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Network Location and Corporate Technological Innovation - Mediating Effects based on Board Academic Capital and R&D Investment

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Abstract

Based on resource dependency theory, agency theory, and social capital theory, using social network analysis, this paper investigates the relationship between chain director networks and corporate technological innovation and explores the path mechanism using a sample of Chinese listed companies in Shanghai and Shenzhen A-shares from 2012 to 2017. It is found that: Network centrality has an inverted U-shaped relationship with corporate technology innovation; The structural hole index has a positive relationship with corporate technology innovation; Financing constraints negatively regulate the relationship between the structural hole index and technological innovation; Organizational redundancy positively regulates the relationship between structural hole index and enterprise technology innovation; Board academic capital and R&D investment play a mediating role in the relationship between chain director network and corporate technology innovation; Further analysis reveals that state-owned enterprises focus more on the role of chain director network by occupying the structural hole position, while non-state-owned enterprises tend to take advantage of the increase in network centrality for resource and information accumulation.

Keywords

Interlocking Director Network; Corporate Technology Innovation; Board Academic Capital; R&D Investment.

1. Introduction

As China's economy enters a stage of high-quality transformation and development, innovation is increasingly becoming an important factor in forming the core competitiveness of enterprises. However, in reality, there are a series of problems in enterprises. such as insufficient innovation capability and unsatisfactory innovation performance. On the one hand, from the perspective of innovation input, enterprises need to continuously invest enough resources, especially the training of R&D personnel. On the other hand, from the perspective of innovation output, the innovation result has high uncertainty, high risk, and low short-term return [1]. These greatly affect the decision-making of firms regarding innovation activities. According to the characteristics of innovation activities, the core problem that enterprises need to solve is how to obtain the "capital" and "knowledge" needed for innovation activities, and then internalize them into their own advantages. If a company wants to maintain its competitive advantage, it can use external networks to seek scarce knowledge and resources for innovation activities [2]. Then the chain of directors' network [3], which is formed by the fact that some members of the board of directors serve on the boards of two or more companies, is one of the options available to the firm to obtain knowledge and resources from external networks.

Regarding the research on chain director networks and corporate innovation, scholars have argued that embedding a chain director network creates an advantage for firms to obtain more information about decision-making on innovation activities, and company CEOs make higher-

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quality innovation investment decisions with this advantage [4]. Chain director networks can save firms' innovation costs by increasing trust among firms. because firms in the same network will accomplish the exchange and flow of innovation knowledge among themselves through informal and non-market-based forms [5]. However, subsequent scholars have found that chained boards cause a decline in corporate governance leading to damage to the market value of the firm [6]. Firms in chained director networks have more severe agency problems, driven by limited rationality, opportunism, and risk aversion, and managers will lack incentives to support corporate innovation activities at this time. This is because the network power and relationships that chain director networks bring to directors induce self-interested behavior [7], while the specificity of chain directors makes them more likely to engage in surplus manipulation, thus indirectly undermining innovative activities that require long-term corporate investment [8]. Helmers et al. (2015) found that director networks influence innovation inputs through innovation effects and influence innovation outputs through innovation decisions [9]. In terms of inputs, Martin (2015) et al. found that the higher the centrality of a firm's chain director network and the richer the structural holes, the greater the innovation inputs [10]. In terms of output, Ahuja (2000) found that a firm's network centrality is positively related to innovation output, but the more structural holes a firm occupies, the more it hurts its ability to invent patents [11]. Bernini et al. (2014) subsequently found that firms with elevated director networks have a higher number of patent applications [12]. This is because the more centrally located the network is, the more valuable information the firm has access to and the greater the competitive advantage [13], while occupying the structural hole position will have a greater innovation advantage [14]. However, Yan et al. (2018) found that the higher the network centrality of chain directors, the more detrimental to corporate innovation investment [15]. Firms with high network centrality cause the board's monitoring efforts to be distracted from monitoring opportunistic behavior within the firm, which indirectly harms the firm's innovation investment decisions. Summarizing the existing studies, it can be seen that: scholars have come to different conclusions about the influence of chain director networks on corporate innovation, and there is a lack of research on the intermediate path mechanism between chain director networks and technological innovation.

Based on the above analysis, this paper, based on resource dependence theory and agency theory, uses network centrality and structural hole index as the variables to measure the characteristics of chain director networks. Analysis and examine the relationship between chain director networks and corporate innovation performance. This paper attempts to answer the following questions: What is the relationship between chain director networks and corporate technological innovation? Is there a mediating mechanism between them?

2. Theoretical Analysis and Research Hypothesis

2.1. Chain Director Network and Enterprise Technology Innovation

Chain director networks can be measured using the network centrality and structural hole indices. Network centrality reflects the "quantitative" characteristics of interlocking relationships [16]. According to the resource dependence theory, resources are the key factor for innovation activities, and the ability of a company to control certain core resources even plays a decisive role in the competitiveness of a company in the market. Generally speaking, the higher the network centrality, the more resources a company can access and control, so the company at the core of the network is more able to take advantage of these resources to promote innovation. From the perspective of innovation-decision, the chain director, due to its special characteristics, can learn more information about innovation among different companies and industries, so the higher the network centrality, the lower the degree of asymmetry of information about innovation, and the lower the risk of decision-making, the

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enterprise is more able to make high-quality innovation decisions, and thus improve the enterprise innovation performance. At the same time, the higher the network centrality, the more centrally located the firm is in the network, and the more opportunities the firm has to identify directors with experience in investing and making decisions about similar innovation projects and to help the firm make higher-quality innovation decisions through them [17].

Along with the increasing network centrality, it means that the number of corporate linkages is increasing, then the agency problem of the company will become more and more serious. First, too many linkages will make the chain directors lack sufficient energy to perform their supervisory and decision-making functions, and maintaining a highly connected network relationship will also cost the company a lot of money and manpower, which will indirectly squeeze out the investment and attention to innovation. At the same time, the higher the number of external firms' linkages, the more likely directors are to form complicity with the executives of these firms and have a greater chance to pursue self-interest and thus seek short-term benefits, which can undermine innovation activities that require long-term attention and long-term investment. Second, the higher the network centrality, the higher the connectivity within the network will bring a large number of homogeneous resources and information, which are not very useful to enhance the innovation performance of the firm, but consume the cost, time, and energy of the firm and directors to distinguish and filter them, which indirectly harm the innovation performance of the firm. Finally, when interlocking relationships among firms are held by a few core firms, or even concentrated only among individual firms, a lock-in effect is induced in the interlocking director network [18]. As a consequence, internal and external information cannot flow between firms and the environment, and the information in the chain director network is no longer heterogeneous [19], which prevents firms from improving their innovation capabilities and causes them to close themselves off. Companies with high network centrality also have the possibility of over-reliance on the network for external information, which reduces the ability of the company to adapt to changes in the market environment.

Unlike network centrality, the structural hole index reflects the "qualitative" characteristics of the chain of relationships. First of all, a firm's structural hole position indicates that the firm assumes the role of "bridge" and "intermediary" in the network, and this characteristic brings information and control advantages to the firm's innovation activities. Information advantage is reflected in the fact that firms occupying structural holes have more access to external information than other firms. The richer the structural hole is, the more heterogeneous information and resources are available, and the faster the firm can identify innovation opportunities and threats compared to other firms. At the same time, the company assumes the function of information transfer and can find potentially differentiated information that is beneficial to the company's innovation. This reduces the level of uncertainty and risk in the innovation process. The advantage of control is the ability of the firm to control the flow of information in the network for itself [20], from the point of view of resource dependence, on the one hand, other firms will be more dependent on the firm occupying the structural hole position. On the other hand, controlling a large number of heterogeneous resources and information is beneficial for firms to further develop their innovation activities and improve their innovation performance. Occupying a structural hole means that firms have access to collaborating firms in the network that are not connected to each other [21], and get less repetitive information and resources, which reduces the cost and effort of firms to sift through information and resources and means that firms build a more efficient chain director network with less cost. Firms with rich structural holes can more easily identify the qualifications of innovation activity collaborators and firms in the network, which is more advantageous in avoiding innovation failures and wrong decisions and improves the success rate of innovation activities [22]. Finally, firms in the structural hole position can more quickly identify redundant

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ties in their own network linkages, which in turn reduces the cost of maintaining the firm's linkages and allows management to focus more energy on the most important relationships [23,24]. Based on the above analysis, the following hypothesis is proposed:

H1: Chain director network centrality has an inverted U-shaped relationship with corporate technology innovation.

H2: Chain director structure hole index positively promotes enterprise technology innovation.

2.2. The Moderating Effect of Financing Constraints

Among the factors that influence corporate innovation, financing constraints are not negligible. Banks selectively ignore the needs of firms' innovation activities when conducting lending operations to them due to their consideration of the risks of firms' innovation activities and the degree of information asymmetry. The high risk, high uncertainty, and low short-term returns of innovation activities make other investors stay on the sidelines. In addition, companies generally face the pressure of financing constraints, and managers tend not to invest too much in innovation activities of companies in order to maintain smooth operations and to force short-term performance pressure. Therefore, when the financing constraint of firms intensifies, in order to avoid risks, firm managers will pursue project activities with stable rates of return, the short-term financial pressure from the financing constraint will force managers to refrain from innovation activities, which in turn will be detrimental to the innovation performance of firms. In his study, Liu (2015) pointed out that the presence of financing constraints can make firms' R&D investment efforts insufficient [25]. Financing constraints are an important reason for firms' lower innovation output [26]. Therefore, the role of chain director networks may be weakened in firms with higher financing constraints. The hypothesis is as follows:

H3a: Financing constraint negatively regulates the relationship between chain director network centrality and firm technological innovation.

H3b: Financing constraint negatively regulates the relationship between chain director structural hole index and firm technological innovation.

2.3. Regulating Effect of Organizational Redundancy

Organizational redundancy is the existing resources within enterprises, which can be understood as “unused resources” of enterprises. Enterprises with high organizational slack are more resilient in the face of adverse situations such as sudden risks and market changes, and organizational slack can stimulate management to make innovative decisions. Then affect the innovation behavior of enterprises. Organizational slack may also cause managers to expand their own interests, aggravate agency problems, and thus indirectly damage enterprise innovation. This paper argues that the key lies in how to convert organizational slack into internal innovation advantages, and how enterprises allocate these human, material and knowledge resources. The potential heterogeneous information and resources brought by the interlocking directorate network to enterprises can complement the redundant resources within enterprises [27], and enterprises will be more likely to succeed in innovation. At this time, the redundant resources of the organization can just support innovation activities, and thus jointly promote enterprise innovation. Therefore, this paper puts forward the following hypothesis:

H4a: Organizational slack positively moderates the relationship between interlocking director network centrality and enterprise technological innovation.

H4b: Organizational slack positively moderates the relationship between the structural hole index of interlocking directors and enterprise technological innovation.

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2.4. The Mediating Role of Board Academic Capital

French sociologist Bourdieu proposed the concept of social capital [28]. The director ' s social capital refers to the internal and external interpersonal relationship formed by the director ' s personal experience in the past and the potential resources and information it can inject into the enterprise. Shen et al. (2016) found that the research on executive education background was scarce [29], and the proportion of executives with academic background in the executive team reached 20%. As the resources owned by enterprises, on the one hand, interpersonal relationship can bring resources to promote innovation activities, and on the other hand, it can bring solutions to the problems in the process of enterprise innovation. The interpersonal relationship formed by directors' past tenure in colleges and universities and the potential resources and information that this academic background can bring to enterprises will promote enterprise innovation activities. Boards with highly educated members have more accurate judgments on innovation information and risks in the whole innovation process, and have higher tolerance for the failure of innovation activities. Therefore, directors with academic background tend to innovate. The following assumptions are made:

H5a: Network centrality of interlocking directorates has a positive effect on board academic capital.

H5b: Network structure hole index of interlocking directorate has positive effect on board academic capital.

The board of directors can connect the internal and external enterprises and make suggestions for the operation and management of enterprises. In the process of external communication, it can bring external support and commitment to enterprises and other resources. The board of directors can become a bridge connecting the internal and external enterprises. Boards with rich academic capital are more likely to screen homogeneous resources and information embedded in the interlocking directorate network and provide advice for enterprise innovation activities. The educational background of board members can provide innovative information screening and high-quality innovation decision support for enterprises, and scientific research experience can provide guarantee for technological innovation of enterprises. Therefore, the knowledge of board members with university experience can not only improve the quality of enterprise innovation decision-making, but also bring more potential knowledge and resources to enterprises, thereby increasing innovation investment and promoting innovation achievements. Assumptions are thus made:

H6a: Board academic capital plays an intermediary role between interlocking directorate network centrality and enterprise technology innovation.

H6b: Academic capital of the board plays a mediating role between the structural hole index of interlocking directors and technological innovation of enterprises.

2.5. The Mediating Effect of R&D Investment

Resource dependence theory holds that enterprises should have sufficient resources and continuous knowledge input for innovation activities. The effect of interlocking directorate network on R&D investment is as follows: The influence of board of directors on R&D investment is mainly reflected in decision-making and strategy formulation. Enterprises with interlocking directors have richer resources and knowledge information. The resources and information embedded in the interlocking director network can be used by enterprises, which reduces the uncertainty and information asymmetry of innovation activities. On the one hand, it can identify risks and opportunities, on the other hand, it can understand the R&D investment and production and operation of other enterprises, so that enterprises will be more willing to use funds for R&D activities. Thus, assumptions are made:

H7a: Interlocking directorate network centrality positively promotes R&D investment.

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H7b: The structural hole index of interlocking directors positively promotes R&D investment.

Chain board has an important impact on board decision-making, which includes investment in enterprise innovation activities. Enterprises in the interlocking directorate network are connected to each other as a whole, which makes enterprises closely related and have high trust. They can reduce transaction costs and operational risks in obtaining market information and resources, and improve enterprise performance. Because of its strong control and control ability, enterprises in the core position of interlocking directorate network can have greater possibility to obtain the key resources and information needed for innovation, grasp the opportunity, promote R&D investment and improve innovation performance. In addition, social capital in the network of interlocking directors will have an important impact, such as academic capital. interlocking directors with different backgrounds and experiences adopt more innovative ways to deal with and make decisions on enterprise innovation information. Existing literature research shows that chain directors with technical background are more willing to carry out innovation activities, which is more inclined to increase R&D investment of enterprises, and then promote technological innovation of enterprises [30,31]. In summary, R&D investment may play a mediating role between interlocking directorate network and enterprise technological innovation. The following assumptions are therefore made:

H8a: R&D investment plays an intermediary role between interlocking directorate network centrality and enterprise technology innovation.

H8b: R&D investment plays an intermediary role between interlocking directorate network structure hole index and enterprise technology innovation.

3. Research Design

3.1. Sample Selection

This paper selects the data of Shanghai and Shenzhen A-share listed companies from 2012 to 2017 as the research sample. All data are mainly collected from the CSMAR database, and directors and related financial information are supplemented and corrected from the annual reports of listed companies. The data processing software was Stata 16.0 and SPSS 26.0. The interlocking director network is constructed by using UCINET 6.0 software.

3.2. Variable Definition

(1) Dependent Variable: Technological Innovation

The number of invention patent applications is used to measure enterprise technological innovation. Data is obtained from the CNRDS database in China. The reason for selecting the number of invention patent applications is that the number of invention patent applications can more intuitively reflect the technological innovation of enterprises and better reflect the innovation level of enterprises.

(2) Independent Variable: interlocking director network

This paper calculates the network centrality and structural hole index of interlocking directorates. Based on the director information of all listed companies during the sample period, this paper constructs the adjacency matrix of 'director-director' by year. If director i and director j are on the board of directors of the same company, the matrix element is 1, otherwise 0. Finally, the matrix is imported into UCINET software. According to existing research, network centrality is usually divided into degree centrality, intermediary centrality and closeness centrality. Degree centrality refers to the number of direct connections between directors and other directors. Intermediary centrality represents the degree of control of directors on different connections in the network. Closeness centrality can be understood as the distance between directors themselves and other owners in the network [32]. In this paper, the most commonly used degree centrality is calculated as follows:

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$$D_i=\frac{\sum_{j\neq i}\delta(i,j)}{g-1} \quad (1)$$

where, $\delta_{(i,j)}$ indicates that if director i and director j hold office in at least one company, it is 1; Otherwise 0. g Represents the number of board members of listed companies in the year, taking into account size differences using (g-1) to eliminate.

The calculation of structural hole index is as follows:

$$H_i=\sum_{i\neq j}[P_{i,j}+\sum_{k\neq i,j}(P_{ik}P_{kj})]^2 \quad (2)$$

In parentheses, the square of the sum of direct relation strength and indirect relation strength represents the restriction that enterprise j brings to enterprise i. $p_{i,j}$ represents the direct relationship strength between enterprise i and j, and $\sum_{k\neq i,j}(P_{ik}P_{kj})$ measures the sum of the indirect strength of enterprise i reaching enterprise j through k. The structural hole index is equal to the number 1 minus limit regime.

(3) Moderating Variable

Financing constraints: Reference Hadlock & Pierce (2010) research using SA index to represent the financing constraints of enterprises [33], SA index is negative, that is, the smaller the value, the greater the financing constraints. Calculated as follows: $SA=-0.737\times Size+0.043Size^2-0.04\times Age$. Size is the logarithm of enterprise size. age is the listed years of enterprises.

Organizational redundancy: organizational redundancy can be divided into absorbed slack and unabsorbed slack [34]. The former is the ratio of management cost and sales cost to main business income, and the latter is the ratio of quick assets to current liabilities. The mean of the two is used to measure organizational redundancy.

Table 1. Definition and description of variables

Property	Name	Symbol	Explanation
Dependent variable	Technological Innovation	Rinvent	Invention patent applications plus one logarithm
Independent variable	Degree centrality	Degree	See Formula (1)
	Structural hole index	Hole	See Formula (2)
Moderating variable	Financing constraints	RZ	SA index
	Organizational redundancy	RY	The mean values of absorbed redundancy and unabsorbed redundancy
Intermediary variable	Board Academic Capital	Academy	The number of board members with university experience is 1 or 0
	R&D investment	R	Number of R&D investment
Control variable	Enterprise size	Size	Number of total assets at end of period
	Board size	Board	Number of board of directors
	The combination of two positions	Dual	Are the chairman and general manager 1, 1, or not 0
	The proportion of independent directors	DL	Number of independent directors except total board of directors
	top three executive pay	Top3Pay	Total salary of top three executives
	The proportion of the largest shareholder	Top1	proportion of the largest shareholder
	Asset-liability ratio	Lev	End-of-period assets divide end-of-period liabilities
	Age of listing	Age	Listed years
	Industry	Industry	Industry virtual variables
	Year	Year	Year virtual variable

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(4) Intermediary Variable

Academic capital of board of directors: members of board of directors with university experience are 1, otherwise 0.

R&D investment: the amount of enterprise' s R&D investment in the year is taken as logarithm.

(5) Control Variable

This paper selects the size of the board of directors, the proportion of independent directors, the combination of two positions, top three executive pay, the proportion of the largest shareholder, asset-liability ratio, enterprise size, age of listing, industry and year to control. The description of all the above variables is shown in table 1.

4. Empirical Result

4.1. Descriptive Statistic

The descriptive statistical results of the main variables are shown in table 2. The average value of enterprise technological innovation is 2.694, and the coefficient of variation (SD/ Mean) is close to 0.5, and the standard deviation is 1.404. It can be seen that there is a certain gap in innovation output between enterprises, and the innovation capabilities of different enterprises are uneven. From the perspective of the mean of network centrality and structural hole index, it reflects that most of the sample companies have formed a certain scale of interlocking directorate network, indicating that the phenomenon of interlocking directors is common in listed companies. The average value of financing constraints-3.754, reflecting the market companies generally face a certain degree of financing constraints. The maximum value of organizational slack is 41.143 and the minimum value is 0.049. There is a big gap between the slack resources of different enterprises. The average value of academic capital is 0.904, indicating that there are directors with academic background in the board of directors of most enterprises. The average value of R & D investment is 18.181. From the standard deviation of 1.368, the investment gap of different enterprises in innovation activities is obvious.

Table 2. Descriptive statistical results of variables

Variable	N	Mean	SD	Min	Max
Rinvent	5610	2.694	1.404	0	8.748
Degree	5610	35.098	15.516	1	99
Hole	5610	0.663	0.093	0	0.890
RZ	5610	-3.754	0.251	-5.156	-2.168
RY	5610	0.803	1.049	0.049	41.143
Academy	5610	0.904	0.294	0	1
R	5610	18.181	1.368	10.262	23.239
Board	5610	8.809	1.698	3	18
Size	5610	22.39	1.229	19.34	28.069
Dual	5610	0.243	0.429	0	1
DL	5610	0.371	0.055	0.231	0.8
Lev	5610	0.440	0.199	0.008	2.578
Top1	5610	0.348	0.146	0.034	0.874
Top3Pay	5610	14.35	0.661	12.09	17.352
Age	5610	10.04	6.196	0	26

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4.2. Regression Result

The basic regression results are shown in table 3. In column (1), the regression coefficient between network centrality and enterprise technology innovation is significantly positive (β = 0.003, p < 0.05), indicating that the network centrality is positively correlated with enterprise technology innovation, which is consistent with most scholars ' research. Chain director network can bring more resources to enterprise innovation. It can be seen from Column (2) that the regression coefficient of the first term of degree centrality is 0.284, which is significantly indigenous at the level of 1 %. At the same time, the second term is negatively correlated with technological innovation of enterprises (β = − 0.000, p < 0.01). The results reflect that listed companies should not excessively pursue the network connection of interlocking directors. The homogeneous connection will cause the disadvantages of decentralized directors' efforts to increase enterprise costs. H1 is supported, and the relationship between network centrality and technological innovation of enterprises is inverted U-shaped. Column (3) shows that the structural hole index is significantly positively correlated with the regression coefficient of enterprise technological innovation (β = 0.429, p < 0.05).

Table 3. Basic regression results

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Variable	Rinvent	Rinvent	Rinvent	Academy	Academy	R	R
Degree	0.003**	0.003***		0.003***		0.003**	
	(2.40)	(2.92)		(11.44)		(2.53)	
$Degree^2$		-0.000**					
		(-2.20)					
Hole			0.429**		0.468***		0.408**
			(2.00)		(7.98)		(2.31)
Board	-0.021*	-0.023*	-0.028**	0.018***	0.011***	-0.014	-0.020*
	(-1.72)	(-1.82)	(-2.01)	(7.34)	(4.11)	(-1.28)	(-1.68)
Dual	0.044	0.043	0.045	0.015*	0.016*	-0.047	-0.047
	(1.17)	(1.12)	(1.18)	(1.66)	(1.69)	(-1.55)	(-1.54)
Size	0.509***	0.508***	0.510***	-0.001	-0.000	0.627***	0.628***
	(25.27)	(25.18)	(25.28)	(-0.29)	(-0.08)	(29.76)	(29.76)
DL	0.682**	0.698**	0.686**	0.021	0.026	0.526*	0.530*
	(2.07)	(2.11)	(2.08)	(0.27)	(0.34)	(1.81)	(1.82)
Top3Pay	0.420***	0.420***	0.419***	-0.004	-0.004	0.461***	0.461***
	(14.82)	(14.86)	(14.78)	(-0.57)	(-0.60)	(18.73)	(18.71)
Top1	-0.488***	-0.482***	-0.483***	0.013	0.019	-0.315***	-0.310***
	(-4.02)	(-3.97)	(-3.98)	(0.48)	(0.69)	(-3.18)	(-3.13)
Lev	-0.082	-0.080	-0.081	-0.089***	-0.086***	-0.087	-0.085
	(-0.85)	(-0.82)	(-0.84)	(-3.19)	(-3.06)	(-0.96)	(-0.95)
Age	-0.002	-0.002	-0.002	0.001*	0.001	-0.013***	-0.013***
	(-0.67)	(-0.65)	(-0.73)	(1.83)	(1.59)	(-5.03)	(-5.04)
Constant	-0.154	-0.134	-0.167	0.023	0.007	-0.428*	-0.440**
	(-0.71)	(-0.62)	(-0.78)	(0.40)	(0.12)	(-1.94)	(-2.00)
Year/Industry	YES	YES	YES	YES	YES	YES	YES
Observations	5610	5610	5610	5610	5610	5610	5610
R-squared	0.291	0.291	0.290	0.048	0.039	0.444	0.444

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Note: The value t is shown in brackets. *, * *, * * *, respectively, represent a prominent 10 per cent, 5 per cent, 1 per cent level. The following is the same.

The richer the structural holes are occupied by enterprises, the more heterogeneous resources and information they control, the greater the internal and external advantages of innovation

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activities are, and the better the innovation performance of enterprises is. Verify hypothesis H2. In column (4), the regression coefficient between network centrality and board academic capital was significantly positive ($\beta = 0.003$, $p < 0.01$). In column (5), the regression coefficient between structural hole index and board academic capital was significantly positive ($\beta = 0.468$, $p < 0.01$). In the process of network connection of interlocking directors, the increase in the number of directors with academic background in the whole network also means the accumulation of academic capital of the board of directors, and H5a and H5b are verified. In Column (6), the regression coefficient of network centrality and R&D investment is significantly positive ($\beta = 0.003$, $p < 0.05$). In Column (7), the structural hole index is significantly positively correlated with the regression coefficient of R&D investment ($\beta = 0.408$, $p < 0.05$). The advantages of resources and information brought by interlocking director network and the identification of risks and opportunities will make enterprises more willing to invest in R&D activities. The assumptions of H7a and H7b are verified.

The regression results of moderating and mediating effects are shown in table 4. In column (1), the regression coefficient of the interaction between financing constraints and network centrality quadratic terms is not obvious and H3a is not verified. Column (2) shows that the regression coefficient of the interaction term between financing constraints and structural hole index is significantly negative ($\beta = -1.441$, $p < 0.05$). Indicates that the greater the financing constraints of enterprises, occupy the structural hole position of innovation advantage will be weakened. The results supported H3b. In column (3), the regression coefficient between organization redundancy and network centrality quadratic terms is not obvious, and H4a is not verified. Column (4) shows that the regression coefficient of the interaction term between organization redundancy and structure hole index is significantly positive ($\beta = 1.133$, $p < 0.05$). It shows that enterprises which occupy the position of structural holes and have rich redundant resources have better innovation output and H4 b verification is successful. Column (5) After adding academic capital, the inverted U-shaped relationship between network centrality and enterprise technological innovation is verified, and H1 is again supported. However, the regression coefficient is lower, and the coefficient of academic capital is significantly positive ($\beta = 0.208$, $p < 0.01$). Column (6) After adding academic capital, the relationship between structural hole index and enterprise innovation performance becomes insignificant, and the coefficient of academic capital is significantly positive ($\beta = 0.221$, $p < 0.01$). With the expansion of interlocking directorate networks, more resources and information are brought to enterprises. The board of directors with rich academic capital can better transform the external advantages of directorate networks into the internal innovation advantages of enterprises and improve the innovation achievements of enterprises. It shows that academic capital of board of directors plays an intermediary role between interlocking directorate network and enterprise technology innovation. H6a and H6b are supported. After adding R&D investment in column (7), the regression coefficient between the first item of network centrality and enterprise technological innovation is significantly positive ($\beta = 0.007$, $p < 0.05$), the second item of network centrality and enterprise technological innovation is no longer significantly indigenous, and the regression coefficient of R&D investment is significantly positive ($\beta = 0.447$, $p < 0.05$). This shows that in the process of increasing the network centrality representing the quantitative characteristics of interlocking directorate networks, if enterprises are always willing to increase financial support for R&D activities, then the increase in R&D investment can alleviate the negative effect brought by the growth of such network quantitative characteristics, and give full play to the promotion effect of interlocking directorate networks on innovation activities. R&D investment plays a partial mediating role in the relationship between the two. Column (8) After adding R&D investment, the relationship between structural hole index and enterprise innovation performance becomes insignificant, and the coefficient of R&D investment is significantly positive ($\beta = 0.448$, $p < 0.01$). Thus, H8a and H8b are supported.

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Table 4. Regression results of moderating and mediating effects

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Variable	Rinvent	Rinvent	Rinvent	Rinvent	Rinvent	Rinvent	Rinvent	Rinvent
Degree	0.003***		0.003***		0.003**		0.002*	
	(2.71)		(2.92)		(2.23)		(1.92)	
$Degree^2$	-0.000**		-0.000*		-0.000*		-0.000	
	(-2.05)		(-1.71)		(-1.90)		(-1.61)	
Hole		0.365*		0.406*		0.326		0.246
		(1.69)		(1.90)		(1.50)		(1.29)
RZ	0.304***	0.318***						
	(3.41)	(4.12)						
RZ×Degree	-0.002							
	(-0.50)							
RZ×$Degree^2$	0.000							
	(0.57)							
RZ×Hole		-1.441**						
		(-2.19)						
RY			0.100***	0.114***				
			(3.39)	(3.69)				
RZ×Degree			0.007***					
			(4.66)					
RY×$Degree^2$			0.000					
			(0.23)					
RY×Hole				1.133***				
				(5.02)				
Academy					0.208***	0.221***		
					(3.79)	(4.08)		
R							0.447***	0.448***
							(21.81)	(21.83)
Controls	YES	YES	YES	YES	YES	YES	YES	YES
Constant	-0.164	-0.196	-0.152	-0.167	-0.141	-0.168	0.051	0.031
	(-0.76)	(-0.92)	(-0.70)	(-0.78)	(-0.64)	(-0.77)	(0.32)	(0.19)
Year/Industry	YES	YES	YES	YES	YES	YES	YES	YES
Observations	5610	5610	5,610	5,610	5610	5610	5610	5610
R-squared	0.293	0.293	0.295	0.294	0.293	0.292	0.397	0.396

Source: Compiled from this article

4.3. Robustness Test

The hypothesis verification is shown in table 5.

To further illustrate the reliability of this conclusion. due to the time lag of innovation results, this paper will be tested by the explanatory variable lag. The results are shown in Table 6, which is consistent with the previous results, indicating that the conclusions of this paper are robust.

Due to the similar operating environment and competitive market, the innovation strategy of companies in the same region is more likely to be consistent. In reality, companies in the same industry and same region are more likely to form interlocking directorate networks. This makes the interlocking directorate network overlap with enterprises in the same group of regional industries to a certain extent. At this time, enterprises' innovation activities will imitate and learn from other enterprises in the same industry of the same region, and enterprises may not be affected by the interlocking directorate network, that is, there is a possibility that the performance of enterprises' innovation performance is only affected by a single 'effect of the same industry of the same region'. This paper divides 935 sample enterprises into six categories finance, public utilities, real estate, industry, integration and commerce. According to China' s provinces, the mean variable (Same) of the innovation performance of other enterprises in the same industry and the same province is added to the model for control. The regression results

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are shown in Table 7. After controlling the innovation performance level of other enterprises in the same industry and same province, all the assumptions above are still robust. At the same time, the average innovation performance of other enterprises is significantly positively correlated at least at the level of 1 %, which also indirectly proves that the innovation performance of the enterprise is affected by the innovation performance level of other enterprises in the same industry and the same province.

Table 5. Validation of assumptions in this article

Hypothesis	Verified Results
H1	**YES**
H2	**YES**
H3a	**NO**
H3b	**YES**
H4a	**NO**
H4b	**YES**
H5a	**YES**
H5b	**YES**
H6a	**YES**
H6b	**YES**
H7a	**YES**
H7b	**YES**
H8a	**YES**
H8b	**YES**

Source: Compiled from this article

Table 6. Regression results after one-period lag

	(1)	(2)	(3)	(4)
Variable	$Rinvent_{t+1}$	$Rinvent_{t+1}$	$Rinvent_{t+1}$	$Rinvent_{t+1}$
Degree	0.003***			
	(2.67)			
$Degree^2$	-0.000*			
	(-1.91)			
Hole		0.413*	0.383	0.379
		(1.71)	(1.57)	(1.57)
RZ			0.325***	
			(3.83)	
RZ×Hole			-1.538**	
			(-2.07)	
RY				0.104***
				(3.68)
RY×Hole				1.129***
				(5.35)
Controls	YES	YES	YES	YES
Constant	0.192	0.160	0.131	0.160
	(1.19)	(1.02)	(0.85)	(1.01)
Year/Industry	YES	YES	YES	YES
Observations	4675	4675	4675	4675
R-squared	0.278	0.277	0.280	0.281

Source: Compiled from this article

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Table 7. Regression results after controlling other enterprises in the same province and industry

	(1)	(2)	(3)	(4)
Variable	**Rinvent**	**Rinvent**	**Rinvent**	**Rinvent**
Degree	**0.003*** **			
	(2.74)			
Degree²	**-0.000****			
	(-2.14)			
Hole		**0.415***	**0.356***	**0.392***
		(1.93)	**(1.65)**	**(1.83)**
RZ			**0.305*** **	
			(3.98)	
RZ×Hole			**-1.346****	
			(-2.05)	
RY				**0.114*** **
				(3.68)
RY×Hole				**1.140*** **
				(5.10)
Same	**0.085*** **	**0.088*** **	**0.081*** **	**0.089*** **
	(3.55)	**(3.67)**	**(3.39)**	**(3.71)**
Controls	**YES**	**YES**	**YES**	**YES**
Constant	**-0.118**	**-0.148**	**-0.178**	**-0.149**
	(-0.55)	**(-0.69)**	**(-0.84)**	**(-0.69)**
Year/Industry	**YES**	**YES**	**YES**	**YES**
Observations	**5610**	**5610**	**5610**	**5610**
R-squared	**0.293**	**0.292**	**0.294**	**0.296**

Source: Compiled from this article

This paper continues to conduct bootstrap and sobel tests on the mediating effect. The results are shown in table 8. Sobel test results are obvious, academic capital and R & D investment intermediary effect test pass. 95 % confidence interval in Bootstrap test does not include 0. In conclusion, the mediating effect of academic capital and R&D investment between interlocking directorate network and enterprise technology innovation is established.

Table 8. Test results of mediating effect

Mediator variable	Independent variable	Sobel Test	Bootstrap Test (95% confidence interval)					
			normal confidence interval		bias-corrected confidence interval		percentile confidence interval	
			Lower	Upper	Lower	Upper	Lower	Upper
Academy	Degree	3.718***	0.0022	0.0072	0.0023	0.0073	0.0023	0.0071
	Hole	3.697***	0.0460	0.1540	0.0505	0.1569	0.0471	0.1554
R	Degree	2.732***	0.0002	0.0020	0.0003	0.0020	0.0002	0.0020
	Hole	2.245**	0.0188	0.3416	0.0328	0.3487	0.0288	0.3425

Source: Compiled from this article

4.4. Further Analysis

Chinese enterprises can be divided into state-owned enterprises and non-state-owned enterprises according to the nature of property rights. There are differences between state-owned and non-state-owned enterprises in obtaining resources, information and the ability to bear innovation risks. So this paper further classifies the sample enterprises according to the nature of property rights, and the regression results are shown in table 9. It can be seen that

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the regression coefficient of network centrality of state-owned enterprises is not obvious, and the coefficient of structural hole coefficient is positively correlated. The regression coefficient of the network centrality of non-state-owned enterprises is obvious, but the structural hole index is no longer obvious. The above results show that state-owned enterprises have a large number of resources, and they are more likely to obtain government support and have strong ability to resist risks. Therefore, the resource effect of interlocking directorate network centrality is not obvious, and the information quality effect of structural hole index is more important. State-owned enterprises are more focused on obtaining high quality resources and information with heterogeneity through interlocking directorate networks. Instead of state-owned enterprises, when conducting innovation activities, they are more focused on the massive accumulation and expansion of resources and information through interlocking directorate networks.

Table 9. Regression results by property right classification

	state-owned enterprise	state-owned enterprise	non-state-owned enterprises	non-state-owned enterprises
Variable	Rinvent $_{t+1}$	Rinvent $_{t+1}$	Rinvent $_{t+1}$	Rinvent $_{t+1}$
Degree	0.004		0.012**	
	(0.52)		(2.54)	
Degree^2	-0.000		-0.000**	
	(-0.33)		(-2.05)	
Hole		1.237***		-0.272
		(2.66)		(-0.96)
Academy				
R				
Controls	YES	YES	YES	YES
Year/Industry	YES	YES	YES	YES
R-squared	0.268	0.271	0.255	0.254
Observations	2286	2286	3242	3242

Source: Compiled from this article

5. Conclusion and Implications

5.1. Research Conclusion

The conclusions of this paper are as follows: (1) The network centrality of interlocking directorates will promote the innovation performance of enterprises, but beyond a certain limit, this promotion effect will gradually weaken, and blind homogeneous connection even becomes the burden of enterprises. (2) The structural hole index is positively correlated with enterprise innovation performance. (3) Financing constraints negatively regulate the relationship between structural hole index and enterprise technological innovation. (4) Organizational slack positively moderates the relationship between structural hole index and enterprise technological innovation. (5) Board academic capital and R&D investment play an intermediary role in the relationship between interlocking directorate network and enterprise technological innovation. (6) The innovation performance of other enterprises in the same region and industry has incentive effect. (7) There are differences between state-owned enterprises and non-state-owned enterprises in the role of interlocking directorate networks in innovation activities. State-owned enterprises are more inclined to occupy the position of structural holes to explore scarce heterogeneous resources and information. Non-state enterprises are more focused on accumulating resources and information in the network.

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5.2. Management Suggestions

This study puts forward the following management suggestions: Based on the resource dependence theory, it is necessary for enterprises to establish a certain number of interlocking directorate connections with external enterprises to seek sufficient resources and information for enterprise innovation activities. In this process, enterprises should avoid excessive pursuit of establishing extensive homogeneous connections. This will weaken the decision-making and supervision function of directors, and even provide a ' hotbed ' for directors ' self-interest behavior. Therefore, the shareholders' meeting and the supervisory board of enterprises should supervise and control the interlocking directors of enterprises. Enterprises should pay attention to the role of interlocking directors in innovation activities. On the one hand, they should use the potential resources in the network to alleviate the asymmetric advantages of information, reduce the financing constraints of enterprises, and let the management rest assured to put more capital into innovation projects. On the other hand, heterogeneous resources and information embedded in the network are mutually promoted with redundant resources within enterprises to improve innovation performance. The board members with heterogeneous professional experience can bring rich external resources and knowledge to the enterprise, and the enterprise can carry out targeted director connection, that is, the enterprise can identify directors with such attributes in the market, such as hiring directors with university professional experience, and thus embedded into the network of directors that is more conducive to enterprise innovation performance. The innovation performance level of other enterprises in the same region and industry has a certain incentive effect on the enterprise, and should actively exchange and cooperate. Finally, enterprises should pay attention to the role of the board of directors as a bridge connecting internal and external enterprises.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the pu-blication of this paper.

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