Ego-network embeddedness, stability of supply chain network and innovation performance

Reception of originals: 03/18/2024
Release for publication: 01/22/2025

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Abstract

The purpose of this paper is to explores the impact of supply chain network membership mobility on the relationship between network embeddedness and innovation performance from a dynamic perspective by introducing supply chain network stability. Utilizing annual report data from 2399 China-listed manufacturing firms (2019-2021), this study constructs a supply chain ego-network. Empirical tests are conducted to examine dynamic network membership changes, and spatial autocorrelation analysis is used for pre-testing. The study reveals a nonlinear relationship between supply chain network embeddedness and innovation performance. Network stability significantly moderates this relationship, and network embeddedness influences innovation performance through a transmission mechanism of absorptive capacity. This study constructs supply chain network distance weight matrix to assess the spatial autocorrelation of knowledge spillovers and provides a pre-testing. It provides a mechanistic perspective on the dual impact of supply chain network embeddedness and network stability on innovation performance, considering the changes in the composition of members in the dynamic supply chain network. The study implies that firms can optimize their network embeddedness to boost innovation, tailored to their industry characteristics. Additionally, by determining their supply chain stability, firms can enhance their innovation performance.

Keywords: Supply chain network. Structural holes. Network centrality. Innovation performance. Supply chain stability

1. Introduction

To achieve high-quality economic development in China, integrating the supply chain with the innovation chain and enhancing the value chain is crucial. Traditional internal R&D-based innovation models fall short in today's competitive landscape. Firms increasingly seek external knowledge and resources across organizational boundaries. The relationship between firms and upstream suppliers extends beyond product collaboration to overall value chain synergy. Vertical supply chain cooperation fosters information, knowledge, and resource spillover (Arora & Gambardella, 2010).

As China's economy advances toward high quality, integrating the supply chain with the innovation chain and enhancing the value chain is crucial. Existing research has explored determinants of firm innovation, including external environment, ownership structure, and network embeddedness. However, prior studies primarily focus on static network indicators or relationship stability (Cao Wei et al., 2019). Overlooking dynamic changes in supply chain networks, it is proposed that both network embeddedness and stability impact innovation performance.

This study extends the configurational lens by exploring how supply chain network changes impact firm innovation performance, considering contingent effects of network stability. Stability, defined as the consistency of a firm's network configuration over time (Kumar & Zaheer, 2019), plays a moderating role in the relationship between supply chain embeddedness and innovation performance.

This study offers three key contributions to the field of network dynamics. First, it introduces a dynamic perspective on member changes within networks, addressing a gap in current research where network embeddedness indicators fail to assess these changes (Li Na et al., 2015; Li Guihua et al., 2020; Jian Zhaoquan et al., 2013; Shi Jinyan et al., 2019). Second, it provides a mechanistic view on the dual impact of supply chain network embeddedness and stability on innovation performance, considering member changes in dynamic supply chain networks. Lastly, by acknowledging member changes as a crucial aspect of network evolution, it facilitates exploration of dynamic supply chain network configurations and lays the groundwork for future research on network dynamics at the corporate behavior level.

2. Literature review and hypotheses

In the cooperation process between firms and suppliers, the relationship mode between members of the supply chain network is more significant than the transaction mode. In the interaction of relationships mode, network members engage in multi-level activities and form long-term cumulative interest relationships (Holm et al., 1999). The most prevalent method for suppliers and companies to collaborate is the sharing of information and knowledge resources. In order to make technical breakthroughs, firms hunt for complementary expertise through corporate ties among the supply chain networks. (Chu et al.,2019).

The embeddedness of firms in the supply chain network indicates their influence and the frequency, depth, and breadth of contact and interaction, which determines their ability to obtain complementary resources and integrate and coordinate the entire value chain. According to Granovetter (2010), network embeddedness encompasses structural embeddedness and relational embeddedness, both of which should be thoroughly considered. The primary focus of structural embeddedness is the size, density, and position of networks. The structural hole is an important indicator of network location and density. In accordance with the existing literature on the measurement indicators of network structure embeddedness, structural holes are utilized to measure network structure embeddedness (Wang Yurong et al., 2018).

Individuals with structural holes, according to social network theory, occupy the "bridge" position in the network, which can access non-redundant information and foster innovation (Burt, 2010; Sun Xiaoming et al., 2011). Relational embeddedness focuses primarily on the strength, continuity, and direction of network ties, such as interaction frequency, strong connection, cooperative content, and other measures of relationship strength (Wang Yurong et al., 2018). The centrality reflects the degree and strength of individual's linkage to other nodes. Referring to the existing research, this study uses centrality to measure network embeddedness (Shi Jinyan et al., 2019). This paper examines the impact of supply chain network embeddedness on innovation performance and the moderating effect of network stability on network embeddedness under the dynamic evolution perspective.

2.1. Network centrality and firm innovation performance

"Centrality" is commonly used to quantify the strength of individual's link to others in the network. It is a measurement of the embeddedness of network relationship, reflecting the degree of power it has or its position in the network, to estimate the effect of individuals (Liu Jun, 2009). The stronger the firm's centrality in the network, the more influence it has over its collaborators. The more collaborators it has, and the stronger their relationships, the greater its success. It will acquire or distribute a broader range of information, knowledge, and resources (Reagans and McEvily, 2003). The findings of previous studies have demonstrated that the extent of embeddedness of various types of networks, such as executive networks, director networks, supply chain networks, and so on, can have an effect on the firm's performance (Kim, 2017; Bell, 2005; Mr. Yang Junqin, 2015; Ho Chi Minh (film), 2016; Hey, 2017; Chuluun, 2014; Engelberg et al., 2012; Nee et al., 2017). The strength of supply chain linkages has a nonlinear effect on exploratory and applied innovation, according to Yang Weining et al. (2018). However, the above studies on the impact of firms' network embeddedness on firms' innovation performance have used Likert scales to obtain data. There is no literature on the use of linked data to construct indicators of network attributes. Also, the inconsistencies of findings suggest that the relationship between firms' degree of network embeddedness and its innovation performance may be non-linear.

As one of the important social networks of firms, firms with a dominant supply chain network position or strong relationship links are expected to gain or share a greater range of information, knowledge and resource advantages. The transfer of knowledge between suppliers, customers and firms and the knowledge spillover effect will promote technological innovation and enhance R&D efficiency (Cui et al., 2018). According to the resource dependence theory, on the one hand, firms with a center position in the supply chain network have more options, control advantages and negotiating power, which is the "power" effect among the supply chain networks (Greve et al., 2010). Firms have more opportunity to capture technological knowledge, information and resources from different markets (Burt, 1995). The rearrangement of varied knowledge and resources will increase the technical innovation of firms. On the other hand, the sharing of information, knowledge and resources is bidirectional. While acquiring the information, knowledge and resources provided by the partners from supply chain network, the focus firm must also give corresponding returns and feedback to the partners in the supply chain network, which is the "reciprocity" effect among the supply chain networks (Aggarwal, 2020). When the multiple partners need to access and seek the knowledge, information, and resources from the focal firm, this will result in congested resource requests and have an impact on the R&D activities of the focal firm, hence reducing its innovation performance.

When the centrality of supply chain network is low, the focal firm stresses the "reciprocity" effect more. Firm is more likely to share, repay, and feedback information and knowledge to partners in the supply chain network in order to gain a greater degree of reputation, trust, and acceptability, and promote itself to a higher level of network centrality in the future (Aggarwal, 2020). Information and knowledge resources that firms can utilize for innovation are regularly demanded by other firms, causing resource access congestion. This reduces the efficiency of integrating and transforming internal and external resources, lowering innovation performance.

Focal firms place more emphasis on the "power" effect when they reach a certain " turning point" of supply chain network centrality. Centrality gives firms the power of selection, control advantages, bargaining power, and asymmetric access to partners' information, knowledge, and resources (Cui et al.,2018). By assimilating and integrating rich, non-redundant data, firms can boost their ability to innovate. Hence, this study proposes:

H1: In a supply chain network, the relationship between the network centrality of the focal firm and its innovation performance is U-shaped.

2.2. Structural holes and innovation performance

Typically, structural holes are used to measure the structural embeddedness of a network. The structural hole theory proposed by Burt (1992) refers to that if an actor is directly connected with the nodes that are not connected to each other, the actor is in the "bridge" position. The more interconnected nodes the actor has, the richer the structural holes it possesses. actors occupying structural holes gain access to non-redundant information because they establish bridging relationships between different groups (Burt,2004).

Within a group, innovative ideas and strategic models tend to be homogeneous, while technical ideas, innovative ideas, and strategic models from different groups have obvious systemic uniqueness. When firms that occupy the structural holes grasp various ideas and concepts, they can better coordinate and incorporate innovative ideas and strategy models. Through communication with other organizations, the firms get inspiration, produce "new ideas", and subsequently promote innovation performance.

When firms have a low degree of supply chain network structure hole, there is a state of " full tripartite structure", and the network can be considered closed. On the one hand, for innovation, the information in a closed network tends to be homogeneous, and redundant knowledge and information lessen the probability of breakthrough innovation. On the other hand, the behavior of a member in a closed network is consistent with that of the entire network. The close interaction among individuals makes the creativity of a single firm contingent on the demands of the entire closed network alliance, resulting in a sluggish pace of innovation. Closed networks are more likely to form technologically stable industries (Tatarynowicz et al.,2016), which reduces the innovation performance of firms.

The focal firm that occupies structural holes over a threshold, is in a nearly open network. In an open network, the partners of the focal firm are not connected to each other. The focal actor serves as "bridges" or "local bridges" connecting distinct groups, so it can not only gain information, knowledge, and resources information, knowledge, and resources from various groups, but also regulate the flow of these resources. According to research on entrepreneurial opportunities, focal firm with rich structural holes can access non-redundant information from various network clusters (Burt, 2000). This enhances the potential of new knowledge reorganization and identification of new opportunities of the focal firm, promotes the dynamic interaction among firms' mobilization of available resources and new opportunities, and makes it easier to achieve technological breakthroughs. According to prior studies, open networks are preferable for technologically dynamic industries (Tatarynowicz et al.,2016). Thus, following hypothesis is posited:

Hypothesis 2: In the supply chain network, there is a U-shaped relationship between the degree of structural holes occupied by firms and their innovation performance.

2.3. Moderating effects of supply chain stability

The current studies on the impact of supply chain relationships on firms' performance are primarily explained from the perspective of "co-opetition theory", which posits that competition and cooperation exist simultaneously among related firms. Competition and cooperation, both of which influence and interact with each other (Bouncken et al.,2015). The discrepancy between value creation and value distribution will also lead to conflicts of interest in the network, such as bargaining and opportunistic behavior between firms and their suppliers or customers. It ultimately results in the shift from cooperation to competition, followed by the replacement of suppliers or customers (Asgari et al.,2018).

The mobility of supply chain network members is a significant issue in the dynamic evolution of organizational networks in actual business operations. Scholars have confirmed that the mobility of supply chain network members will inhibit the firms' innovation performance (Cao Wei et al., 2019). From the perspectives of co-opetition theory and resource dependence theory, this study examines the effect of supply chain network stability on the relationship between supply chain network embeddedness and innovation performance.

First of all, when firms gradually approach the centrality of supply chain network in the initial stage, stable supply chain networks can strengthen supply chain relationship embeddedness and innovation performance. First, firms utilize the centrality of supply chain network to get external diversity information, novel knowledge and new ideas to promote their own innovation. However, at the initial stage when the firm is close to the centrality of supply chain network, the firm does not have strong options, control advantages and bargaining power. If the firm has a stable supply chain at this time, it will enhance the relationship strength, trust and shared belief between the focal firm and its supply chain companies. These could promote the efficiency of knowledge transfer (Hansen,1999; Reagans and McEvily, 2003). Firms need a certain amount of time to absorb and transform external information and knowledge. A stable cooperative relationship can enable firms to obtain external reliable and sustainable resources. Therefore, the stable supply chain relationship strengthens the positive effect between network centrality and innovation performance. Second, when firms occupy a low degree of structural holes, the supply chain network in this status can be regarded as a closed network. Stable supply chains and subsequent repeated interactions among firms reinforce the homogeneity of information and knowledge bases among firms, as well as consistency of firms’ innovation direction, which makes firms’ innovation form path dependence and inert behavior, reducing the flexibility of innovation cooperation, thus exacerbating the negative relationship between the degree of structural hole and innovation performance.

Secondly, as the degree of firms' embeddedness in supply chain networks advances, the influence of supply chain network stability on the relationship between firms' network embeddedness and innovation performance will change. First, as the centrality of the enterprise network exceeds the " turning point", the stability of network members reduces the diversity of knowledge and the level of non-redundant information required for innovation, giving focal firms in the higher centrality of the supply chain network less access to complementary resources and slowing the transfer and absorption of knowledge. Stable partners in the supply chain will lead to stronger cohesion between focal companies with superior network structure embeddedness and network members, forming path dependency and cooperation inertia, which causes focal companies to maintain the past innovation direction, miss the opportunity for breakthrough innovation, and inhibit innovation. Second, as the focal firm has the structural hole after reaching the threshold, the supply chain network approximates to an open network. Stable supply chains reduce risky opportunity transfer across groups and markets for focal firms, mitigate risk-taking, and maintain a reasonable allocation of available resources between risk-taking and operational management capabilities, reinforcing the positive relationship between supply chain ownership structural hole and innovation performance. At the same time, a stable supply chain network inhibits opportunistic behaviors such as low trust among partners, weak willingness to share knowledge, and knowledge leakage in open networks (Raza-Ullah et al.,2014).

Based on the above analysis, this study makes proposals:

Hypothesis 3a: Stability in supply chain network weakens the U-shaped relationship between the level of network centrality and the firms’ innovation performance.

Hypothesis 3b: Stability in supply chain network reinforces the U-shaped relationship between the extent to which firms occupy structural holes and their innovation performance.

Based on the analysis and collation of the above hypotheses, Figure 1 illustrates the theoretical framework of this paper.

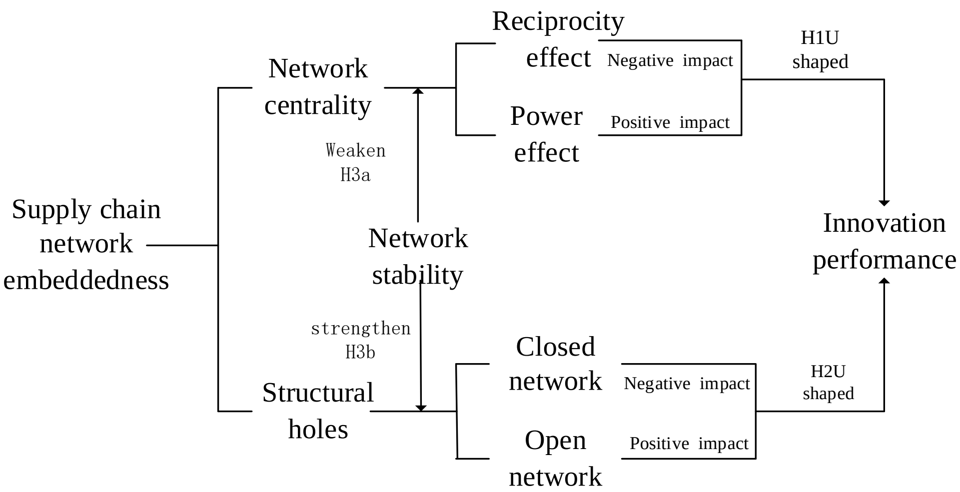

Figure 1: Theoretical Framework

3. Methods

3.1. Research setting, data and samples

The China Securities Regulatory Commission issued the "Guidelines on Content and Format of Information Disclosure by Companies Issuing Public Securities No. 2 - Content and Format of Annual Reports (Revised 2016)" on December 9, 2016, encouraging listed companies to disclose the names of the top 5 major suppliers, the top 5 customers, and the related transaction amounts. This study selects manufacturing companies in China's A-share market from 2019-2021 as the research sample, and supplements relevant data by manually collecting information on the top 5 suppliers and customers disclosed in the annual reports of each listed company based on the supply chain research database of the CSMAR. In the gathered sample, companies whose primary suppliers or customers are foreign nations are omitted, and the names of subsidiaries who are primary suppliers or customers are replaced with the names of parent companies. Excel is used to count the list of relationships between the names of listed focal companies - major suppliers and customer names for 3 years. Createpajek software was utilized to convert the list of relationships for the three years into a social network matrix, which was then input into Pajek software to determine the network centrality and structural hole indicators for each company in the supply chain network. In this paper, the information of the top 5 suppliers and customers voluntarily disclosed by Chinese A-share market manufacturing companies from 2019 to 2021 is collected, and the ego-network of supply chain in corresponding years is constructed. A total of 2399 valid observation samples are obtained. In this study, enterprise basic information, financial and patent data come from WIND and CSMAR.

3.2. Model estimation and variables

To test the hypothesis of the relationship between the focal firm's supply chain network embeddedness and its innovation performance, the following regression model is constructed.

$$InPat_{i,t} = \beta_0 + \beta_1 X_{i,t} + \beta_2 (X_{i,t})^2 + \beta_3\ Stability + \beta_4\ Stability * (X_{i,t})^2 + \Sigma \beta_j Control_{i,t} + \varepsilon_{i,t} \quad (1)$$

3.2.1. Dependent variable

Most extant studies of innovation performance measure innovation performance using the number of new products, the number of new processes, and Likert scale (Bell, 2005; Qian, Xihong et al., 2010). The quantity of patent applications filed in a year has strong objectivity and is difficult to manipulate as an input dimension assessment method. Referring to the method of Cornaggia et al. (2015), this study adopts the natural logarithm of the number of a firm's current year patent applications filed in a year plus one to measure its innovation output (InPat). In addition, the data of patent grants with a lag of 1 year was chosen to replace the number of patent applications filed in the current year for robustness testing.

3.2.2 Independent Variables

In this paper, network embeddedness properties are measured using network centrality and structural hole.

Network Centrality

For network centrality, Freeman (1978) pointed out that specific centrality metrics should be chosen according to the actual situation. When the emphasis is on information or connection control, betweenness centrality might be used. To consider the reliability and impartiality of information transmission, closeness centrality can be used. The degree centrality can be used to quantify interactions in a study. This study focuses on the influence of information, knowledge, and resource transfer and exchange through the supply chain ego-network on the innovation performance of the focal firm. Therefore, the choice of betweenness centrality is more appropriate for this study's objective.

Structural hole

Burt (1995) presented four types of structural hole measurements, including effective network size, efficiency, constraint, and stratification. Most prevalent is the network constraint. When the maximum value of constraint is 1, it indicates that the network is entirely closed and all of its nodes are interconnected without any structural holes. The smaller the constraint value, the more open the network and the greater the number of structural holes. In general, scholars consider the difference between 1 and the constraint value as a measure of the degree to which the ego-network possesses a structural hole, with greater values indicating a more robust structural hole. Referring to the existing literature (Jinyan Shi et al.,2019), the natural logarithm of the difference between 1 and the constraint value is employed as a measure of the density of structural holes occupied by the focal firm.

3.2.3. Moderating variables

Network Stability

Supply chain network stability is embedded in the configuration of supply chain network structure, while the study of social network structural properties often ignores the dynamic phenomenon of network member changes. This study refers to Kumar and Zaheer (2019) et al. and Sytch and Tatarynowicz (2014) et al. for measures of network stability and member mobility. Firstly, the rate of change of the focal firm's supply chain network is calculated by taking the sum of the number of new ties added and the number of old ties lost in the focal firm's supply chain network between years t1 and t2 as the numerator and the total number of unique ties which focal firms owned in the supply chain network between years t1 and t2 as the denominator. The formula is:

1- (Ties added + Ties lost)/ Firm’s total number of unique ties during period t_1t_2

As shown in Figure 2, the supply chain network centrality and structural hole of firm F in 2019 and 2020 are the same, but the members of supply chain network have changed from A, B, C, D, and E to A, B, G, H, and I. Its supply chain network stability has changed. Supply chain network stability of firm F in 2019-2020 = 1 - (6/10) = 0.4.

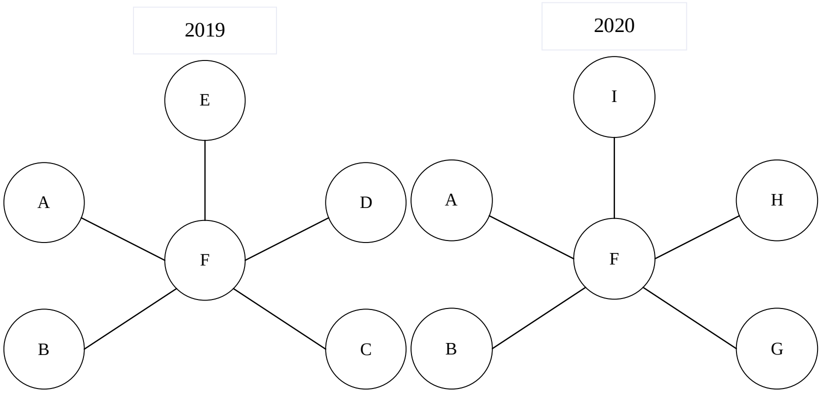

Figure 2: Supply chain network member change

3.2.4. Control Variables

Firm size

Due to scale effects, larger firms may have higher innovation performance (Kumar and Zaheer, 2019). Hence, the natural logarithm of the total assets of the firm is used to control for the impact of firm size.

Firm listing age

Older firms have a stronger knowledge base that can be utilised to innovations (Gittelman and Kogut, 2003). Therefore, the listing age of the firm is considered in determining the innovation performance of a firm.

Asset-Liability Ratio (Leverage Ratio)

Asset-liability ratio is calculated as the ratio of total liabilities to total assets. Jiang, Z et al., 2022 find that corporations with a high asset-liability ratio improve their innovation performance more obviously.

Return on Assets (ROA)

An alliance partner's desirability is determined by its return on assets (Beckman et al., 2004). Therefore, ROA is controlled for in this study. ROA is measured as ratio of net profit to total assets.

Fixed Assets Ratio

Fixed assets ratio is calculated as ratio of fixed assets to total assets. The greater fixed assets ratio, the less financial resources can be used for innovation (Moretti and Biancardi, 2020). Hence, the fixed assets ratio is controlled in this study.

The symbols and measurements for each variable are shown in Table 1.

Table 1: Variables, symbols and measurements

Variable types	Variables	Symbols	Measurements
Dependent variable	Innovation performance	InPat	In (the counts of firm's patent application +1)
Independent variables	Network Centrality	InNC	The betweenness centrality is calculated by Pajek, and its natural logarithm is taken in this paper
	Structural hole	InSH	The constraint is calculated by Pajek , and the InSH is calculated as In(1-constraint)
	Network Stability	Stability	1- (Ties added + Ties lost)/ Firm's total number of unique ties during period t
Control variables	Firm size	Size	In (total assets)
	Firm listing age	Age	In (firm listing age +1)
	Asset-liability ratio	LEV	total liabilities / total assets
	Return on Assets	ROA	net profit to/ total assets
	Fixed Assets Ratio	FAR	fixed assets/ total assets

5. Results

5.1. Descriptive statistics

This study utilizes firms listed in Shanghai and Shenzhen A-shares that disclose their top five suppliers and customers as the initial sample, and constructs a supply chain network between the company's top five suppliers/customers and the focal firm. The study constructs a supply chain network for 2019–2021 with the following network sizes for each year: 2019, 690 firms; 2020, a total of 645 firms; and 2021, a total of 1,064 firms.

Table 2 displays descriptive statistics for every variable. The mean of firms' innovation performance (InPat) is 3.204925, with the minimum and maximum being 0.693147 and 7.011214, respectively, with a standard deviation of 1.394415, indicating a substantial difference in the number of annual patent applications filed among the firms comprising this study's supply chain network. In accordance with the descriptive statistics of the intermediate centrality measure, the mean value of InNC is -6.72854, the minimum and maximum values are -15.1389 and -3.92265, respectively, and the standard deviation is 2.466213, indicating a wide range of network centrality levels among firms. The mean value of the structural hole measurement index InSH is -0.06336, the standard deviation is 0.042401, the minimum value and maximum value are -0.47 and -0.01635, respectively, indicating that there are obvious differences in the richness of structural holes owned by different firms. The mean value of supply chain network stability index is 0.345227, the standard deviation is 0.207896, and the minimum value and maximum value are 0 and 1 respectively, indicating that supply chain member mobility varies significantly among companies. The above descriptive statistics demonstrate that the sample firms' innovation performance, network embeddedness traits, and supply chain network stability are all noticeably distinct from each other and are thus appropriate for further analysis in this research.

Table 2: Descriptive statistics

Variable	Sample size	Mean	S.D.	Min	Max
InPat	2,399	3.204925	1.394415	0.693147	7.011214
InNC	2,399	-6.72854	2.466213	-15.1389	-3.92265
InSH	2,399	-0.06336	0.042401	-0.47	-0.01635
Stability	2,399	0.345227	0.207896	0	1
LEV	2,399	0.404644	0.212117	0.001295	1.426604
FAR	2,399	0.191329	0.147115	0	0.792239
ROA	2,399	0.017045	0.036981	-0.6252	0.229965
Size	2,399	22.20705	1.226845	19.40497	25.97107
Age	2,399	2.537552	0.555671	0.693147	3.218876

In this study, correlation analysis was conducted between the variables to test whether there was any multicollinearity problem in the model. According to Table 3's correlation matrix, the correlation coefficients between the variables were small (<0.55) and the variance inflation factors VIF were all less than 2, indicating that the problem of multicollinearity was less serious. To minimize research error, all variables of the interaction term were centralised in this study.

TABLE 3: Correlation coefficient matrix between variables

	InPat	InZXD	InJGD	GYLWD	LEV	FAR	ROA	Size	Age
InPat	1								
InNC	0.00700	1							
InSH	-0.0290	0.504***	1						
Stability	0.086***	0.065***	0.104***	1					
LEV	0.198***	0.048**	-0.00200	0.0200	1				
FAR	-0.098***	0.0320	-0.0330	0.097***	0.309***	1			
ROA	0.175***	0.0330	-0.00100	0.101***	-0.190***	-0.120***	1		
Size	0.512***	0.00200	-0.0280	0.182***	0.531***	0.214***	0.065***	1	
Age	0.125***	-0.034*	0.0330	0.188***	0.282***	0.168***	-0.073***	0.300***	1

5.2. Test of the hypotheses

Initially, the relationship between supply chain network embeddedness and innovation performance of the central firm is examined. On this premise, the moderating effect of supply chain network stability on the association between network embeddedness and innovation performance is examined.

Table 4 shows results of the regression analysis using the fixed-effects panel models. Betweenness centrality (InNC), square term of betweenness centrality ($InNC^2$) and control variables are added into model 1. The results show that the coefficient of primary term of intermediate centrality is significantly positive (β= 0.288, P <0.01), and the coefficient of square term of intermediate centrality is also significantly positive (β=0.0128, P <0.01). The results indicate that there is a U-shaped non-linear relationship between the centrality of enterprise supply chain network and enterprise innovation performance, which supports hypothesis 1.

Model 2 shows that the coefficient of the first term of structural hole constraint value (InSH) is significantly positive (β=8.579, P <0.01), and the coefficient of the square term of structural hole constraint value ($InSH^2$) is positive and significant (β=28.048, P <0.1), indicating that there is a U-shaped relationship between the degree of firm occupying the structural hole of supply chain network and innovation performance. The empirical results support hypothesis 2.

From model 3, the coefficient of the interaction term between supply chain network stability and the squared term of centrality is significantly positive (β=0.0381, p<0.01), indicating that supply chain network stability weakens the U-shaped relationship between centrality and innovation performance. Hypothesis 3a is supported.

From model 4, the coefficient of the interaction term between supply chain network stability and the squared term of the structural hole constraint value is significantly negative (β=-12.10, p<0.01), indicating that supply chain network stability strengthens the U-shaped relationship between the structural hole and innovation performance. Hypothesis 3b is supported.

TABLE 4: Network centrality, structural holes, supply chain stability and innovation performance

Variables	Model1	Model2	Model3	Model4
	InPat	InPat	InPat	InPat
InNC	0.288*** (6.57)		0.247*** (5.61)	
$InNC^2$	0.0128*** (5.64)		0.0108*** (4.71)	
InSH		8.579*** (3.81)		9.251*** (5.46)
$InSH^2$		28.048* (1.78)		31.87*** (3.05)
Stability			0.524*** (5.98)	-2.290*** (-7.00)
InNC*Stability			0.730*** (3.59)	
$InNC^2$* Stability			0.0381*** (3.55)	
InSH* Stability				-12.10*** (-3.66)
$InSH^2$* Stability				-99.07*** (-7.38)
InAge	0.289** (2.27)	-0.254* (-1.74)	0.0239 (0.18)	-0.627*** (-4.02)
LEV	-0.200** (-2.02)	-0.173* (-1.66)	-0.174* (-1.78)	-0.138 (-1.44)
FAR	-0.227** (-2.52)	-0.205** (-2.29)	-0.216** (-2.43)	-0.194** (-2.24)
ROA	-1.138*** (-3.79)	-1.106*** (-3.73)	-1.178*** (-3.98)	-1.042*** (-3.60)
InSize	0.0477* (1.67)	0.066** (1.97)	0.0442 (1.57)	0.0242 (0.88)
_cons	2.838*** (3.86)	2.901*** (3.59)	3.224*** (4.41)	5.508*** (7.53)
N	2399	2399	2399	2399
r^2	0.0883	0.103	0.114	0.157

N=2399. Note: two-tailed tests for all variables.
*p < 0.10
**p < 0.05
***p < 0.01

5.3. Robustness tests

To confirm the validity of the conclusions, the following robustness tests were undertaken.

5.3.1. Alternative measure

This paper uses alternative measure of the dependent variable to robustly test the findings of the study. Patent applications filed in a certain year for inventions are typically granted in China between one to three years. Hence for the dependent variable, data on the number of patents granted with a one-year lag is utilised to replace the number of patent applications filed for the current year. The regression results in Table 5 demonstrate that the regression results after calculating the alternative measures are basically consistent with the above conclusions.

Table 5: Regression results of alternate measures

Variables	Model1	Model2	Model3	Model4
	$InPat_{t+1}$	$InPat_{t+1}$	$InPat_{t+1}$	$InPat_{t+1}$
InNC	0.745*** (0.181)		1.654*** (0.231)	
$InNC^2$	0.040*** (0.009)		0.085*** (0.012)	
InSH		4.339* (2.226)		14.354*** (2.396)
$InSH^2$		28.040** (13.774)		84.040*** (14.743)
Stability			1.386*** (0.472)	1.478*** (0.395)
InNC * Stability			7.194*** (1.453)	
$InNC^2$ * Stability			0.342*** (0.074)	
InSH * Stability				18.432*** (4.846)
$InSH^2$* Stability				37.288** (16.817)
Control				
r^2	0.006	0.004	0.126	0.136
N	2399	2399	2399	2399

N=2399. Note: two-tailed tests for all variables.
*p < 0.10
**p < 0.05
***p < 0.01

5.3.2. Reverse causality check

As the level of innovation performance of an enterprise reflects its industry status to some extent, it is one of the factors that determines whether or not other firms will enter into the supply and sale relationship with it, and thus the degree to which the firm is embedded in the supply chain network. In this study, there may be a problem with reverse causality between explanatory variables and response variables. In order to control this endogeneity issue, the original model is modified using the two-stage least squares regression (2SLS). Through the second stage regression analysis, the test results support the previous conclusion. Therefore, the conclusion of this study has certain robustness.

5.4. Mechanism tests

The previous section verified that the supply chain network in which a firm is embedded has a non-linear effect on innovation performance. Based on the analysis of the theoretical assumptions in this paper, the following explanations can be given for the verified results:

Firstly, in a supply chain network, firms that are closer to the centrality will have more opportunities to capture technical knowledge, information and resources from different markets. Therefore, it is easy to develop the "free rider" phenomena, "Copinism" and simple imitation of external innovation, thereby diminishing the incentive for firms to absorb new external information. Secondly, firms with abundant structural holes are in an approximately open network, and access non-redundant information by bridging each cohesive subgroup. The collaboration and restructuring of non-redundant knowledge require firms to pay higher absorption capacity.

The mediating effect of network embeddedness and innovation performance is further examined using absorptive capacity as the mediating variable. Based on model (1) and the mediating variable of absorptive capacity, the following model was constructed:

$$Absorb_{i,t}=\gamma_0+\gamma_1 X_{i,t}+\gamma_2 Control_{i,t}+\varepsilon_{i,t} \quad (2)$$

$$InPat_{i,t}=\alpha_0+\alpha_1 X_{i,t}+\alpha_2 (X_{i,t})^2+\alpha_3 Absorb_{it}+\alpha_4 Control_{i,t}+\varepsilon_{i,t} \quad (3)$$

$Absorb_{i,t}$ is the absorptive capacity of a firm. According to Cohen and Levinthal (1990) et al., the R&D investment of firms has double-sided characteristics, i.e., the R&D investment of enterprises can not only directly promote the innovation and progress of enterprises but also increase their ability to imitate and digest foreign technologies. Therefore, the ratio of R&D investment to operating revenue is used to measure absorptive capacity (Rothaermel and Alexandre,2009). $X_{i,t}$ denotes the network embeddedness variables, including network centrality and structural holes. Model (2) tests the correlation between firm’s supply chain network embeddedness and absorptive capacity, and introduces all control variables of model (1), including firm size (InSize), listed years (Age), asset-liability ratio (LEV), return on assets (ROA), and fixed assets ratio (FAR). Model (3) tests the mediating effect of firms' absorptive capacity, with control variables consistent with models (1) and (2).

Table 6 shows the regression results of model (2) for firm network embeddedness and absorptive capacity. The coefficient of the effect of betweenness centrality (InNC) on the firm's absorptive capacity (Absorb) is -0.024 and significant at the 5% level, indicating that the closer the firm is to the centrality of the supply chain network, the lower the level of its absorptive capacity. Accordingly, the regression coefficient between the richness of structural holes (InSH) occupied by firms and the absorptive capacity of firms is 1.284, which is significant at the 10% level, indicating that the richer the degree of structural holes owned by firms, the higher the level of absorptive capacity of firms.

Table 6: Network embeddedness and absorption capacity

VARIABLES	X=InNC (1) Absorb	X=InSH (2) Absorb
X	-0.024**	1.284*
	(-2.48)	(1.66)
InAge	-0.662***	-1.129***
	(-3.23)	(-4.20)
LEV	-0.926***	-0.882***
	(-4.97)	(-4.71)
FAR	-0.007	-0.007
	(-0.04)	(-0.04)
ROA	-1.827***	-1.983***
	(-3.21)	(-3.48)
InSize	-0.117**	-0.131**
	(-1.97)	(-2.21)
Constant	8.074***	9.785***
	(6.02)	(6.84)
Observations	2,269	2,269
R-squared	0.031	0.029

Two-tailed tests for all variables.
*p < 0.10
**p < 0.05
***p < 0.01

Table 7 displays the regression analysis results of model (3). The regression coefficients of the first and second terms of betweenness centrality (InNC) and innovation performance are both significant at the 1% level, and the regression coefficients of the first and second terms of structural hole and innovation performance are both significant at the 5% level, indicating that network embeddedness has a partial mediating effect on enterprise innovation. The direct effect of supply chain network betweenness centrality (InNC) on innovation performance is 0.313 in the first term and 0.015 in the second term, which is significant at 1% level. The coefficients of the first and second terms of the direct effect of structure hole (InSH) on innovation performance are -7.366 and -49.800, respectively, which are significant at the 5% level. The influence coefficients of betweenness centrality (InNC) and structural hole (InSH) on innovation performance through absorptive capacity are 0.042 and 0.153, respectively, which are both significant at 1% level, indicating that network embeddedness has both a direct impact on firms' innovation and a mediating effect via absorptive capacity. From the perspective of mediating effect, the network centrality and structural hole occupied by the firm indirectly affect the firm's innovation performance through influencing the firm's absorptive capacity.The absorptive capacity of a firm reflects its ability to absorb and use external knowledge spillovers to its own innovations (Yao and Chang, 2017).

Table 7: Network embeddedness, absorptive capacity and innovation performance

VARIABLES	X=InNC (1) InPat	X=InSH (2) InPat
X	0.313***	-7.366**
	(7.08)	(-2.44)
X^2	0.015***	-49.800**
	(6.44)	(-2.55)
Absorb	0.042***	0.153***
	(3.61)	(20.17)
InAge	0.285**	0.254***
	(2.23)	(5.75)
LEV	-0.246**	0.231*
	(-2.40)	(1.68)
FAR	-0.235**	-1.615***
	(-2.53)	(-9.84)
ROA	-0.922***	4.507***
	(-2.95)	(7.17)
InSize	0.107***	0.630***
	(3.31)	(27.37)
Constant	1.512*	-12.011***
	(1.89)	(-25.22)
Observations	2,269	2,269
R-squared	0.085	0.426

Two-tailed tests for all variables.
*p < 0.10
**p < 0.05
***p < 0.01

Sobel test was utilised to further test the significance of the mediating effect of absorptive capacity. Results indicate that the effect of firm network centrality on firm innovation performance through absorptive capacity is 0.00416691 and is significant at the 10% level. The effect of the degree of structural hole occupation by firms on their innovation performance through absorptive capacity is -0.88885947 and is significant at the 10% level.

The above empirical results confirm that supply chain network embeddedness affects innovation performance through absorptive capacity. Moreover, the results indicate that absorptive capacity is merely one of the transmission mechanisms underlying the impact of firm supply chain network embeddedness on innovation performance. The exploration of alternative transmission mechanisms could be a future research direction to pursue.

6. Discussion and Conclusion

In the context of stable, complementary, and strong supply chains, how manufacturing enterprises utilize supply chain network embeddedness for continuous innovation warrants attention. Unlike prior studies focusing solely on static network attributes, our research dynamically examines the impact of supply chain network membership mobility on the relationship between embeddedness and innovation performance. By introducing supply chain network stability, we uncover four key findings.

- In supply chain networks, the relationship between a firm's network centrality and innovation performance follows a U-shaped trajectory. Initially, low centrality fosters reciprocal collaboration. As centrality improves, firms connect to more partners, leading to increased resource demand. However, when multiple relationships vie for the same resources, knowledge limitations emerge, hindering innovation. At a critical "turning point," firms prioritize leveraging power dynamics to access information and resources. Bargaining strength and asymmetric access play pivotal roles in enhancing innovation outcomes.
- In supply chain networks, the relationship between firms' structural hole occupancy and innovation performance follows a U-shaped pattern. When firms occupy a low level of structural holes, the network tends to be "closed," resulting in homogeneity of information and limited access to non-redundant knowledge. This hinders innovation. Conversely, when firms bridge structural holes in an "open" network, diverse information facilitates novel idea combinations, accelerates knowledge transfer, and fosters innovation.
- In supply chain networks, stability impacts innovation performance differently based on network centrality and structural holes. When firms lack the 'power' effect, stable supply chains foster trust, collaboration, and knowledge exchange, enhancing innovation. However, highly central firms face reduced advantages due to stability, resulting in cognitive lock. For firms in rich structural holes, stable networks mitigate opportunistic behavior, reinforcing the U-shaped relationship between structural holes and innovation.
- In this study, supply chain network centrality and structural holes impact firms' innovation performance. Firms near network centrality often exhibit 'free-riding'

behavior, hindering their motivation to absorb external knowledge. Conversely, firms with rich structural holes benefit from an open network, enhancing their capacity to absorb non-redundant knowledge and drive innovation.

Firms can enhance innovation by optimizing network embeddedness based on industry characteristics. Additionally, stability within supply chains contributes to improved innovation performance.

7. Limitations and Future Research

Supply chain networks in this study are based on disclosed information from annual reports of listed manufacturing companies in China. While the network's integrity is limited due to unlisted companies and undisclosed top suppliers, future research could enhance data completeness using web-crawling software. Additionally, this study introduces the concepts of 'reciprocity' and 'power' effects to explore network embeddedness. While the proposed mechanisms weren't directly tested due to data limitations, future research can examine alternative transmission channels between supply chain network embeddedness and innovation performance.

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9. Disclosure Statement

I have no conflicts of interest to disclose.