Bulgarian Chemical Communications, Volume 49, Special Edition K2, (pp. 98 – 103) 2017

Social network analysis of innovation of industry-university-research cooperation in chemical industry (based on China patent licensing data)

H.Y. Yan, X.Z. Bao *, Q. He

Management College， Beijing Union University, Beijing, China

Received August 15, 2017 Accepted November 15, 2017

Industry-university-research cooperation is one of the main ways for an enterprise to gain a competitive advantage. Based on the research perspective of social networks, this paper uses patent licensing announcement in the chemical industry among universities, research institutes and enterprises in 2010-2013 as the data source, and draws a map of innovation network of industry-university-research cooperation in the chemical industry using the software of Pajek and Gephi, and makes an analysis on trend and innovative subject analysis as well as the characteristics of innovation network of industry-university-research cooperation in the chemical industry. The results show that innovation network of industry-university-research cooperation in the chemical industry is a complex network system as a whole with more nodes and uneven distribution, showing scale-free and small-world properties. Chemical enterprises should actively participate in the industry-university-research cooperation and play the role of innovative subject in the industry. They need to establish a stable and effective incentive mechanism for innovation network environment, information and resource sharing, and promote interaction among network actors to enhance innovation ability of all parties.

Key words: Chemical industry, Industry-university-research innovation network, Network structure

INTRODUCTION

With the continuous development of the economy, various dividends have disappeared and the economic growth has declined. Innovation-driven social and economic development has become an inevitable approach. However, innovation requires an appropriate system and environment. To this end, China has proposed that universities, research institutes, enterprises and other organizations jointly establish industry-university-research projects and promote innovation through creating an industry-university-research (IUR) cooperative innovation network [1]. The paradigm of innovation is experiencing a shift from a linear structure to a networked paradigm. In the process of IUR cooperative innovation, all innovation subjects spontaneously form an informal cooperation network and make full use of the communication function and collision effect of the cooperation network to stimulate innovation. At present, domestic and foreign scholars carry out various research and discussion on the relevant contents of IUR cooperative innovation network. Lavie and Drori(2012) think that the cooperation model between enterprises and universities or research institutes is mainly exploratory, while the cooperation between enterprises and enterprises focuses on exploitative innovation[2]; Guan and Zhao. (2013) find that small-world structure has parabolical effect on patent value at firm-level [3]. Hemmert *et al*., studied trust formation in university–industry research collaborations (UICs) and analyzed survey data on UICs in the US, Japan and South Korea [4]. Laurens and Noelle unraveled the interaction between champions and what this entails in terms of role complementarities and conflicts as regards innovation network orchestration [5]. Hong and Su found that the central Ministries and local governments are two sources of institutional force that could impose or encourage university–industry collaborations without considering the geographic distance between them[6].The university industry collaboration network in the emerging and rapidly evolving interdisciplinary field are examined at firm-level [7].Yoon found that university-industry collaboration is the strongest within the triplehelix in recent years, followed by industry-government relations and then UIG relations[8].Throughout the above studies, we find that there are few researches on the IUR cooperation network in the chemical industry. In the existing empirical study, most cooperative networks are built on the basis of national, provincial and industrial levels. However, given the availability of data, there are fewer cooperation networks based on the level of enterprises, universities and research institutes. Scholars mainly use the co-authored sci-tech papers and patent data to construct IUR cooperative innovation network, which is confined to the research output stage of innovation, and short of production stage brought by exploitation of patent

To whom all correspondence should be sent:
E-mail: yanhy819@126.com

and empirical research on the micro-level of IUR cooperative innovation network subjects. This paper includes following parts: The first part builds the IUR cooperative innovation network in the chemical industry; the second part analyses the main body of the IUR cooperative innovation network in the chemical industry; the third part analyzes the characteristics of IUR cooperative innovation network; and the fourth part offers proposals based on the findings of the study.

EXPERIMENTAL

IUR cooperative innovation network is a network system established among innovative subjects of enterprises, universities and scientific research institutes. Its purpose is to provide a better platform for resources interexchange among innovation subjects to better meet the market demand and achieve higher economic benefits. Regarding the establishment of IUR cooperative innovation network, most scholars mainly use co-authored scientific papers and jointly applied patents, and most of which are utility patents. Patent licensing data not only reflects the cooperation among network subjects, but also reflects innovation. This paper uses patent licensing data as the data source of IUR cooperative innovation network in the chemical industry to study the impact of network structure on the innovation output of IUR cooperation network members in the chemical industry.

The patent licensing data studied in this paper comes from the State Intellectual Property Office (SIPO) and the patent service information platform. According to the purpose of this article, the innovation network has a few search conditions: Chinese invention patents; the application date is from 2010 to 2013; applicants of patent include enterprises, universities, colleges or research institutes, or their combinations, such as “enterprises % universities”, “enterprises % research institutes”, “colleges % enterprises” and “enterprises % enterprises”. By analyzing status quo of the industry-university-research cooperation on innovative technology in the chemical industry, it is found that the cooperation among industry, universities and research institutes in the chemical industry is frequent and the intricate network system is formed. Innovative products have been fully introduced with a large number of innovative outputs to enhance the level of economic development in the chemical industry. Therefore, this article builds IUR cooperative innovation network based on the patent licensing data in the chemical industry. Enterprises, universities and research institutes in the chemical industry participating in the industry-university-research cooperation from 2010 to 2013 represent nodes in the IUR cooperative innovation network, and IUR cooperative innovation network represents a collection of cooperative relationships among innovation subjects. After data screening, 1313 valid nodes were found in the innovation network, which mainly include enterprises, universities and research institutes. This paper uses Pajek to build an innovation network and draws the IUR cooperative innovation network for chemical industry during 2010-2013 and universities, research institutes and enterprises respectively. When building an innovation network, the size of each node is adjusted according to the centrality of the innovation subjects, that is, the larger the network node, the more prominent central position in the network is. The thickness of the line represents the weight of the edge where the node is located.

RESULTS AND DISCUSSION

Subjects of IUR cooperative innovation network in the chemical industry

Fig.1. shows the network structure diagram based on the patent licensing data in the chemical industry from 2009 to 2013. Wherein, the network with high centrality (the larger node) has fewer network subjects, and the centrality degree 1 (green) has the closest cooperative relationships.

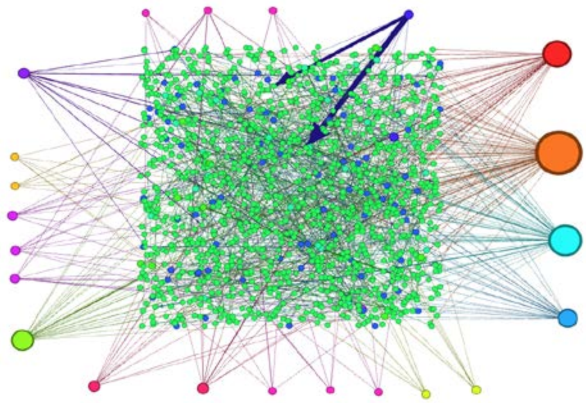

Fig. 1. IUR cooperation network structure diagram in the chemical industry

In this study, the main body of IUR cooperative innovation network in the chemical industry is divided into colleges and universities, research institutes and enterprises. Innovation network size refers to the total number of participants involved in the innovation network, that is, the number of nodes in the network. Table 1. Shows that the larger the size of an innovation network, the more complex its network structure is, and the more likely it is that the network structure will affect the network main body. The innovation network size of enterprises plays the greatest role.

Table 1. Distribution list of IUR cooperation scale in the chemical industry

Time	Organization type	Network size	Percentage
2010	Colleges universities	88	16.57%
	Research institutes	82	15.44%
	Enterprises	361	67.99%
	Total	531	100%
2011	Colleges universities	130	19.94%
	Research institutes	126	19.33%
	Enterprises	396	60.73%
	Total	652	100%
2012	Colleges, universities	71	8.39%
	Research	211	24.94%
	Enterprises	536	63.36%
	Personal	28	3.31%
	Total	846	100%
2013	Colleges, universities	62	10.18%
	Research institutes	106	17.41%
	Enterprises	385	63.21%
	Personal	56	9.20%
	Total	609	100%

Due to the incomplete patent licensing data after 2012, and taking into account that there is little change in the structure of innovation network from 2010 to 2013, the innovation output after the patent licensing lags in terms of time points, and it is unclear how many years of hysteresis, so this article studies innovation network of four years, which will not only have little effect on the results of the study, but also offset the hysteretic nature of patents. The different types of network subjects have different positions in the IUR cooperative innovation network of chemical industry, and network densities vary in different years. It can be seen that the centrality of universities and research institutes is larger and the number of central nodes is smaller, and the proportion of one-to-many cooperation is larger than the cooperation network of enterprises. Enterprises' innovative network structure is most similar to the overall network structure. A few nodes are at the core status and establish a patent licensing relationship with a large number of enterprises and public institutions. They have frequent internal exchanges and more opportunities to obtain innovative achievements with a stronger competitive edge. Most of the enterprises are at the edge of the innovation network, and only establish cooperation relations with a small number of enterprises and public institutions. In addition, there are more one-to-many partnerships between universities and research institutes in the chemical industry, while the cooperative relationships among enterprises are relatively fragmented, mainly on a one-on-one basis.

Scaleless property of IUR innovation network

Scale-free networks are complex networks whose degree distribution satisfies the power-law distribution, in which the connection status of each node is not evenly distributed and has serious heterogeneity.

Table 2 shows the calculation of the centrality of nodes in the innovation network. In terms of the overall network, the relevance of each subject (mean value of the centrality) is 2.91546, which means that on average, each subject has about 3 relationships with other subjects. The variance of the network centrality is 55.84891, and the maximum centrality (159) is larger, while the overall network density (0.001) is smaller, which indicates that the network connections are unevenly distributed in the innovation network. The centrality of the nodes in the IUR cooperative innovation network of chemical industry is calculated according to the frequency of appearances, and the frequency distribution of each node's centrality can be obtained. The probability distribution of the centrality of the nodes is plotted in the double logarithmic coordinate system.The centrality of network nodes is extremely uneven in the network. Most of the nodes have a low degree of centrality while fewer nodes have a larger centrality, which follows the power-law distribution, thus the innovation network is a scale-free network.

Small-work property of IUR innovation network

A small-world network is a kind of mathematical graph based network, most of the nodes are not directly connected, but can be connected by any other nodes in a few steps. In the industry-university-research innovation network, the small-world phenomenon mainly affects the length of path that various nodes need to communicate with each other.

Table 2. Statistics of IUR cooperative innovation network node centrality in the chemical industry

Index	Centrality
Mean value	2.915
Std. Dev.	7.473
Variance	55.848
Total degree	3828.000
Maximum	159.000
Minimum	1.000
Network average degree	0.694
Network density	0.001
Network average weighted	1.458

The shorter the node path of innovation network is, the shorter the path of information exchange among enterprises, colleges and universities and scientific research institutions in the innovation network, and the shorter the characteristic path length of innovation network, the higher transmission efficiency of information in innovation network. The lower the degree of information distortion is, the higher the clustering coefficient in the innovation networks.

The higher the probability of coincidence among innovative subjects in the innovation network, the higher the possibility of establishing cooperative relationships, indicating that such innovation networks have high development potential.

According to the statistical analysis of node data in IUR cooperative innovation network in the chemical industry from 2010 to 2013 shown in Table 3, the average path length of chemical industry IUR cooperative innovation network is 1.994 and the average clustering coefficient is 0.001, which indicate that any two of the 1313 cooperating parties of the IUR cooperative innovation network can establish relationship through 2-3 intermediaries on average.

Table 3. Statistics of innovation network

Distance	Value
Average characteristic path length	1.994
Average clustering coefficient	0.001

The characteristic path length of the IUR cooperative innovation network is small, the speed of information exchange among innovation subjects is high, the clustering coefficient is large, and the innovation subjects are more likely to establish cooperative relationships, indicating that the IUR cooperative innovation network in the chemical industry is a small-world network with great development potential.

Centrality of IUR innovation network

The eigenvector centrality of the network refers to the ratio of the number of eigenvectors of a connected node to the total number of other eigenvectors connected to the node, which can be used to measure the centrality of the network.

By calculating and comparing the centrality of network eigenvectors, we can observe the nodes at the core of the network. The higher the centrality of nodes in the network, the better the development prospect of the network. In the IUR cooperative innovation network, cooperative partners at the core position have greater potential for innovation and more access to innovative resources, which is more conducive to the innovation output of enterprises. By calculating the eigenvector centrality of the network, we get the statistical table of eigenvectors of IUR cooperative innovation network, as shown in Table 4.

Table 4. Eigenvector centrality of integrated network

Items	Eigenvector centrality (digraph)	Eigenvector centrality (undigraph)
Mean value	0.0417710	0.0151951
Std. Dev.	0.0831275	0.0416054
Variance	0.0069102	0.0017310
Total	54.8452610	19.9511565
Maximum	1.0000000	1.0000000
Minimum	0.0000000	0.0016465
Number of nodes	1313.0000000	1313.000000

The organizations with larger centrality have a special network location and easier access to the resources needed for innovation output, making other agencies are more willing to cooperate with them to further promote inter-agency cooperation and social development. The more subjects at central position of the innovation network, the higher the innovation level of the network and the greater the competitive advantage. According to the study, the nodes that connect with the organization will affect the content or quality of the information acquired by the organization, thereby affecting the innovation potential of the organization in the central network.

Density of IUR innovation network

Network density refers to the degree of closeness among nodes in the network, reflecting the rate and range of network information diffusion. When there is no link between nodes, the density is 0, and when any two nodes are directly connected, the density is 1. The range of network density is [0,1]. According to Gephi software analysis, the density of IUR cooperative innovation network in the chemical industry is 0.001.

Proposals for development of industry-university-research cooperation in the chemical industry

IUR cooperative innovation network is a relatively stable network, which mainly refers to the network cooperation established by innovation entities such as enterprises, colleges and universities or research institutes in some region. At present, industry-university-research cooperation has good potential for development in the chemical industry. However, there are also some factors that constrain long-term development, mainly due to the large environmental differences and the low conversion rate of scientific and technological achievements. In order to further promote the development of industry-university-research in the chemical industry, this paper combines the results of social network research and views of domestic and foreign scholars, and puts forward the following suggestions for industry-university-research cooperation in the chemical industry.

From the research results, we can see that in the industry-university-research innovation network of chemical industry, colleges and universities, research institutes and enterprises in the process of industry-university-research cooperation should fully understand their respective advantages and characteristics, put them in the right position and give full play to their own advantages. As training bases for talents, colleges and universities can increase the scope of cooperation with enterprises and research institutes through talent transfer and scientific research cooperation to increase the number of nodes, their centrality and their structural holes. Enterprises and research institutes can boost innovation output, and the innovation output of the entire IUR cooperative innovation network will also be greatly improved. Enterprises are located at the key point of the IUR cooperative innovation network, and play an important role in the transformation of innovative achievements and also the biggest interest recipient in innovation cooperation. Although enterprises of different sizes have different degrees of resource allocation, capital and technology in the network, they should effectively combine their own advantages and develop better under the industry-university-research development system. Enterprises can take advantage of the network location and resource advantages, expand the industrial chain according to the development direction of the market, promote innovation within the network, and then promote the optimization and integration of the innovation elements within the network. They can also make full use of relevant preferential policies and actively participate in the industry-university-research cooperation to play the role of innovative subject in the industry.

The positive impact of structural holes and centrality on innovation output is based on the assumption that subjects that span structural holes can efficiently access and receive information and resources, and that structural holes do not enclose their own information and resources on both sides. Structural holes in industry-university-research innovation networks have a negative impact on the innovation output of research institutes and enterprises, which is most likely due to the existence of social competition mechanisms that lead to the reluctance of sharing resources and information, resulting in the main body of structural holes or subject with high betweenness centrality cannot give full play to their advantages, access to information and resources, and decline in innovation output. Therefore, in the process of promoting industry-university-research cooperation, we need to establish a reasonable incentive mechanism for sharing information and resources so as to promote prompt access to information among network subjects.

A stable and effective innovation network environment is conducive to the exchange of information and cooperation between members of the network. The construction of overall network can promote the creation and development of all small networks, and the steady development of small networks will in turn promote the development of the whole network and promote the innovation output of all network members. Therefore, in order to promote the influence of IUR cooperative innovation network on the innovation output of network members, not only the innovation network needs to be built on the whole, but also the development of each small network needs to be considered.

CONCLUSIONS

Based on the research perspective of social networks, this paper uses patent licensing data in the chemical industry among universities, research institutes and enterprises in 2010-2013 as the data source, and draws a map of innovation network of industry-university-research cooperation in the chemical industry using the software of Pajek and Gephi, and makes an analysis on trend and innovative subject analysis as well as the characteristics of innovation network of industry-university-research cooperation in the chemical industry. The results show that innovation network of industry-university-research cooperation in the chemical industry is a complex network system as a whole with more nodes and uneven distribution, showing scale-free and small-world properties.

As SIPO has changed the way of announcing the patent licensing data since 2013, the researcher cannot obtain sufficient patent licensing data, which affects the timeliness of the research in this article. In the next step, we need to further update the data to explore the influence of network characteristics such as centrality and structural holes on the innovation output of network members.

Acknowledgements: *This paper is funded by Beijing Social Science Fund Project (16YJC046), Beijing University Great Wall Scholar personnel training project (OITOTCD2015031), The innovation ability promotion plan project of Beijing municipal education Commission municipal colleges and universities (PXM2016_014209_ 000018_00202730_FCG) and Institute of Beijing Studies.*

REFERENCES

1. J. f. Yuan, Z. Xu, C. Zhai, *Science and Management* of *S.&.T.* **2**, 115 (2017).
2. D. Lavie, I. Drori, *Organization Science*, **23**, 704 (2012).
3. J.C. Guan, Q.J. Zhao, *Technological Forecasting & Social Change*, **7**, 1271(2013).
4. M. Hemmert, L. Bstieler, H. Okamuro, *Technovation*, **34**, 605 (2014).
5. K. Laurens, A. Noelle, *Technovation*, **6**, 193 (2013).
6. W. Hong, Y.S. Su, *Research Policy*, **42**, 454 (2013).
7. J. Guan, Q. Zhao, *Technological Forecasting and Social Change*, **80**(7), 1271 (2013).
8. J. Yoon, T*Scientometrics*, **104**, 265 (2015).