the core of incubation networks. Tiago et al. (2009) carried out a survey and empirical analysis of the incubation institutions in Portugal, showing that the cooperation among the incubators, incubates, research institutions and universities is particularly pivotal for the operations of regional incubation networks. Both the individual and organizational resources in the regional incubator network are considered as the key factors to improve the performance of start-ups (Bollingtoft and Ulhoi 2005; Studdard 2006; Chung-Jen 2009; McAdam 2006). Incubates have the ability to utilize two kinds of networks: internal networks and external networks (Fetters et al. 2010). The internal network refers to the network relationship in an incubator, and the external network deals with the connections to a local entrepreneurial ecosystem. In accordance with Lyons (2000), these have equivalent importance as they both help the incubates gain access to the business networks. Following these authors and Aaboen (2009) who view incubators as strategic actors, such actors transcends the typical, operational incubation activities and embraces the strategic level. In this context, the choice and interaction of incubators are mainly concerned with value creation related to external participants (Ramirez 1999; Clarysse et al. 2014).

In recent years, the dynamic interaction among the subjects in the regional incubation networks has attracted extensive attention. Indeed, business incubator models are increasingly seen as evolutionary, non-linear and interactive processes between various stakeholders in a regional context (Ivanova 2014), accordingly, the complex network theory is employed for investigating the dynamic interaction between the subjects (Pathak et al. 2007; César and Laurent 2014; Illenberger et al. 2013; Bellingeri et al. 2014; Soetanto and Sarah 2016). The interaction between incubation networks promotes the information flow, resource sharing and the generation of synergistic effect (Phelps et al. 2012; Salido et al. 2013). Gong (2009) discovered that there was a higher risk of entrepreneurship in Zhong Guan cun industrial cluster network for the short average length and a high degree of cluster. The incubation network is an open system, which is far from equilibrium and has the function of incubating new ventures, transforming scientific and technological achievements, and making the network continuously generate negative entropy flow (Fritsch and Kauffeld-Monz 2010; Voss 2013). The subjects in the regional incubation network act as the nodes and relationships are developed by means of the exchange of information among nodes, constituting the structure of the incubator network (Barbero et al. 2014; Spithoven and Teirlinck 2015). There are complicated nonlinear effects between incubators where all the kinds of subjects have extensive connections in knowledge, information, technology and products (Zaheer et al. 2010; Soetanto and Jack 2013). In this respect, much of the literature has emphasized the distinct value of connectivity of information flows between incubations, which can accelerate the development and growth of both the start-ups and SMEs, as these networks encourage them to open up their boundaries and explore a wide range of internal and external sources for searching and exploiting the innovative opportunities (Hansen et al. 2000; Reggiani et al. 2002).

This network-centred approach to the incubation seems to be especially relevant to the regional growth, given the systemic complexity that typically surrounds such contexts (Levidow et al. 2016). All these substantial works help us understand the connectivity of both the flows and the networks properties of incubations to a specific extent. Nevertheless, the evolution characteristics of the incubations resulted from variations of information flows are still creating confusions for us. The research works presented above suggested that the regional incubation network is a complex network of multi-agent interaction and the interaction between subjects determines the overall behaviour of the network. The flow of information between the subjects leads to the formation, change and unpredictable behaviour of networks, accordingly the structures of regional incubation networks present the characteristics of the dynamic change. However, what are the direction and intensity of the information flow between different regions? What are the structures of networks resulting from the information flow between the incubators? How do the structures of the regional incubation network vary over time? And, which areas are the centres of the formed incubation networks? The discussions regarding the structure of the regional incubation network are limited owing to its complexity, so the above questions have not been resolved. Moreover, there lacks the empirical research. The solutions for these questions are quite conducive to the optimization of the allocation of regional innovation resources and promotion of the integration of the regional economy.

For the purpose of solving the questions stated above, the information entropy theory is firstly employed for analysing the structure and dynamics of regional incubation networks. Agent model and social network analysis have been used in the previous studies to measure the structures of the network (Borgatti and Li 2009; Sakurama and Miura 2017). The agent model requires a lot of assumptions, and the structures of the network require to be fully understood in advance in a social network analysis. However, the interaction between agents in a regional incubation network is dynamic, accordingly making it quite hard to completely understand the structures of the networks in advance. Moreover, assumptions on the behaviour of the subjects are not consistent with the actual situation. While this area of studying founding offers a foundation for the explanation of the information exchanges between incubation networks and the networks characteristics of incubations to a certain extent, the directional and dynamical characteristics of economic information flows between incubations are still unexplored. There is a lack of research discussing these issues and the answers to them are of great significance to stimulate the creation of new job and reduce unemployment, in addition to fostering the economic growth of regions. Accordingly, there is a pressing need to identify the structure and its dynamic change of the regional incubation networks. The information theory and information dynamics provide a novel framework to overcome some of the difficulties associated with the modelling networks. In the paper, the transfer entropy put forward by Schreiber (2000) is introduced for the first time to analyse the structure and its dynamic change of the regional incubation networks. The structure of the network and its dynamic change are determined with the use of the realistic data of the number of start-ups obtaining investment and financing every year, whereas, the potential relationships are likely to be found when the transfer entropy is employed to measure the structure of the network. The transfer entropy is employed for calculating the asymmetric information flow between the incubators in different regions for determining the directional structures of regional incubation networks. Then, analysis of the dynamics of the network structures is carried out through the calculation of the local transfer entropy. We have put efforts to cast light on the development of regional incubation networks in China, considering dimensions of both the time and space.

We have contributed to both the research in entrepreneurship and regional studies in the following ways. Firstly, the investigation of the structure of regional incubator network considering the perspective of complex networks opens up a new avenue for the comparative research in innovation, since an increasing number of researches aim at understanding the interaction of the incubation networks. It provides insights into the information flow in Chinese regional incubation networks. The sample period ranges from 1990 to 2016, covering the reform and opening up policy and different regional development strategies of China. Secondly, we empirically examine the structure of the incubation network and its dynamic change process from the holistic network level. While the research has figured out the complexity of regional incubation networks, most of this research has emphasized modelling the local network structure rather than the structure of the holistic incubation networks. To the best of our knowledge, empirical research has not yet examined the structure of the incubation network and its evolution from the overall network level. Finally, the transfer entropy and local transfer entropy are introduced for the first time for the analysis of the structure and dynamics of the regional incubation networks. This method allows us to identify the direction and dynamic of the economical information flow present in the regional incubation networks. Besides that, the method can overcome key difficulties in the previous studies where lots of assumptions are needed, in addition to providing a novel method for the study of the incubation networks.

2 Methodology

2.1 Transfer Entropy

The transfer entropy which quantifies the flow of time series in a nonparametric and asymmetric manner was put forward by Schreiber (2000), developed on the basis of the concept of Shannon's entropy as defined in the information theory. In comparison with the mutual information method in the information theory, the transfer entropy not only describes the nonlinear relations between systems, but also reflects the direction and intensity of their flow (Vicente et al. 2011; Faes et al. 2013).

The transfer entropy is the independent deviation of the state transition between the information source Y of the previous state and the target X. More formally, as the time series of variable X is a Markov process of K degree, the state i_{n+1} of X is dependent on the K previous states of the same variable,

$$P(i_{n+1}|i_n, i_{n-1}\ldots i_0) = P(i_{n+1}|i_n, i_{n-1}\ldots i_{n-k+1}) \quad (1)$$

$P(A| B)$ is the conditional probability of A given B, defined as $P(A| B) = P(A, B)/P(B)$. If the variable X is dependent on the variable Y, we develop an assumption that the state i_{n+1} of X is dependent on the l previous states j_n of Y. The transfer entropy from Y to X refers to the average information contained in the source Y regarding the next state of destination X, which was not contained in the previous states of X. Besides that, an assumption is made that the state i_{n+1} of the time series X is impacted by the k previous states of X and l previous states of Y. The values of k, l are likely to vary in accordance with the data. The transfer entropy (TE) from Y to X is defined as follows:

$$TE_{Y\to X}(k,l) = I\left(Y_n^{(l)}; X_{n+1}|X_n^{(k)}\right) \quad (2)$$

$$TE_{Y\to X}(k,l) = \sum\nolimits_{x_{n+1}} x_n^{(k)} y_n^{(l)} \times \left[P\left(x_{n+1}, x_n^{(k)}, y_n^{(l)}\right)\log 2\frac{P\left(x_{n+1}|x_n^{(k)}, y_n^{(l)}\right)}{P\left(x_{n+1}|x_n^{(k)}\right)}\right. \quad (3)$$

Where x_n indicates the n element of the time-series X, which represents the discrete value of the time-series X at the n moment. Furthermore, y_n indicates the n $n$element of the time-series Y, denoting the discrete value of the time-series$Y$ at the n moment. $P\left(x_{n+1}, x_n^{(k)}, y_n^{(l)}\right)$ indicates the joint probability of x_n and y_n. $P\left(x_{n+1}|x_n^{(K)}, y_n^{(l)}\right)$ is the conditional probability y_n. $P(x_{n+1}| x_n{}^{(k)}, y_n{}^{(l)})$istheof x_{n+1} given $x_n{}^{(k)}$ and $y_n^{(l)}$. $P\left(x_{n+1}|x_n^{(K)}\right)$ is the conditional probability of x_{n+1} given $x_n{}^{(k)}$. k. k and l as the delay of time series l, asthedelayoftimeseries, are typically assumed k = l=1.

The transfer entropy can reveal the asymmetric information flow between nodes and determine the direction of causality, so it could be considered as the nonlinear Grainger's causality, which is reduced to the simple linear Grainger's regression in the process of vector auto regression (Barnett 2009). Transfer entropy from Y to X represents the extent that the dynamic process of X is affected by Y.

2.2 Effective Transfer Entropy

For the finite sample effects, TE estimates derived in Eq. (3) are liable to be biased. In order to minimize the bias, the effective transfer entropy (ETE) is adopted. The more accurate method for the analysis of the deviation caused by a finite sample involves retaining the dynamics of the time series assumption without information flow while estimating the values of ETE. In this paper, we have adopted the bootstrap in Markov process proposed by Horowitz. Firstly, the time- series Y is simulated in accordance with the probability distribution of the TE matrix of the original variable X and the interactivity of X and Y is disrupted under the condition of retaining the dynamics of Y. Thereafter, ETE is estimated by simulated time-series Y. The process is repeated assuming that there is no information flow, maintaining the probability distribution of the TE. The ETE is calculated as:

$$ETE^{boot}_{Y\to X} = T_{Y\to X}(k,l) - T_{Yboot\to X}(k,l) \tag{4}$$

2.3 Transfer Entropy Network

The TE network is developed on the basis of the correlation matrix of the ETE. The regions are the nodes and the bi-directed, and weighted and connected entropy networks are developed with the ETE of the regions as the link weights. The nodes with a high level of centrality play a key role in the formation of incubation networks through the delivery of more information on the regional incubator networks. Eigenvector centrality is a method of measuring the level of centrality, considering not only how many connected edges a node has but also whether it is located in a region where several nodes are connected. The influence of adjacent nodes on the centrality of the current node is considered. We not only consider the importance of an area, but also need to consider the network level of the whole region in which it is located. Therefore, we have adopted the eigenvector centrality for the measurement of the centrality of the node. Contrary to the undirected network, the ingoing edges and outgoing edges of a node need to be determined in a directed network.ECS_i^{in} is the in- eigenvector centrality of a node, whereas, ECS_i^{out} is the out-eigenvector centrality of a node.

$$ECS_i^{in} = \frac{1}{\lambda}\sum_{j=1}^{N_{in}} A_{ij}W_{ji} \quad ECS_i^{out} = \frac{1}{\lambda}\sum_{j=1}^{N_{out}} A_{ij}W_{ij} \tag{5}$$

Where A_{ij} indicates the adjacency matrix of the network. When the i th node is adjacent to the j th node, $A_{ij} = 1$, otherwise, $A_{ij} = 0$. N_{in} denotes the measurement of the sum of edges to node i, N_{out} implies the measurement of the sum of edges from node i. λ suggests the constant, representing a characteristic value, $AX = \lambda X$. W_{ji} is an indication of the value of ETE from the region j to the region i. W_{ij} signifies the value of ETE from the region i to the region j.

2.4 Local transfer entropy

Local transfer entropy (LTE) provides the time process of transfer entropy, so it could be used to explore the dynamic structure of regional incubation networks. The LTE is the value of TE at each time step n, which is defined by the previous states, $x_n^{(k)}$. The Y_n^k quantifies the amount of information contained within information source Y regarding the state x_{n+1} of target variableX. The LTE is the mean of TE at each time step n, thus, it is calculated as:

$$LTE_{Y \to X_{n+1}} = \log2 \frac{P\left(x_{n+1} | x_n^{(k)}, y_n^{(l)}\right)}{P\left(x_{n+1} | x_n^{(k)}\right)} \tag{6}$$

3 Data and Analysis

We aim at developing the entropy-based regional incubation network, which makes use of the time series of the number of start-ups obtaining the investment and financing across 41 regions in China. The regional incubation network corresponds to the connections between incubators, as opposed to the internal connections associated with an incubator. Therefore, time series of the number of start-ups obtaining investment and financing which is an overall indicator of incubation performance as a consequence of the highly dynamic and interactive process between incubators (Mian 1997) was chosen to calculate the transfer entropy. The number of start-ups that acquire investment and financing every year is an important index to measure the circulation of information between the incubators and reflect the network degree of incubators (Thomas et al. 2004; Hongseok et al. 2006; Liu and Liang 2008; Li 2012). This approach of transfer entropy is not constrained by the number of variables, together with being capable of flexibly dealing with the asymmetric and nonlinear processes (Dimpfl and Peter 2012; Daugherty and Jithendranathan 2015). For the purpose of lowering the finite size effects, the ETE is put forward for determining the directional, and dynamical information flows of time series. We determine the entropy-based regional incubation networks using the time series of a number of start-ups that acquire investment and financing across the 41 regions in China. There are 34 provincial-level administrative regions in China. The sample includes 30 provincial-level administrative regions except Hainan, Hong Kong, Macao and Taiwan (lack of statistical data), and 11 cities in China that are publicly-recognized innovation cities and counted annually by the Chinese government. These cities are economical developed and represent significant innovation level in China. Despite the fact that 41 regions have different sizes, yet the scale of time is same. Thus, the calculation of the results is not affected by the size of the regions. Both the name and number of 41 regions have been presented in the appendix. The number of national incubators has been presented in Fig. 1. The sum of invested start-ups every year in national incubators is shown in Fig. 2. The time span is between 1990 and 2016, which covers the whole period since the establishment of incubators in China, as well as the reform and opening up policy of China. Data associated with the period between 1990 and 2007 came from the Chinese statistical yearbook of science and technology. The data from 2008 to 2016 came from the Chinese torch statistics yearbook. It was reported in 2016 Chinese torch statistics yearbooks that it is a preliminary stage of incubators from 1990 to 2002, and incubators have undergone accelerated development stage from 2003 to 2016 in China. Therefore, we divided the time into the above two periods for revealing different characteristics of structures and evolutions of regional incubation networks in the above two phases. The descriptive statistics of the data have been presented in Table 1.

4 Empirical Results

4.1 Heat Map for Correlation

We first calculated TE of the original variables using k, $l = 1$, *and* the correlation matrices in two periods is created. The Heat maps for correlation in two periods are shown in Fig. 3a and b. The brighter tones of the heat map indicate the higher value and the darker tones indicate a relatively lower value. Part of the bright tones is due to inherent relationships among the variables and other parts are caused by data noise. Accordingly, it is necessary to extract the noise to obtain high quality TE for proving that the network structure is not formed by random correlations. In accordance with the above method, the correlation matrix of ETE is obtained by removing the TE matrix of

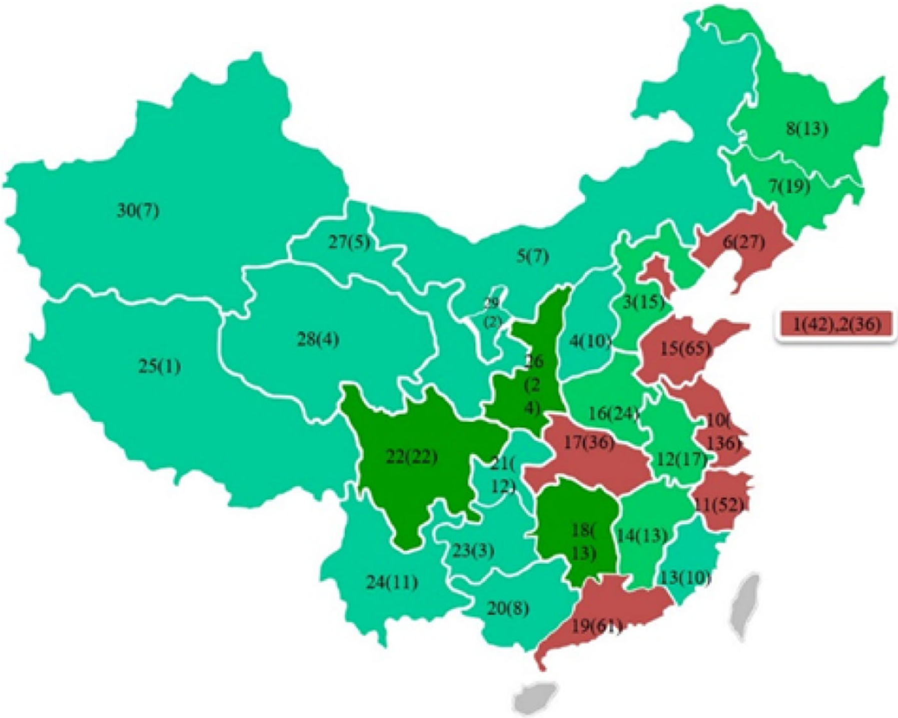


Fig. 1 Number of national incubators in provinces and municipalities

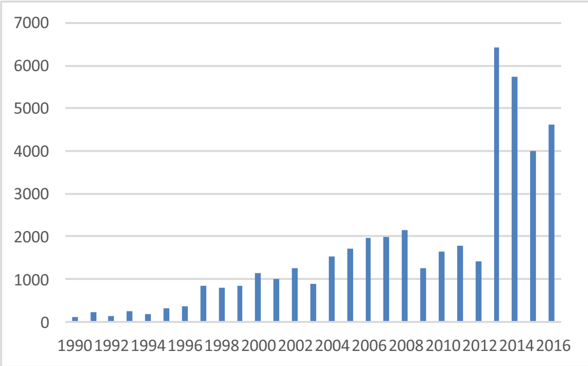


Fig. 2 The sum of invested start-ups every year in national incubators

the simulation time series from original variables. The Heat maps of ETE matrices in the two periods are presented in Fig. 3c and d.

As shown in Fig. 3c, the brighter tones appear in the bottom left quadrant over period I, reflecting the information flow between the regional incubators emerges in the Bohai and southeaster coastal regions. There are nine groups including (1,2), (9,10), (9,11), (10,11), (10,15), (15,6), (19,13), (35,19), and (35,37), which have higher level of information flow, reflecting more information contacts emerging between Beijing(1) and Tianjin(2), Shanghai (9) and Jiangsu(10), Shanghai(9) and Zhejiang(11), Jiangsu (10) and Shandong(15), Shandong(15) and Liaoning(6), Guangdong(19) and Fujian(13), Guangdong (19) and Shenzhen(35), and Shenzhen(35) and Guangzhou(37). The selected representative cities (1,2) and (35,37) are the brightest ones, suggesting that there are stronger connections between the incubators of Beijing(1) and Tianjin(2), and Shenzhen(35) and Guangzhou (37). Lines 1, 9, 10, 19, and 35 are brighter as compared with the other lines, suggesting that the information outflows of Beijing (1), Shanghai(9), Jiangsu (10), Guangdong (19) and Shenzhen (35) are higher in comparison with the other regions. The dark tones are located in the left upper quadrant and lower right quadrant, indicating that there exists little information flow between incubators in the Midwest. The result indicates that over Period I, there exist strong economic relations between the adjacent areas that obey the first law of geography. It is well known that the unbalanced development strategy is raised by the Chinese government to stimulate the regional economic development in the early stage of reform and opening policy. That is why more links are developed between adjacent areas, aimed at saving the costs. The most influential areas include Beijing and Shenzhen in the beginning of reform and open policy. As a capital city, Beijing has an important leading effect on the development of innovation in China. Shenzhen is located in the south-east coastal area with convenient transportation and was set up as a special economic zone at the beginning of the reform and opening policy. The Chinese government has developed various investment policies to foster the development of Beijing and the south-east coastal areas as leading economical regions, aimed at driving the growth of adjacent areas. Therefore, the information flow between the incubators is concentrated in the south-east coastal areas over period I where the regional incubation networks are preliminarily formed. Information flows between the incubators in the Mid-west are low and regional incubator networks are not established.

Table 1 The descriptive statistics of the data

Region	Mean	Std.Dev
Beijing	619.961	10.024
Tianjin	471.703	8.359
Hebei	247.592	4.231
Shanxi	127.197	3.358
Neimenggu	124.229	3.216
Liaoning	209.563	3.981
Jilin	83.195	2.637
Heilongjiang	63.561	2.351
Shanghai	625.962	8.246
Jiangsu	1268.356	9.152
Zhejiang	1143.743	8.248
Anhui	227.042	4.157
Fujian	349.375	3.149
Jiangxi	78.708	1.923
Shandong	488.749	5.153
Henan	192.046	2.362
Hubei	213.593	3.168
Hunan	87.045	1.143
Guangdong	598.595	4.491
Guangxi	68.074	1.925
Chongqing	112.049	1.024
Sichuan	267.113	1.825
Guizhou	43.962	0.736
Yunnan	51.746	0.921
Xizang	13.192	0.361
Shanxi	178.331	1.542
Gansu	36.672	0.837
Qinghai	24.071	0.931
Ningxia	25.265	0.472
Xinjiang	15.564	0.325
Dalian	58.227	1.264
Ningbo	141.152	1.536
Qingdao	103.702	1.427
Xiamen	98.591	1.113
Shenzhen	487.632	2.735
Wuhan	165.372	2.813
Guangzhou	318.305	1.952
Xian	115.932	1.347
Chengdu	146.739	1.582
Zhengzhou	147.672	1.692
Nanjing	196.077	1.237

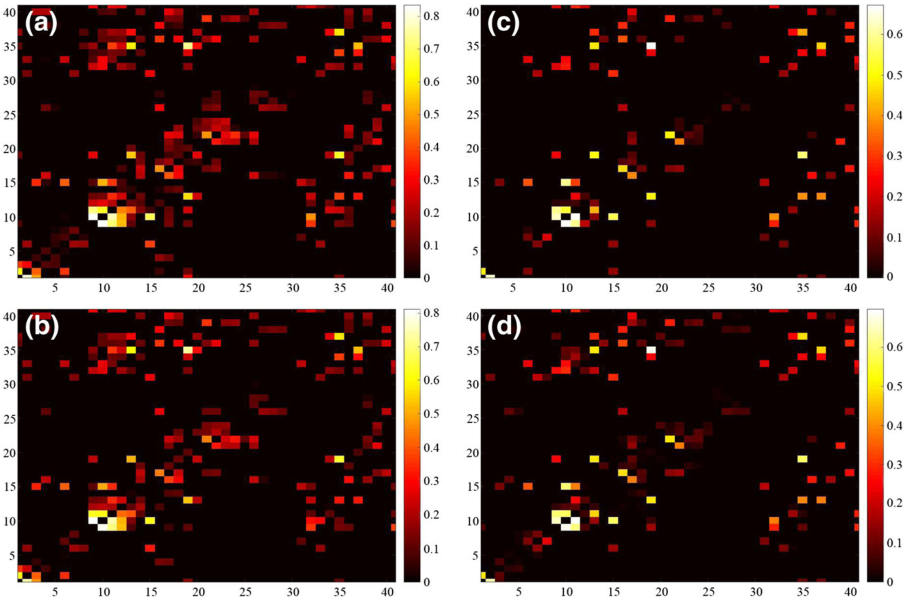


Fig. 3 Heat map of TE over period I (a), Heat map of TE over period II (b), Heat map of ETE over period I (c), Heat map of ETE over period II (d). Brighter tones represent higher connection and the darker tones represent lower connection

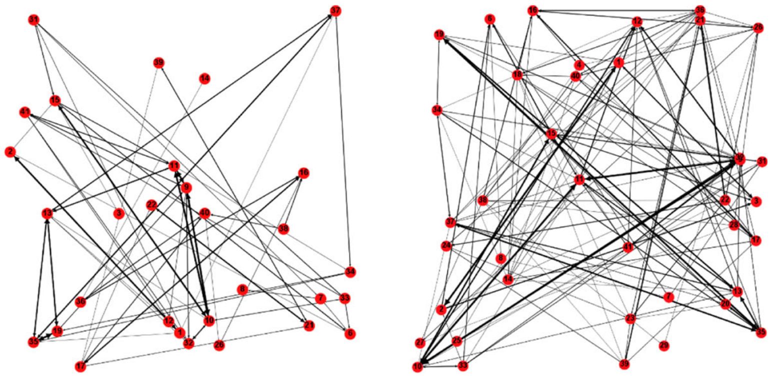
Similar analyses over the period II are carried out. The brighter tones include following 15 groups, as presented in Fig. 3d over the period II: (1, 2), (1, 3), (2, 3), (9, 10), (9, 11), (10, 11), (9, 12), (10, 12), (10, 15), (13, 14), (13, 35), (16, 17), (19, 20), (19,35), and (36,40), suggesting that the information flow between the above regional incubators is higher as compared with the other regions and there are higher connections of incubators between Beijing (1) and Tianjin(2), Beijing (1) and Hebei(3), Tianjin(2) and Hebei(3), Shanghai(9) and Jiangsu(10), Shanghai(9) and Zhejiang(11), Jiangsu(10) and Zhejiang(11), Shanghai (9) and Anhui(12), Jiangsu (10) and Anhui(12), Jiangsu(10) and Shandong(15), Fujian(13) and Jiangxi(14), Fujian(13) and Shenzhen(35), Henan(16) and Hubei(17), Guangdong(19) and Guangxi(20), Guangdong(19) and Shenzhen(35), and Wuhan(36) and Zhengzhou(40). Besides that, following six regions are brighter in the selected representative cities, (31, 33), (2, 33), (32, 41), (35, 37), (36, 40) and (39, 36), casting light on the fact that the information flow between the above regional incubators is higher as compared with the other cities and incubators between Qingdao (31) and Dalian(33), Tianjin(2) and Dalian(33), Ningbo (32) and Nanjing(41), Shenzhen(35) and Guangzhou(37), Wuhan(36) and Zhengzhou(40), and Chengdu (39) and Wuhan (36) are highly connected. Lines1, 2, 10, 15, 17, 19, 22, 26, and 35 are brighter in comparison with the other lines, revealing that there is more information flowing out from the incubators of Beijing(1), Tianjin(2), Jiangsu(10), Shandong(15), Hubei(17), Guangdong(19), Sichuan(22), Shanxi(26) and Shenzhen(35), implying that such areas are economic information dominant regions. Columns 3, 12, 14, 16, 20, 23, 24 and 27 are brighter as compared with the other columns, revealing that there is more information flowing to the incubators of Hebei(3), Anhui(12), Jiangxi(14), Henan(16), Guangxi(20), Guizhou(23), Yunnan(24) and Gansu(27). As revealed by the findings, there are more information flows from the southeast coastal areas into inland areas. The results are related to the development strategy of the Midwest in China over this period. Affected by the geographical environment and policies, the economy in the central and western China has lagged behind the eastern coastal regions for a long time. The entrepreneurial atmosphere of the south-east coastal areas is stronger than that of the central and western regions. Over period II, the Chinese government has established a development strategy to improve the investment environment of the Midwest areas. While maintaining the economic superiority of the south-east coastal areas, the Chinese governments encourages the eastern, central and western regions to achieve complementary advantages and coordinate development. Therefore, more innovative resources are flowing to the central and western regions, and the incubation network in the central and western regions has initially formed.

4.2 Network Structure

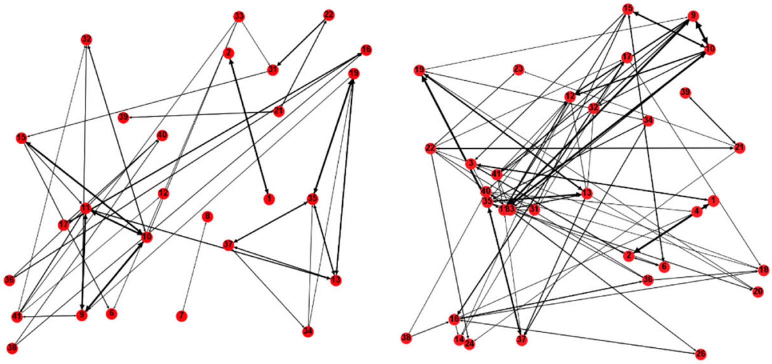
The existing structures of the incubation networks are formed by the circulation of information between regional incubators. The regions are the nodes and the bi-directed, weighted and connected entropy networks are developed with ETE of the regions as the link weights. Different values of weights could be used to find out the network degree of regional incubators, and identify the regional incubators with the highest degree of networks.

Fig. 4 shows the structure of the regional incubation networks with thresholds ranging from T = 0.1 to T = 0.6 over two periods. For T = 0.6, in the period I, the following regional incubators have the maximum degree of network. Information flow between the incubators takes place in both the southern and eastern regions of China. There exist bidirectional links between the incubators of Shanghai and Jiangsu, and Jiangsu and Shandong in eastern China. Bi-lateral linkages between incubators occur in Guangdong, and Shenzhen in southern China. In the periods II, the regions of higher information flow have been extended to the northern China. The geographical ranges of the regional incubation networks in both the eastern and southern regions of China have been extended to the encompassing inland regions. There exist stronger connections between the incubators in Shanghai, Jiangsu, Zhejiang and Shandong in the regional incubation network of the eastern China. Incubators between Beijing and Tianjin in northern China manifest a high connection with the bilateral links. For T = 0.5, in the period I, incubators between Chongqing and Sichuan exhibit strong association, together with connections developed in addition to the period I of T = 0.6. In the period 2, a unilateral link from Beijing to Hebei is developed in the north China, in addition to the connections developed over the period I. For T = 0.4, in the period I, there are observed the highest connections between the incubators in Shanghai, Jiangsu, Zhejiang and Shandong; together, the information flow is termed as the largest in the region incubation networks; Connections of the incubators between Beijing and Tianjin, Chongqing and Sichuan, Henan and Hubei are developed; besides that, connections are developed all through the period II. Connections of incubators between Tianjin, Liaoning and Shandong in Bohai region are developed, together with the linkages developed all through the period I. At T = 0.3, the links between the incubators are concentrated in the eastern, northern, and southern parts of China, whereas, the Bohai region is in the period I. The substantial links of incubators in the representative cities emerge between Guangzhou and Shenzhen, Ningbo and Nanjing, Xiamen and Shenzhen, Beijing and Tianjin, and Qingdao and Dalian. Scopes of all the regional incubation networks manifest expansion in the period II. Unilateral links from Beijing and Tianjin to Hebei are developed in the regional incubation network of the northern China. Additionally, one-way connections from Shanghai and Jiangsu to Anhui are developed in the regional incubation network of the eastern China. Incubators between Henan and Hubei, and Hubei and Hunan show high connections in the regional incubation network of the central China. One-way connections from Sichuan to Guizhou and Yunnan appear in the regional incubation network of the southwest China. At $T = 0.2$ and 0.1, large cluster regional incubation networks are developed in the period I. Connections of the incubators between Shanghai, and Jiangsu and Zhejiang are developed in the regional incubation network of the eastern China, having the largest values of ETE. Furthermore, there exist two-way connections between the incubators in Guangdong, Shenzhen and Fujian in the southern China; Incubators in Beijing and Tianjin manifest high connections in the northern China; Connections of incubators between Tianjin and Shandong, Tianjin and Liaoning, Hubei and Henan, and Chongqing and Sichuan are developed. Regarding the period II, the added connections are as hereunder. One-way connections from Beijing and Tianjin to Hebei are developed in the north China; together, a one-way connection from Guangdong to Guangxi emerges in the southern China; one-way connections from Shanghai, and Zhejiang and Jiangsu to Anhui are developed in the eastern China; a link from Hubei to Hunan appears in the central China; connections from Sichuan to Guizhou and Yunnan are developed in the southwest China; connections from Shanxi to Gansu and Qinghai are developed in the northwest China.

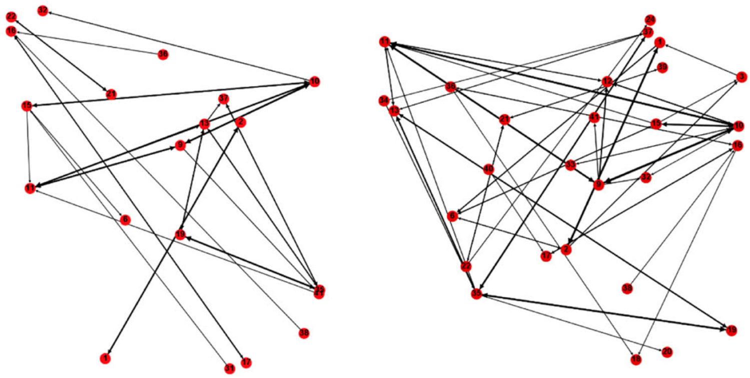
As shown in the above analysis, the network-level of regional incubators is low and the regional differences are obvious over the period I. Because of the superior geographical environment and economic foundation in the eastern region, the Chinese government formulated a regional development strategy to attach priority to the development of the Eastern region in the beginning of the reform and opening policy. Regional incubation networks in the South-Eastern coastal areas are preliminaries formed, including regional incubation networks in the Eastern China. Beijing and Tianjin are incorporated into the regional incubation networks of north China. The incubation networks in the central and western China are not formed, and the incubators developed independently. The innovation resources in the regions are scattered, and there is no platform for sharing resources and exchanging information. The levels of regional incubation networks have increased over period II, but regional differences are still obvious. This is largely due to a policy of the development strategy concerned to central and western regions for reducing regional disparities. Moreover, the degree of incubation networks in the South-East coastal areas is the highest and incubators are closely linked. The regional incubation networks in north China is formed with Beijing and Tianjin as the core, including the province of Hebei. In recent years, the range of the network has been extended to surrounding areas of Hebei characterized by one-way output from Beijing. Beijing, Tianjin and Hebei are connected with human affinity, regional integration and culture, with the profound historical origin and a suitable communication radius, which could be fully integrated and coordinated. Beijing, Tianjin and Hebei are located in the heartland of Bohai, Northeast China, and are the largest and most dynamic regions in the northern China.



T=0.1

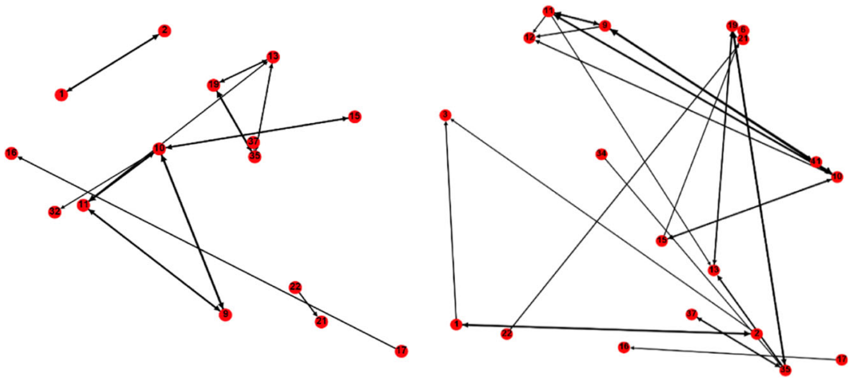


T=0.2

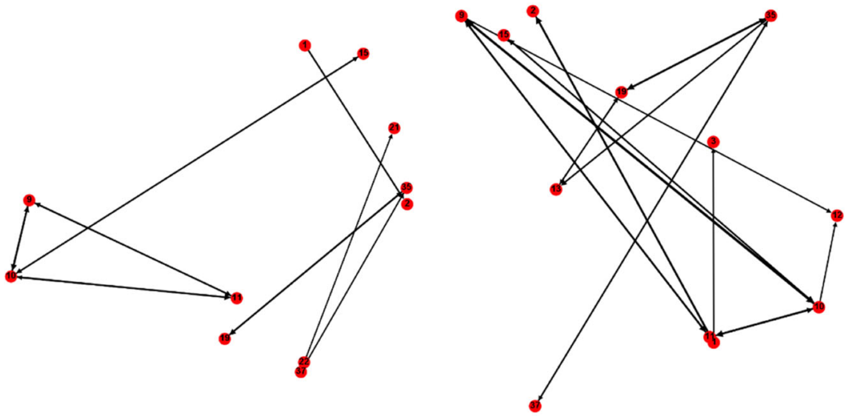


T=0.3

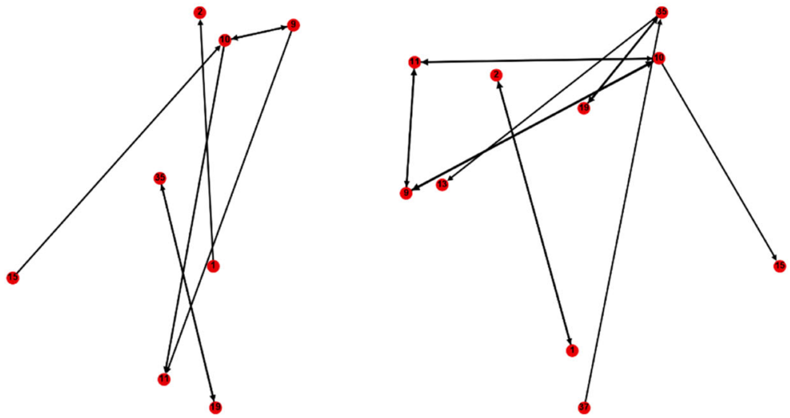
Fig. 4 The structure of the regional incubation networks with thresholds ranging from T = 0.1 to T = 0.6 over two periods. The network structure diagrams for the period I are on the left and the period II are on the right. The deeper colors of the links indicate the higher values of the ETE between corresponding regional incubators



T=0.4



T=0.5



T=0.6

Fig. 4 (continue)

The regional incubation networks in central China are formed with Hubei as the core, including provinces of Henan, Hunan and Jiangxi. The regional incubation networks are initially established and the network level of incubators is lower than that in the southeast coastal areas. Wuhan and Zhengzhou are capital cities of Hubei and Henan, which are central part of the network. The flow of information between Hubei and Henan has increased, and the incubators in these two regions have developed close connections.

The regional incubation network in the southwestern China region is preliminarily developed with Sichuan at its core, which includes the provinces of Chongqing, Guizhou and Yunnan. Chengdu, the capital of Sichuan province, is the core of the network.

The regional incubation network in north-west China that has the lowest level of a network is preliminaries formed with Shanxi as its core, including the provinces of Gansu, Qinghai and Ningxia. Xi an, the capital city of Shanxi province, is the centre of the network and outputs information to Gansu and Qinghai.

We conclude that the network level of the south-east coastal regions has consistently been the highest from the comparison to the structure of regional incubation networks over two periods. Regional incubation networks for the Central and Western china is not formed from 1990 to 2002, and they are developed from 2003 to 2016. Regional coordinated development strategy is developed by Chinese government for maintaining the rapid growth of the East and accelerating the development of the Central, Western and Northeast regions, gradually reduce the regional gap and achieve regional coordinated development. However, the network level of the Central and Western is significantly lower as compared with the southeast coastal areas. On the one hand, the growth of investment in the East region is fast as the state has taken the preferential policies for attracting external investment towards the eastern regions. On the other hand, the capital flow ability of both the central and western regions is constrained by the weakness of the economic foundation and the unsound external investment environment.

4.3 Network Dynamics

We select all the significant links as determined by the transfer entropy calculations in the static network analysis. Calculation of the local transfer entropy is carried out for all

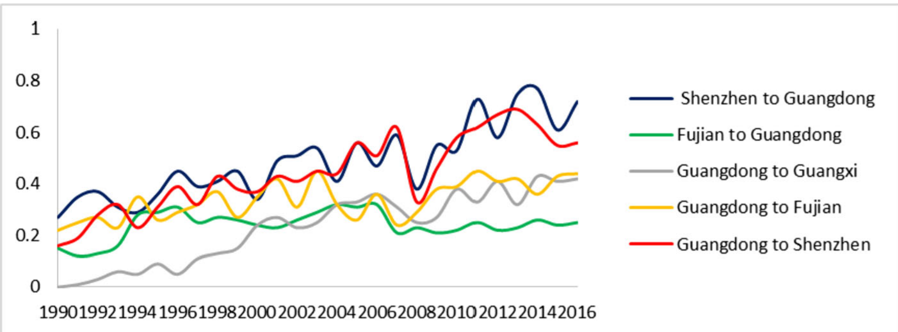


Fig. 5 Local transfer entropy for all significant links in incubation network of southeastern China

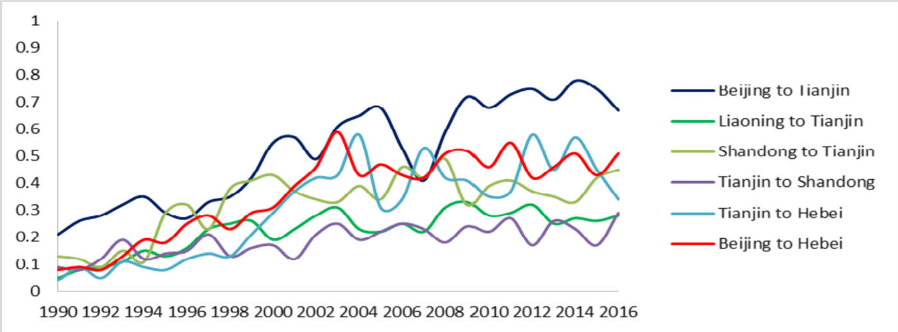


Fig. 6 Local transfer entropy for all significant links in incubation network of north China

the significant connections for analysing how the structure of network is changing with time, which is useful for administrations to formulate policy for regional innovation.

Fig. 5 shows that the information outflow of Guangdong and Shenzhen is higher than other areas in the region incubation networks of southern China, accordingly, they are the core of the network. Shenzhen and Fujian are information sources of Guangdong, whereas, the amount of information flow from Shenzhen to Guangdong is higher than other regions. The information outputs from Shenzhen to Guangdong is rising generally. However, it has declined significantly in 2008 affected by the financial crisis. Information flow between coastal areas and the surrounding interior areas has increased encouraged by innovative policies that encourage coastal areas to promote innovation in inland areas. Consequently, information output from Fujian to Guangdong has also manifested a decline in recent years, whereas, more information has been transferred to the interior regions of Jiangxi. Guangdong constitutes the primary information source of Guangxi. There is little information flow from Guangdong to Guangxi over period I. The information outflow from Guangdong to Guangxi has increased significantly after 2002, indicating that incubators between Guangdong and Guangxi are highly connected in recent years. The results are consistent with the above results of the network structures in southern China.

As illustrated in Fig. 6, the outflowing information of Beijing is higher than other regions in regional incubation networks of northern China, so Beijing is the centre of the network. Beijing has been the prime information source of Tianjin and the

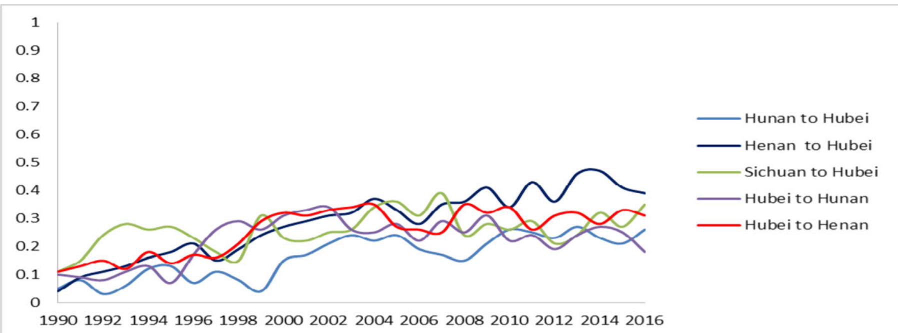


Fig. 7 Local transfer entropy for all significant links in incubation network of central China

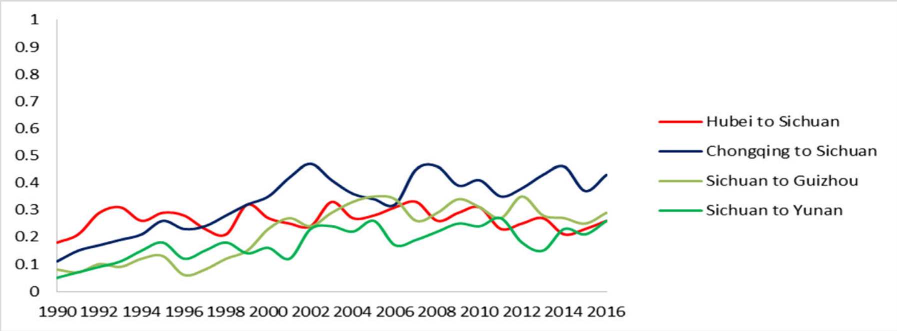


Fig. 8 Local transfer entropy for all significant links in incubation network of southwestern China

outflowing information from Beijing to Tianjin is significantly higher than the information from Liaoning and Shandong. Beijing and Tianjin are not information sources for Hebei over period I, and there is little information transferred to Hebei. Beijing and Tianjin become the prime information sources of Hebei after 2002, indicating that innovative resources that Beijing and Tianjin transferred to Hebei are increasing in recent years. The range of incubation networks has extended to Hebei, which is consistent with the structure of the incubation networks in north china.

Fig. 7 shows that outflowing information of Hubei is greater as compared with the other regions in the incubation network of the central China. Therefore, Hubei constitutes the centre of the network. The strategy concerned for rise of Central China proposed by the central government provides Hubei with the opportunity of development. Sichuan is the prime information source of Hubei over period I, and Henan is the prime information source of Hubei over period II. Hubei is a prime information source of Henan and Hunan, and more information is transferred to Henan. Hubei has always been information source of Henan. Compared with the period I, outflowing information from Hubei to Henan has increased. Incubators between Hubei and Henan have been highly linked and the flow of innovative resources between the two provinces has been accelerated. More information from incubators of Hubei is transferred to Hunan, and Hubei emerges as the key information source of Hunan in recent years. These results are in line with the results of the network structure in Central China.

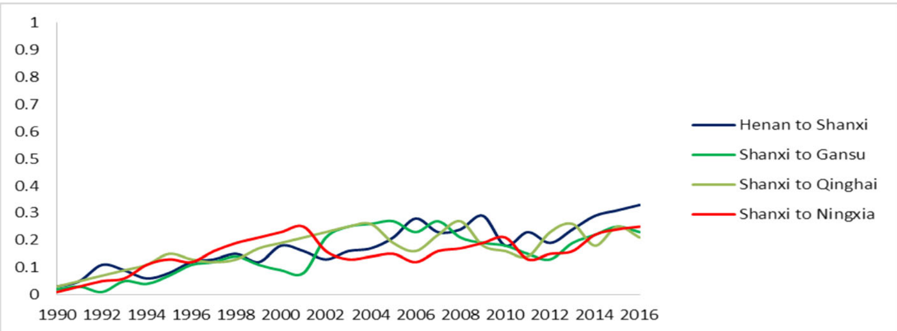


Fig. 9 Local transfer entropy for all significant links in incubation network of north-western China region

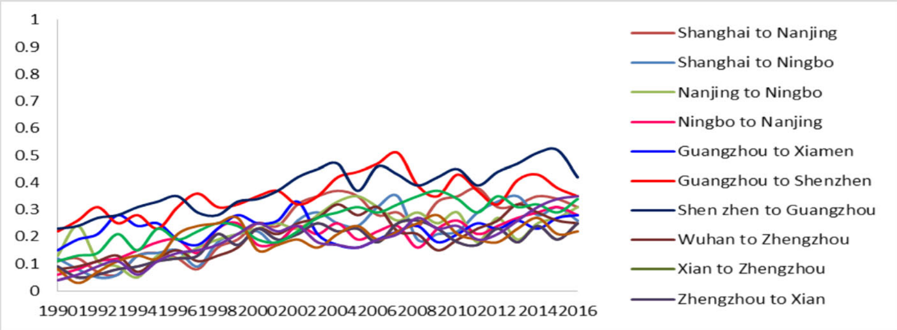


Fig. 10 Local transfer entropy for all significant links in representative cities

Fig. 8 suggests that Chongqing constitutes a key information source of Sichuan. Chongqing is termed as the economic, political and cultural centre in the southwest region. Incubators between Sichuan and Chongqing have high connections owing to the close geographic location as well as similar economic and cultural environment. There is little information transferred to Guizhou, Yunnan. Sichuan is not the major information source of Guizhou and Yunnan over period I. Sichuan becomes the major source of information for Guizhou and Yunnan over period II, and more information is transferred to Guizhou and Yunnan.

Fig. 9 shows that outflowing information of Shanxi is higher than other areas within the incubation networks of north-western China. The information flow from Henan to Shanxi is increasing, and Henan has been the major source of information for Shanxi over period II. There is little information transferred from Shanxi to Qinghai and Ningxia, so Shanxi is not a source of information for provinces of Gansu in the period I. The outgoing information from Shanxi to Gansu, Qinghai and Ningxia has also increased. Shanxi emerges as the major information source of Gansu, Qinghai and Ningxia over period II. The incubation network of north-western China is preliminaries formed, but the degree of a network is the lowest, featured by one-way links from Shanxi. Over period II, while ensuring the regional economic development in the Eastern region, strategy of Western development provides the support for the economic development of the Western region and the corresponding priority investment policy promotes the innovation development in the Western region.

Fig. 10 shows that the information flow among 11 cities exhibits an upward trend, suggesting that the innovation resources have been integrated and the rate of resource sharing is enhanced. Shenzhen has been a key informative source of Guangzhou, and Shanghai has been an informative source of Nanjing and Ningbo in the south-eastern coastal regions. Guangzhou is the primary information source of Xiamen over the period I, but Guangzhou is no longer termed as the major information source of Xiamen over the period II. The reduction of information from Guangzhou to Xiamen is associated with the policies that encourage innovation in inland areas. Wuhan has been the major source of information for Zhengzhou in period II. The information that Zhengzhou transferred to Xi’an is little, accordingly, Zhengzhou is not the major information source of Xi’an over period I. The information that Zhengzhou transferred to Xi’an has increased in period II and incubators between them are highly connected. Chengdu and Chongqing are major information sources for each other and the flow of information between the incubators is high. From the above analysis, we can conclude that the distributions of resources in the region of incubation networks are uneven, and most of the information flow takes place among the provincial capitals. The provincial capital cities with economic advantages and abundant innovative resources play a vital role for the construction of regional incubation networks. The provincial capital cities, possessing economic advantages, together with abundant innovation resources, play a critical role in the development of the regional incubation networks.

5 Conclusions and Implications

5.1 Conclusions

The development of a regional incubation network is beneficial to the transformation of regional economics from being the investment-driven to be the innovation-driven. The regional incubation network is a complex network that has multi-agent interaction and the information theory provides a new approach for investigating the complex network. We selected the data of the invested start-ups from the national incubators in 41 Chinese regions. Thereafter, the transfer entropy was used to calculate the information flow between the incubators in different regions and the effective transfer entropy was calculated based on the transfer entropy to determine the structure of the regional incubation networks in China. Finally, the local transfer entropy between the regions with significant links was calculated to reveal the dynamics of the network structures. The conclusions are presented as follows:

The government's regional development policy is a key factor that guides the formation and change of the regional incubation network. The government's policy orientation affects the flow of innovative resources between regions, thus affecting the formation and development tendency of regional incubation network, which is especially obvious in China. The construction of China's regional incubator network, especially in the early stage of its development, is even more dependent on the guidance of government policies and regulations. In recent years, the scopes of incubation networks in both the eastern and southern China have extended to the surrounding inland areas affected by the regional coordinated development strategy. The south-eastern coastal regions have increased its output of information to the surrounding interior areas with their advantages in the innovative resources. The integration of innovative resources in the adjacent regions is beneficial for the improvement of the level of regional incubation networks. The scope of incubation networks in the southern China has extended to the surrounding inland areas. Resource sharing is realized and the innovative abilities have been enhanced across the region.

Adjacent geographic location and similar culture are the important reasons for the formation of the regional incubation networks. The geographical proximity promotes the development of regional incubator networking. The scale effect brought by the geographical cluster to the incubator promotes the coordinated development of the incubator, thus promoting the development of the regional incubator networking. In accordance with the results of the structure and dynamic process of the incubation networks, we can conclude that the establishment of incubation networks is based on the adjacent geographic location. The information flow between the adjacent areas is high, and the adjacent geographic location has the potential to reduce the cost of resource exchange to accelerate the flow of resources and facilitate the integration of innovative resources. Therefore, close geographic location is an important factor for the formation of regional incubation networks. The result is related to the unbalanced regional development strategy in the beginning of the reform and opening policy. Moreover, the investment policy was put forward to encourage the coordinated development of the adjacent areas to save costs.

The economic environment such as regional economic integration and knowledge economy has promoted the development of regional incubator networking. Networking is conducive to information exchange, resource sharing and technical cooperation, so that it can achieve the requirements of resource allocation optimization. There are six regional incubation networks in China. The first network is the regional incubation network of east China with Shanghai, Jiangsu and Zhejiang as the core, which also include the interior province of Anhui. The regional incubation network of the southern China is the second network with Shenzhen, Guangdong and Fujian as the core, which also includes the inland region of Guangxi. Regional incubation network of the northern China is the third network with Beijing and Tianjin as the core, including Hebei province. Regional incubation network of central China is the fourth network with Hubei at its core, which also includes the provinces of Henan, Hunan and Jiangxi. The fifth network is the regional incubation network of the south-west China with Sichuan as the core, also including the provinces of Chongqing, Guizhou and Yunnan. Moreover, the regional incubation network of the northwest China has the lowest level of networking with Shanxi as the core, including the provinces of Gansu, Qinghai and Ningxia. The facts indicate that with the introduction of the market mechanisms and open-up strategy in Mid-west, increasing investment activities have gradually shifted from coast to the inland China over Period II. Therefore, the regional incubation network of the central and western China is formed while the east China is still the leading innovation region.

Network-level in different regions is seriously unbalanced and the gap exists in the two periods. The degree of networking in the south-east coastal areas is significantly higher than that in the Mid-west. The bidirectional information flow is larger as compared with the other regions where the incubators are closely connected in the regional incubation networks of the south-east coastal area. The overall network level is low despite the fact that the incubation networks in the Mid-west have been developed in recent years. Furthermore, the one-way information flow occurs place in the above regions and there are fewer connections between the incubators. The reason for this difference is that the south-eastern coastal areas have the advantages of superior geographical position, developed economy, superior policy and majority of innovative resources. The economy in the Mid-west China has a big gap with the south-east coastal areas all the time. Low capacity of innovation in the Mid-west China is caused by the scarce innovation resources and policy supports. The cross-regional incubator network will be strengthened in the future. Cross-regional cooperation promotes the accelerated development of regional incubator network and thus it forms an incubator development pattern of intra-regional and cross-regional regional incubator networks.

The resources in the regional incubation networks are unevenly distributed and they are concentrated in the large cities, especially in the Mid-west. China's regional development is unbalanced as a result of the geographical location, national policies and education. Moreover, innovative resources are concentrated in the large cities. The central incubation network is characterized by the outgoing information from Wuhan and Zhengzhou. The southwest incubator network is featured by Chengdu and Chongqing, which transfer information to other regions. Xi'an emerges as the centre of the incubation network in the north-western China. The radiation effect that the incubator in central cities brings to the surrounding areas will be further enhanced, and the bilateral interaction of the innovative and entrepreneurial resources and the entrepreneurial service institutions between the central cities and surrounding cities will become closer, which will further promote the improvement of the entire regional incubator networking.

5.2 Management Implications

The results of this paper can provide references for the decision-making of the relevant government departments. The network is an inevitable trend of the incubator's development and the reasonable structure of the network is the premise for the optimization of resources allocation. Both the structure and dynamic attributes of the regional incubation networks in China are revealed drawn from the actual data, which is capable of providing references for the government departments to make decisions regarding the allocation of the resources.

We put efforts to explore the impacts of policies on the evolution of the regional incubation networks. This paper confirms that the level of incubators networking in the Mid-west is significantly lower than that in the south-east coastal areas. The possible reason for the serious imbalance is that there are not enough policy supports for innovation in the Mid-west. Firstly, the government guides the cross-regional incubator cooperation. The government should encourage and guide the eastern region and western regions to carry out strategic cooperation in incubators through joint construction, scientific and technological achievements transformation, etc., and promote the cross-regional flow of innovative and entrepreneurial factors such as capital, technology and talents. The coordinated development of incubators in the central and western regions can be achieved though combination of the high-quality scientific and technological resources in the eastern region and advantages of western regions in terms of natural resources, policies, and environment. Secondly, the government increases its policy inclination and strength of support for innovative talents of science and technology in the western regions. The shortage and outflow of high-quality innovative talents in the western region are an important factor that hinders the entrepreneurship and innovation ability of the western region. The government's financial and policy support for scientific and technological talents in the western region should not only be reflected in strengthening the introduction of high-level scientific and technological talents, but also in paying attention to the cultivation of young scientific and technological talents.

It is beneficial to improve the management efficiency of the incubator management departments, together with strengthening the operational efficiency of the regional incubation networks. The incubator management departments should realize that the regional incubation network is an important source for the incubator to acquire resources and meet the diversified needs of start-ups. Departments should actively create a platform and emphasize the establishment of the formal or informal network links with other incubators. On the one hand, density and breadth of the network relationship should be improved for obtaining the direct or indirect information from various subjects of consumer groups, professional service agencies, universities, investors and other related organizations and individuals. On the other hand, connections with all the important nodes should be established. Management departments should send information about new ventures to other related entities for promoting the social understanding and support for the entrepreneurship.

Appendix

The name and number of the 41 Chinese regions

Region	Number	Region	Number
Beijing	1	Guizhou	23
Tianjin	2	Yunnan	24
Hebei	3	Xizang	25
Shanxi	4	Shanxi	26
Neimenggu	5	Gansu	27
Liaoning	6	Qinghai	28
Jilin	7	Ningxia	29
Heilongjiang	8	Xinjiang	30
Shanghai	9	Dalian	31
Jiangsu	10	Ningbo	32
Zhejiang	11	Qingdao	33
Anhui	12	Xiamen	34
Fujian	13	Shenzhen	35
Jiangxi	14	Wuhan	36
Shandong	15	Guangzhou	37
Henan	16	Xian	38
Hubei	17	Chengdu	39
Hunan	18	Zhengzhou	40
Guangdong	19	Nanjing	41
Guangxi	20		
Chongqing	21		
Sichuan	22		

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