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Study on the Impact of Network Structure Embedding on Corporate Green Innovation: A Case Study of Listed Chemical Companies

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Abstract

This paper uses STATA17 software to establish a multiple regression model to explore the effect of network structure embedding on corporate green innovation. The results show that the network structure embedding indicators point centrality, betweenness centrality and closeness centrality have significant effects on corporate green innovation performance, among which point centrality and betweenness centrality have positive effects and closeness centrality has negative effects.

Keywords

Innovation cooperation network; Structural embedding; Green innovation performance.

1. INTRODUCTION

Green innovation is an important support for China to transform the economic growth mode and achieve sustainable development. in 2020, China clearly put forward the dual carbon targets of "peak carbon" and "carbon neutral". In order to ensure the successful completion of the dual carbon targets, in 2021, the State Council issued the "Opinions on the Complete and Accurate Implementation of the New Development Concept and the Carbon Neutral Work" and the "Action Plan for Carbon Peaking by 2030" to deploy the dual carbon work in general. Green low-carbon science and technology innovation is the key path to achieving the double carbon target. Enterprises, as the main innovation subjects, are both key producers and key users of green innovation results, playing a major role as a bridge between technology, market and environment. Therefore, it is crucial to study the factors influencing the improvement of enterprises' green innovation level to achieve the double carbon target.

Green innovation is the optimal decision of the innovation subject under the dual constraints of resources and ecology [1]. Existing research has explored the driving factors of green innovation from both micro and macro levels. From a macro perspective, research has mainly analyzed the impact of green finance [2] [3], foreign direct investment [4], and knowledge diversity [5] on green innovation. YANG et al. [6] studied how green finance and environmental regulations affect green innovation in China, and the results showed that both can promote green innovation, and their impact on the eastern region is stronger than that of other regions. Luo et al. [7] have also studied the impact of foreign direct investment (IFDI) and foreign direct investment (OFDI) on green innovation in China. The results show that IFDI has played a positive role in developing China's green innovation, while OFDI has a reverse green technology effect on China's green innovation. Investing in foreign technology intensive industries can obtain more green technology spillovers and improve China's green innovation capacity. Liao et

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al. [8] analyzed the influencing factors of green innovation efficiency in 284 cities in China, and found that knowledge sharing has a positive impact on urban green innovation efficiency and has a significant demonstration effect on surrounding areas.

At the micro level, a growing body of literature shows that green innovation can help firms gain competitive advantage [9][10][11], and that green innovation is conducive to improving corporate productivity, enhancing corporate reputation and image, and promoting high-quality and sustainable development. How to promote the level of green innovation in enterprises has received increasing attention from scholars.

In terms of internal factors, corporate green strategy [12], corporate absorptive capacity [13], and internal control capacity [14] [15] are the key factors that affect the level of green innovation. For example, Du et al [16] divided green innovation into green product innovation and green process innovation and studied the effects of green market orientation and firm absorptive capacity on green innovation, and the results showed that the effects of firm absorptive capacity on both green product innovation and green process innovation were positive, and the effects of green market orientation on green product innovation were significant but not significant on green process innovation. Ma et al [17] explored the impact of internal control on green innovation and the results showed that the improvement of internal control motivates firms to increase their investment in environmental protection, which further influences green innovation.

From the perspective of external factors of enterprises, the first factors that affect green innovation of enterprises are environmental regulation [18] and green financial policies [19]. Society attaches great importance to the environment, while strict environmental regulations have increased enterprise costs, which have forced enterprises to carry out green innovation. Green innovation is accompanied by high investment and high risk of enterprises, requiring a large amount of funds. Green financial policies such as green bonds have increased the proportion of long-term debt of enterprises, optimized their debt structure [20], and provided an effective way to solve the problem of financing difficulties for enterprises. Secondly, external factors that affect green innovation in enterprises also include relevant stakeholders in the supply chain. The implementation of green innovation requires not only the integration of internal resources within the enterprise, but also the integration of resources with customers, suppliers, and other supply chain partners [21] [22]. Finally, open innovation has become the main mode for enterprises to carry out innovation activities [23]. Strengthening effective cooperation between enterprises and solving the free rider phenomenon [27] is one of the ways to promote enterprises to actively carry out green innovation.

In summary, although green innovation has received increasing attention from the academic community in recent years, there are still the following shortcomings in relevant research: (1) From a macro and micro perspective, scholars have paid more attention to the impact factors of green innovation, focusing on the development level of green innovation in countries, regions, and other areas, while there has been less research on the level of green innovation in enterprises; (2) Research on the impact of green innovation in enterprises mostly focuses on the macro environment and digital finance. Scholars have demonstrated the impact of macro policies, regional digital level, and digital finance on green innovation in enterprises [25-28]. There are few articles studying the relationship between embedding of enterprise innovation networks and improving the level of green innovation.

Network embedding is conducive to cooperation and communication between enterprises. Enterprises can obtain complementary resources in the network through frequent communication, forming the utilization and absorption of heterogeneous innovation knowledge. Therefore, network embedding can reduce the cost of green innovation to a certain extent. On the one hand, the cost reduction comes from making up for the lack of enterprise

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resource capacity. Through network embedding, more information, knowledge, and technical resources can be obtained, and even attracting research and development investment from various aspects of the network and society; On the other hand, it comes from the long-term value brought by green innovation. Through green technology learning, experience exchange and accumulation, the uncertainty of green innovation is reduced, and the sustainability of enterprise green development is achieved.

Therefore, this article focuses on the impact of enterprise network embeddedness on the level of green innovation, and proves whether the position of enterprises in the innovation network has a positive impact on the level of green innovation of enterprises. Exploring the factors that affect the improvement of enterprises' green innovation level enriches theoretical research on green innovation, and provides beneficial references for the government to formulate corresponding innovation network platform building policies to solve the problem of insufficient green innovation capacity of enterprises.

2. RESEARCH DESIGN

2.1. Sample selection and data source

Compared to other industries, the chemical industry faces more acute ecological and environmental conflicts, and there is an urgent need to address the contradiction between enterprise development and environmental protection. Moreover, the chemical industry occupies an important position in the national economy and is in a critical transition period of green development. Therefore, this study focuses on chemical enterprises to explore the relationship between network embeddedness and green innovation.

The network embedded data comes from the individual characteristics calculation results of the petrochemical industry innovation cooperation network, the enterprise green innovation data comes from the green innovation evaluation results of chemical enterprises, and other data comes from the CSMAR database. In order to reduce the interference of abnormal values, this paper conducts a bilateral 1% tail reduction treatment for all variables.

2.2. Variable Definitions

2.2.1 Explanatory variable: green innovation

The data of enterprise green innovation come from the evaluation value of enterprise green innovation performance. The calculation process is as follows: first, the enterprise green innovation performance evaluation index system is designed, and relevant data are collected according to the evaluation index; secondly, the entropy-TOPSIS method is applied to the chemical enterprises among them to calculate the evaluation value of each enterprise from 2010 to 2020.

(1) Corporate green innovation performance evaluation index system

Green innovation output performance is generally expressed as follows: economic benefits, i.e., through the invention of new technologies or the introduction of new technologies, the replacement or improvement of production equipment, thus reducing production costs and increasing production capacity in order to increase business income; environmental benefits, i.e., the adoption of new technologies or new processes in order to reduce enterprise energy consumption and pollutant emissions, thus reducing the pollution of the environment from production activities; social performance, i.e., the adoption of new technologies and techniques helps to improve labor productivity and increase the number of social jobs, thus improving the social welfare of employees. In this paper, based on the innovation network perspective, network performance is added to establish the evaluation index system of enterprise green innovation performance based on the innovation network perspective, as shown in Table 1.

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Table 1. Enterprise green innovation performance evaluation index system

Objectives	Primary indicator	Secondary indicators	Indicator Description
Enterprise green innovation performance evaluation index system	Network performance(A1)	point centrality(A11)	Calculated from the innovation cooperation network
		betweenness centrality(A12)	Calculated from the innovation cooperation network
		closeness centrality(A13)	Calculated from the innovation cooperation network
	Innovation performance(A2)	Number of patent applications(A21)	Number of patent applications in the current year
		Number of green patent applications(A22)	Number of green patent applications in the current year
		Proportion of green patent applications(A23)	Number of green patent applications in the current year/Number of patent applications in the current year
		Number of R&D personnel(A24)	Number of R&D personnel in the current year
		Proportion of R&D personnel(A25)	Number of R&D personnel/Total number of enterprises in the current year
		R&D investment amountA26	Amount invested in the current year
		R&D investment intensity(A27)	R&D investment/Total operating income of the current year
	Economic performance(A3)	Net profit growth rate(A31)	(Net profit of the current year - Net profit of the previous year)/Net profit of the previous year
		Earnings per share growth rate(A32)	(Earnings per share for the current year - Earnings per share for the previous year)/Earnings per share for the previous year
	Environmental performance(A4)	Investment in environmental protection(A41)	Current year's long-term asset investment amount
		Treatment of waste gas emission reduction(A42)	0=no description; 1=qualitative description; 2=Quantitative description (currency/numerical type description)
		Wastewater emission reduction and treatment(A43)	0=no description; 1=qualitative description; 2=Quantitative description (currency/numerical type description)
		Dust and smoke control(A44)	0=no description; 1=qualitative description; 2=Quantitative description (currency/numerical type description)
		Utilization and disposal of solid waste(A45)	0=no description; 1=qualitative description; 2=Quantitative description (currency/numerical type description)
		Implementation of cleaner production(A46)	0=no description; 1=qualitative description; 2=Quantitative description (currency/numerical type description)
	Social performance(A5)	New jobs(A51)	Number of employees on duty at the end of the year - Number of employees on duty at the beginning of the year
		Enterprise tax amount(A52)	Total tax amount of the current year

(2) Calculate green innovation performance evaluation results

This paper uses entropy weight TOPSIS method to evaluate the green innovation performance of chemical enterprises. The entropy weight TOPSIS method evaluation model combines the entropy weight method with TOPSIS method, which effectively avoids the impact

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of subjective factors caused by subjective weighting methods, and solves the problems of limited distribution patterns of evaluation index data sets and high sample size requirements. The evaluation steps are as follows:

① Construct the initial decision matrix

Let the set of enterprise green innovation performance have m samples, evaluation indexes are n, and the initial value of the j index of the i sample is x_{ij}, then the decision matrix of all enterprise green innovation performance sets is:

$$A = (x_{ij}) = \begin{bmatrix} x_{11} & \cdots & x_{1n} \\ \vdots & \ddots & \vdots \\ x_{m1} & \cdots & x_{mn} \end{bmatrix} \quad (1)$$

② Standardization of the index system

The units of each index in the green innovation performance evaluation index system constructed in this paper are different, and in order to eliminate the influence of the differences between different index units, the indexes are de-quantified, and the following formula is used for the standardization of the indexes:

The normalized data for the positive indicators are:

$$Y_{ij} = \frac{x_{ij} - min(x_{.j})}{max(x_{.j}) - min(x_{.j})} \quad (2)$$

The normalized data for the negative indicators are:

$$Y_{ij} = \frac{\max(x_{.j}) - x_{ij}}{\max(x_{.j}) - \min(x_{.j})} \quad (3)$$

where x_{ij} is the raw data of the i enterprise in the j evaluation index.

③ Determine the weight of each indicator

To avoid calculating logarithmic nonsense when finding entropy values and weights, the normalized data Y_{ij} is processed so that all normalized data are greater than zero, and the following transformation is done on Y_{ij} after the normalization process:

$$Y'_{ij} = Y_{ij} + 0.01 \quad (4)$$

After processing $Y'_{ij} > 0$, the final normalization process is:

$$r_{ij} = \frac{Y'_{ij}}{\sum_{i=1}^{m} Y'_{ij}}, i = 1,2,\cdots,m; j = 1,2,\cdots,n \quad (5)$$

The normalized decision matrix is obtained:$R = (r_{ij})_{m\times n}$

The entropy of the j indicator of the standardized decision matrix is:

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$$e_j = -k\sum_{i=1}^{m} r_{ij}\ln r_{ij}, j = 1,2,\cdots,n \tag{6}$$

Among them, $k = \frac{1}{\ln m}, 0 \leq e_j \leq 1$

Denoting the total entropy of the indicator by E, then:

$$E = \sum_{j=1}^{n} e_j = \frac{1}{\ln m}\sum_{j=1}^{n}\sum_{i=1}^{m} r_{ij}\ln r_{ij} \tag{7}$$

The coefficient of variability d_j of the evaluation value data for the j indicator is expressed as:

$$d_j = 1 - e_j, j = 1,2,\cdots,n \tag{8}$$

The weighting factor for the j indicator is:

$$w_j = \frac{d_j}{\sum_{j=1}^{n} d_j} = \frac{(1-e_j)}{\sum_{j=1}^{n}(1-e_j)} = \frac{(1-e_j)}{(n-E)} \tag{9}$$

Calculate the weights of each indicator and form the weight vector $W = (w_1, w_2, \cdots, w_n)$.

④ Weighting matrix of indicator values

The weighted judgment matrix S of index values is calculated based on the normalized decision matrix $R = (r_{ij})_{m\times n}$ and the weight vector W.

$$S = RW = \begin{bmatrix} r_{11} & \cdots & r_{1n} \\ \vdots & \ddots & \vdots \\ r_{m1} & \cdots & r_{mn} \end{bmatrix}\begin{bmatrix} w_1 & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & w_n \end{bmatrix} = \begin{bmatrix} s_{11} & \cdots & s_{1n} \\ \vdots & \ddots & \vdots \\ s_{m1} & \cdots & s_{mn} \end{bmatrix} \tag{10}$$

Where, S denotes the weighted judgment matrix of index values, W denotes the evaluation index weight matrix, w_j denotes the entropy weight of the j index, and s_{ij} denotes the weighted index value of the j index of the i evaluation object.

⑤ Determine the positive ideal solution and negative ideal solution

$$S^+ = \{r_1^+, r_2^+, \cdots, r_n^+\} = \left(\max r_{ij} \middle| j \in J_1 \middle| i = 1,2,\cdots,m\right) \tag{11}$$

$$S^- = \{r_1^-, r_2^-, \cdots, r_n^-\} = \left(\min r_{ij} \middle| j \in J_1 \middle| i = 1,2,\cdots,m\right) \tag{12}$$

where S^+ denotes a positive ideal solution and S^- denotes a negative ideal solution.

⑥ Calculate the Euclidean distance

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$$L^{+} = \sqrt{\sum_{i=1}^{n}\left(r_{ij} - r_{j}^{+}\right)^{2}}\ , i = 1,2,\cdots,m \tag{13}$$

$$L^{-} = \sqrt{\sum_{i=1}^{n}\left(r_{ij} - r_{j}^{-}\right)^{2}}\ , i = 1,2,\cdots,m \tag{14}$$

⑦ Calculate the evaluation value

$$Y_{i} = \frac{L_{i}^{-}}{(L_{i}^{+} + L_{i}^{-})} \tag{15}$$

2.2.2 Core explanatory variable: network structure embedding

The enterprise network embedding comes from the collation of the award information of China Petroleum and Chemical Industry Federation. Firstly, the award information from 2010-2020 was downloaded from the website of China Petroleum and Chemical Industry Federation; secondly, the names of the award winners were organized, and each award winner was used as a node according to the cooperation relationship, and the connection between the award winners was used as a connected edge to form the petrochemical industry innovation cooperation network; finally, according to the innovation cooperation network relationship, the pajek software was used to calculate the centrality of each node. The point centrality, betweenness centrality and closeness centrality of each node are calculated. Finally, according to the innovation cooperation network relationship using the pajek software. As a network embedding measure, a total of 102 chemical companies were screened.

(1) Point Centrality

Point centrality measures the ability of a node to develop relationships with other nodes in the network, and can intuitively reflect the number of other nodes that are in contact with that node. If a point has the maximum degree of centrality, it is considered to be in a central position and most likely to have the greatest power. The calculation formula is: $C_D(v_i) = \frac{k_i}{N-1}$

(2) Betweenness Centrality

Betweenness centrality measures the extent to which one point in a network is located "in the middle" of other points in the network. If a point is on a network path of many interactions, it can influence other points by controlling or distorting the transmission of information, and thus can be considered to have an important position in the network. The betweenness centrality of a point measures its ability to control the communication of other points. If the betweenness centrality of a point is greater, it indicates that the point has a stronger ability to control other points in the network. The node is at the core of the network and has greater power. The calculation formula is: $C_B(v_i) = \frac{2B_i}{(N-1)(N-2)}$

(3) Closeness Centrality

Closeness centrality describes the accessibility of a network node, that is, whether a node can easily establish cooperative relationships with other nodes. It describes the ability of a node to

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be independent of the control or influence of other nodes in its network. The calculation formula is: $C_C(v_i)=\frac{N-1}{\sum_{\substack{i=1\\ j\neq i}}^{N} d_{ij}}$

2.2.3 Control variables

In order to avoid possible errors in measurement testing due to the omission of important variables, this article introduces a series of control variables, including the total assets of the enterprise (SIZE), the number of R&D personnel (RDP), and the amount of R&D investment (RDI). Among them, the natural logarithm of the total assets of the enterprise is used as the proxy variable for the total assets of the enterprise; the natural logarithm of the number of R&D personnel is used as the proxy variable for the number of enterprise R&D personnel; the natural logarithm of the natural logarithm of the enterprise's R&D investment amount is used as the proxy variable for the amount of R&D investment.

2.3. Model

In order to study the impact of network embeddedness on the level of green innovation of enterprises, this paper constructs the following multiple linear regression equation (16) to test it:

$$GI_{i,t}=\alpha+\beta_0\mathrm{PC}_{i,t}+\beta_1\mathrm{BC}_{i,t}+\beta_2\mathrm{CC}_{i,t}+\sum\theta_i\,Controls_{i,t}+YEAR_t+PRVN_j \qquad (16)$$

Where the subscript i represents the enterprise and t represents the year; $GI_{i,t}$ is the explained variable, indicating the green innovation level of enterprise i in year t; $\mathrm{PC}_{i,t}$,$\mathrm{BC}_{i,t}$,$\mathrm{CC}_{i,t}$is the core explanatory variable that represents the network embedding index of enterprise i in year t, where PC represents point centrality, BC represents betweenness centrality, and CC represents closeness centrality; $Controls_{i,t}$ represents all control variables of enterprise i in year t, $YEAR_t$ is a time fixed effect, $PRVN_j$ is the regional fixed effect.

3. EMPIRICAL RESEARCH AND ANALYSIS

3.1. Descriptive Analysis

Table 3 shows a descriptive analysis of all data. From Table 3, it can be seen that the average score of green innovation performance of 102 chemical enterprises from 2010 to 2020 was 0.098, with a minimum value of 0.013 and a maximum value of 0.372, indicating that the overall level of green innovation in chemical enterprises is low, and there are significant differences in green innovation levels among enterprises. The average level of point centrality, betweenness centrality and closeness centrality is low, indicating that chemical enterprises have fewer nodes at the center of the innovation cooperation network in the petrochemical industry, and most enterprises need to improve their cooperation enthusiasm.

3.2. Benchmark regression

This article uses stata17 software to process and regression analyze the data, and the results are shown in Table 3. Column (1) and Column (2) of Table 3 report the benchmark regression results of network embeddedness on enterprise green innovation performance. Column (1) does not add control variables, but only controls the fixed effects of year and region. The results show that enterprise network embeddedness has a significant impact on enterprise green innovation performance; Column (2) adds control variables to column (1), and the results show that the impact of enterprise network embedding on enterprise green innovation performance is still significant.

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Table 2. Variable Meaning and Descriptive Statistics

Variable	Measuring method	Obs	Mean	Std.dev.	Min	Max
GI	Calculated	684	0.098	0.069	0.013	0.372
PC	Calculated	684	0.002	0.002	0.000	0.008
CC	Calculated	684	0.116	0.091	0.000	0.243
BC	Calculated	684	0.001	0.002	0.000	0.009
SIZE	Natural logarithm of total assets of an enterprise	684	22.355	1.246	19.991	25.114
RDP	Natural logarithm of the number of enterprise R&D personnel	684	5.558	0.984	2.708	7.820
RDI	Natural logarithm of enterprise R&D investment amount	684	18.118	1.316	14.340	20.793

Table 3. Benchmark Regression Results

	(1) GI	(2) GI
PC	6.477***	5.673***
	(1.806)	(1.761)
CC	-0.121***	-0.096***
	(0.032)	(0.032)
BC	23.337***	21.371***
	(1.785)	(1.754)
SIZE		0.003
		(0.002)
RDP		0.002
		(0.003)
RDI		0.008***
		(0.002)
N	684.000	684.000
r2	0.527	0.561
r2_a	0.502	0.535
YEAR	YES	YES
PRVN	YES	YES

Note: The values in ( ) represent t statistics, * p<0.1, * * p<0.05, * * * p<0.01

From the perspective of regression results, the impact of PC and BC on green innovation performance is significant at the 0.01 level, and the regression coefficient is positive, indicating that point centrality and betweenness centrality have a positive promotion effect on green innovation performance of enterprises. The more core the enterprise is in the innovation network, the easier it is for the enterprise to obtain innovation resources, thereby promoting the improvement of green innovation performance level of enterprises. The regression coefficient of CC is negative and significant at 0.01 level, indicating that closeness centrality has a significant inhibitory effect on the improvement of green innovation performance of enterprises.

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4. CONCLUSION

At present, the level of green innovation in China's chemical enterprises is still at a relatively low level, with a weak awareness of cooperative innovation among enterprises. Innovation cooperation between a few enterprises is relatively frequent, while cooperation between most enterprises is relatively sparse. Therefore, there is still a large space for innovation cooperation between enterprises and the improvement of the level of green innovation among enterprises. This study uses a multiple linear regression model, selects point centrality, betweenness centrality and closeness centrality as network embedding indicators, and the level of green innovation performance of enterprises as the explanatory variable. It conducts an empirical analysis of the factors affecting the level of green innovation in Chinese chemical enterprises, and draws the following conclusions.

(1) The higher point centrality, the higher the level of green innovation performance of the enterprise. The possible reason is that the output and promotion of green innovation achievements cannot be separated from the acquisition and dissemination of heterogeneous knowledge and technology among enterprises. The higher point centrality of an enterprise, the greater the number of other enterprises that have connections with the enterprise. The higher the frequency of cooperation and communication between enterprises and other enterprises, the greater the scope of cooperation, and the easier it is to obtain innovative resources.

(2) The higher closeness centrality to the center, the less conducive to the improvement of green innovation performance of enterprises. The higher a company's proximity to the center, the easier it is for it to establish relationships with other companies. Due to the large scale of its partners, companies need to spend more time and energy establishing relationships and maintaining partnerships with more innovation entities, resulting in a negative impact on their green innovation performance.

(3) Betweenness centrality plays a positive role in promoting the level of green innovation performance of enterprises. It can be seen that enterprises in the middle position play an important bridge role, not only conducive to the cross dissemination of knowledge and technology in the network, but also conducive to the absorption and utilization of their own innovation resources, ultimately promoting the improvement of green innovation performance of enterprises.

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