Construction and Evolution of the Collaborative Innovation Network for Industry-University in the Petroleum and Petrochemical Industry in China's Heilongjiang Province

Zhihong Zhu[1,2], Shuang Zhang[2, *]

Zhihong Zhu: zzh79@126.com; Shuang Zhang: 1987087492@qq.com

[1]Department of Economics and Management, Chuzhou University, Chuzhou 239000, China
[2]Institute of Petroleum Economics and Management, Northeast Petroleum University, Daqing 163318, China

Abstract: The social network analysis method is proposed as an analytical tool to build a collaborative innovation network of industry-university in the petroleum and petrochemical industry in Heilongjiang Province in China and analyze the evolution and structural characteristics of the network in different stages. The research results show that the patent cooperation of industry-university in the petroleum and petrochemical industry in China's Heilongjiang Province is gradually increasing, the scale of the network is constantly expanding, the density of the network is increasing, the cooperation between nodes is getting closer, and the number of sub-networks for cooperation is continuously growing. The patent cooperation innovation between universities and enterprises, research institutes and enterprises has achieved fruitful results, and the creation between universities and research institutes needs further strengthening.

Key terms: industry-university; collaborative innovation network; social network analysis; petroleum and petrochemical industry

1   Introduction

With the development of the Chinese economy and the adjustment of industrial structure, market competition is increasingly fierce. Therefore, innovation has become the enterprise survival and development in market competition necessary support [1]. The petroleum and petrochemical industries are the pillar industry of China's economy. In the current political and economic environment, the innovation of the petroleum and petrochemical industry is particularly significant [2]. However, for the petroleum and petrochemical industry, the enterprise's R&D innovation ability is not enough to support the enterprise development better and faster, so how to establish cooperation with universities, and research institutes, to improve the enterprise's scientific research innovation ability to promote the enterprise better and faster development is a problem of petroleum and petrochemical enterprises must face. After China introduced the industry-university collaborative innovation model in the 1980s, it has gradually been widely applied in China, promoting the cooperative innovation ability of universities, enterprises, and research institutes within the region [3].

Many scholars have analyzed the current situation and model evolution of University-Industry-Research (UIR) collaboration in different fields and aspects. However, from previous research results, it is easy to see that the collaborative innovation model of industry-university-research has been applied in aerospace and aviation, biopharmaceuticals, the information industry, and the electronics industry. Still, there is less research on the collaborative innovation network of industry-university-research in the petroleum and petrochemical industry in Heilongjiang Province, China, especially the research on the cooperation mechanism of nodes in the network and the evolution of the cooperative network by applying the social network analysis method. Therefore, in this study, we will use the social network analysis method to analyze the characteristics and evolution law of the petroleum and petrochemical industry-university-research cooperative network in Heilongjiang Province, China, from the time and space dimensions.

2   Research Design

2.1   Research Methods

Social analysis to network (SAN research method) is adopted to build the industry-university collaborative innovation network, which should consider the individual nodes and pay attention to the connections between nodes [4]. The network diagram shows the interaction among universities, research institutes, and enterprises involved in the petroleum and petrochemical industry of Heilongjiang Province, China. Data Park 3.0 and Cooci 1.7 are used to wash and process the data[5]. The data were input into Usenet software, and Netdraw was used to draw the industry-university collaborative innovation network map of the petroleum and petrochemical industry in Heilongjiang Province, China. The collected data were used to calculate the network density, centrality, structural hole, and other related indicators, and the current situation and evolution trend of industry-university collaborative innovation in the petroleum and petrochemical industry in the Heilongjiang Province, China, were analyzed in stages. This paper examines the current situation of collaborative innovation among various innovation entities in the Heilongjiang petroleum and petrochemical industry. It points to the primary analysis of China's petroleum and petrochemical industry in the Heilongjiang Province industry university.

2.2   Data Sources and Processing

The patent is one of the essential indicators to measure the industry-university collaborative innovation ability [6]. More than 800 universities, research institutes, and enterprises with patent information in the petroleum and petrochemical industry of Heilongjiang Province were queried by China's Tianyancha app. They were searched online through the PATVIEWER database of Intellectual Property Publishing House of the National Intellectual Property Office. The patents that did not meet the research requirements of the industry-university Collaborative innovation network were deleted. For example, after deleting the data of only one applicant or individual applicant, 636 cooperative patents were sorted out, and the number of cooperative patents whose country and province code was 23 (Heilongjiang, China) was 306.

This paper mainly researches the industry-university collaborative innovation network of the petroleum and petrochemical industry in Heilongjiang Province, China. In selecting joint patent

data, we specifically choose the data that the final research results belong to Heilongjiang Province. In contrast, those belonging to research results outside Heilongjiang Province are not included in the research scope.

3 China's petroleum and petrochemical industry in Heilongjiang province of collaborative innovation of industry, network building, and analysis

3.1 The first stage（1991-2000）

Early Chinese petroleum and petrochemical industry in Heilongjiang province patent "industry-university-institute" cooperation is less, cooperation network sparse [7]. Only a few universities and enterprises or research institutes and enterprises cooperate, such as Harbin industrial university and the third production plant of Daqing petroleum administration bureau. Chinese [8] Academy of Sciences Institute of petroleum chemical and Harbin in Heilongjiang Province Gaoming new technology development co, etc.

The characteristics of the industry-university patent cooperation network in the petroleum and petrochemical industry of Heilongjiang Province during 1991-2000 are shown in Table 1. Oilfield Construction Design and Research Institute of Daqing Petroleum Administration Bureau（degree center degree 4） and Institute of Electronic Engineering Technology, Harbin Institute of Technology（degree center degree 2）, whose degree of centrality is significantly higher than that of other nodes. It shows that the largest production-university-research sub-network is formed with the Oilfield Construction Design and Research Institute of Daqing Petroleum Administration Bureau and the Electronic Engineering Technology Institute of Harbin Institute of Technology as the core. This sub-network is mainly the patent cooperation of Daqing Petroleum Administration Bureau Oilfield Construction Design and Research Institute and four other enterprises and universities. Moreover, the Oilfield Construction Design and Research Institute of Daqing Petroleum Administration Bureau has the highest intermediate centrality (6), indicating that Daqing Oilfield Construction Design and Research Institute has substantial control over its cooperative sub-network and is in the core position.

Table 1. Characteristics of industry-university patent cooperation network of petroleum and petrochemical industry in Heilongjiang Province from 1991 to 2000

node	Power center degrees	Degree of proximity to the center	Intermediate centrality	Individual network scale
Oilfield Construction Design and Research Institute of Daqing Petroleum Administration Bureau	4	378	6	4
Electronic Engineering Technology Institute of Harbin Institute of Technology	2	420	0	1
Oil Production Technology Research Institute of Daqing Petroleum Administration Bureau	1	441	0	1

Daqing Petroleum Administration Bureau, Heilongjiang Province, China	1	441	0	1
	......			
The sixth Oil Production Plant of the Daqing Petroleum Administration Bureau	1	381	0	1
Mean value	1.271	424.364	0.273	1, 136
variance	0.471	24.866	1.25	0, 640
Minimum value	1	378	6	1
Maximum value	4	461	0	4

3.2   The second stage（2001-2010）

The patent cooperation network improved significantly in the second phase (2001-2010) compared to the first phase. The number of network nodes cooperative has increased from 22 to 31, and the cooperation between nodes has become tighter. In addition, the number of cooperative nodes has risen from 22 to 31, and the association between nodes has become faster. As a result, the industry-university cooperation network of Northeast Petroleum University has surpassed that of the Oilfield Construction Design and Research Institute of Daqing Petroleum Administration Bureau.

The typical indicators of the industry-university patent cooperation network of the petroleum and petrochemical industry in Heilongjiang Province during 2001-2010 are shown in Table 2. It can be seen that Daqing Petroleum Administration Bureau has the highest degree of centrality (4) and the highest intermediate centrality (6), indicating that it has the most robust control over the patent cooperation sub-network. The maximum individual network size of this node is 4. Northeast Petroleum University was the second, with three degrees of centralities, three intermediate centralities, and three individual scales, and was second only to Daqing Petroleum Administration Bureau in all aspects.

Table 2. Characteristics of industry-university patent cooperation network in the petroleum and petrochemical industry of Heilongjiang Province, China, during 2001-2010

Node	Degree center degree	Degree of proximity to the center	Intermediate centrality	Individual network scale
Daqing Petroleum Administration Bureau	4	810	6	4
Northeast Petroleum University	3	840	3	3
PetroChina Daqing Chemical Research Center	1	842	0	1
Daqing Oilfield Co. LTD	1	842	0	1
Daqing Petroleum Administration Bureau Technology Development Industrial Company	1		0	1
	......			
The sixth Oil Production Plant of the Daqing Petroleum Administration Bureau	1	381	0	1
Mean value	1.097	876.828	0.29	1.097

Variance	0.689	35.475	1.169	0.700
Minimum value	0	810	0	0
Maximum value	4	900	6	4

3.3 The third stage (2011-2022)

In the third stage, compared with the second stage, the patent cooperation network has been improved more significantly[9]. The number of cooperation nodes in the network has increased from 31 to 101, and the cooperation between nodes is also closer. As a result, the industry-university network of Northeast Petroleum University and Daqing Petroleum Administration Co., Ltd. has a large scale of cooperation, while the other nodes are loose. In the third stage, the density of the cooperation network of Northeast Petroleum University has surpassed that of the Daqing Petroleum Administration Bureau, ranking first place. In the third stage (2011-2022), the industry-university patent cooperation in the petroleum and petrochemical industry in Heilongjiang Province reached a higher level. Northeast Petroleum University, Daqing Oilfield Administration Bureau, Daqing Oilfield Administration Co., Ltd., and other companies have significantly increased their applications for patent cooperation in petroleum and petrochemical fields, with a larger network scale. The characteristics of the industry-university patent cooperation network in the petroleum and petrochemical industry of Heilongjiang Province from 2011-2022 are shown in Table 3. From the point of view of node characteristics, the degree centrality of Northeast Petroleum University is the highest, which means that the node has an enormous subnetwork scale. Meanwhile, its intermediary centrality (6.333) is the highest, indicating it has the most robust control over the subnetwork. Meanwhile, its network scale is also the largest. The degree centrality of Daqing Petroleum Administration Co., Ltd. is 6, second only to that of Northeast Petroleum University, which means that the sub-network scale of this node is relatively large. Meanwhile, its intermediary centrality is 19, indicating that its control over the sub-network is relatively strong, and its network scale of 4.892 is also rather large.

Table 3. Characteristics of industry-university patent cooperation network in the petroleum and petrochemical industry of Heilongjiang Province, China, during 2011-2022

Node	Degree center degree	Degree of proximity to the center	Intermediate centrality	Individual network scale
Northeast Petroleum University	7	1.087	31	6.333
Daqing Petroleum Management Bureau Co. LTD	6	1.098	19	4.829
Daqing Petroleum Administration Bureau	5	1.098	24.5	5
Daqing Oilfield Construction Group Co. LTD	4	1.098	14.5	3.102
......				
Daqing Zhongji Petroleum Communication Construction Co. LTD	1	1	0	1
Mean value	1.56	1.56	1.267	1.310
Varance	1.085	1.085	4.597	0.847
Minimum value	1	1	0	1
Maximum value	7	7	31	6.333

4 Analysis of the evolution of the industry-university cooperation network in the petroleum and petrochemical industry in Heilongjiang Province, China

The network characteristics indicators of the above three stages are compared and analyzed. Then the evolution pattern and trend of the patent cooperation between industry, academia, and research in the petroleum and petrochemical industry in Heilongjiang Province, China, is explored [10]. The evolutionary characteristics of the patent cooperation network of petroleum and petrochemical industries, universities, and research institutes in Heilongjiang Province, China, are shown in Table 4. In the first stage of the industry-academia-research patent, cooperation is low, with only 22 nodes. In addition, the network density is low, indicating that the relationship between the nodes is loose. In the second phase, the scale of collaboration between industry, academia, and research patents has increased significantly, expanding to 31 nodes, a 40.91% increase in the number of relationships. In the third stage, the number of nodes in the overall network increased significantly compared to the previous two steps, reaching 101, and the overall density of the network reached 0.156, indicating a further tightening of the links between the nodes and a qualitative improvement in the cooperation between industry, academia, and research. Compared with the second stage, the concentration trend of the industry-university patent cooperation network becomes more muscular, and more industry-university patent cooperation is concentrated in some nodes in the network. Overall, patent cooperation showed a clear trend of strengthening in the third stage, with the levels of all the network characteristics indicators showing an increasing trend, patent cooperation between nodes becoming more frequent, the frequency of collaboration increasing substantially, and the ability to communicate information between nodes being strengthened.

Table 4. Evolutionary characteristics of the patent cooperation network of petroleum and petrochemical industries, universities, and research institutes in Heilongjiang Province, China

Overall network characteristics	Stage 1	Stage 2		Stage 3	
		Indicator values	Rate of change	Indicator values	Rate of change
Number of network nodes	22	31	40.91%	101	225.81
Network Node Relationships	14	17	21.43%	79	364.71
Overall network density	0.060	0.0366	510%	0.156	326.23 %

5 Conclusions

The development status and evolution trend of the industry-university collaborative innovation network in the petroleum and petrochemical industry in Heilongjiang Province, China, were explored using social network analysis methods. Based on the analysis of cooperative patent data, the patent innovation cooperation in the petroleum and petrochemical industry in Heilongjiang Province has gradually increased, and more and more universities, enterprises, and research institutes have participated in the innovation activities of the petroleum and

petrochemical industry, forming a more obvious industry-university cooperation model. From the research results, the patent innovation momentum of the petroleum and petrochemical industry in Heilongjiang Province of China is good, the scale of the industry-university cooperation network is increasing, and the network density is rising, indicating that the cooperation between nodes is getting closer and closer. In addition, the sub-network of collaboration is also growing. Overall, patent cooperation showed a clear trend of strengthening in the third stage, with the levels of all the network characteristics indicators showing an increasing trend, patent cooperation between nodes becoming more frequent, the frequency of collaboration increasing substantially, and the ability to communicate information between nodes being strengthened.

The petroleum and petrochemical industries are the pillar industry of the country. In patent cooperation of the petroleum and petrochemical industry, universities, enterprises, and research institutes continue to increase and promote the petroleum industry field of innovation ability continues to improve. Therefore, China Heilongjiang Province needs to pay attention to the innovative role of industry-university patent cooperation in the petroleum and petrochemical industry in Heilongjiang Province in China. In this analysis, universities play a prominent role in the network of industry-university collaboration, so we should attach great importance to the role of universities in industry-university cooperation in the petroleum and petrochemical industry in Heilongjiang Province, China. In addition, it is necessary to pay attention to the part of the institute, the amount of research institutes in the petroleum and petrochemical industry in Heilongjiang Province in China is weak, and the scientific research and innovation ability of the institute should be paid attention to, give full play to the innovation ability of the institute, and further promote the collaborative innovation and development of production, education, and research.

Reference

[1]   Wang, Y., Yuan, C. (2023) Has integrating industry-university research promoted the high-quality development of small and medium-sized manufacturing enterprises. Journal of Management Engineering, 5:1-14. https://doi.org/10.13587/j.cnki.jieem.2023.06.009.

[2]   Wu, L., Zhong, Y. C., Lin, C. (2023) Research on selecting digital collaborative innovation R&D model of equipment manufacturing industry-university-research. Journal of Harbin Engineering University, 6:1-8. http://kns.cnki.net/kcms/detail/23.1390.U.20230329.1442.004.html.

[3]   Cao, X., Zhang, X. (2023) Evolution of innovation network and proximity mechanism of new energy vehicle industry-university-research. Scientology Research, 5:1-14. https://doi.org/10.16192/j.cnki.1003-2053.20230306.001.

[4]   Peng, S. X., Li, H., Zhang R. X. (2023) Research on the model and mechanism of deep integration of production-university-research in agricultural enterprises based on elemental synergy. Agricultural Economic Issues, 5: 1-17. https://doi.org/10.13246/j.cnki.iae.20230216.001.

[5]   Liu, F.R., Hu, L.J., Fan, X.Q. (2023) How does industry-academia-research cooperation affect the market performance of firms? Scientific Research Management, 44: 155-163. DOI: 10.19571/j.cnki.1000-2995.2023.01.016.

[6]   Chen, Z.T., Yuan, M., Meng, F.R. (2023) Government funding, science, and technology social organizations and industry-academia-research collaborative innovation. Scientology Research, 5:1-18. https://doi.org/10.16192/j.cnki.1003-2053.20221102.001.

[7]   Xiao, Z.H., Li, Y. Green technology innovation model, environmental regulation and collaborative green innovation between industry, university, and research. Journal of Management Engineering, 5: 1-14. https://doi.org/10.13587/j.cnki.jieem.2023.04.002.

[8]   Zhang, Y., Su, J. (2023) University-Industry-Research Cooperation, University Innovation and Technological Progress in the Perspective of Innovation Chain. Scientific Research, 5: 1-16. https://doi.org/10.16192/j.cnki.1003-2053.20220921.003.

[9]   Zhang, S.M., Zhang, Y.F., Yuan, C.H. (2023) How geographic concentration of industry-academia-research alliance portfolio partners affects firms' innovation performance-an analysis of mediating and moderating effects. Journal of Management Engineering, 37: 35-47. DOI: 10.13587/j.cnki.jieem.2023.02.004.

[10]   Li, L.C., Chen, X.J. (2018) Research on collaborative innovation policy of industry-university-research based on social network analysis. Enterprise Economy, 37: 173-180. DOI:10.13529/j.cnki.enterprise.economy.2018.06.025.