Supply chain network structure and firm’s R&D investments: Empirical evidence from Chinese manufacturing firms

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**Abstract**

**Purpose-** The purpose of this research is to investigate the R&D investment (RDI) of manufacturing firms from the perspective of supply chain network, especially the effect of firms’ supply chain network structures (network power and network cohesion) on its RDI, and further to explore the contingency conditions of this effect within the context of Chinese manufacturing supply chains.

**Design/methodology/approach-** We collect a large sample of Chinese manufacturing firms over the period 2014–2019 and construct a large-scale supply chain network, and finally obtain 2,390 firms from 20,483 observations. Ordinary least squares regression was adopted to analyse how supply chain network structures affect RDI in manufacturing firms.

**Findings**- It’s surprising that firm’s supply chain network structures have a negative effect on RDI. In addition, knowledge and technology intensity (KTI) positively moderate the relationship between network cohesion and RDI.

**Originality/value**- This study contributes to the innovation stream from the perspectives of supply chain network, and provides the empirical findings that the negative role of a firm’s supply chain network structure on its RDI for the first time. The rationale for these negative effects is straightforward according to the social capital theory that manufacturing firms with a high level of social capital that are possibly to accept established patterns of thinking and behaviour, causing them to decrease the enthusiasm of RDI.

**Keywords**: manufacturing firms; RDI; supply chain network; social capital theory; network power; network cohesion

# Introduction

R&D investment (RDI) plays an important role in the economic growth and technological progress of various industries. As a pillar industry in mainland China, the manufacturing industry directly reflects the country’s productive capability and plays an irreplaceable role in economic wealth creation ([Kusi-Sarpong et al. 2018](#_ENREF_32), [Guo et al. 2020](#_ENREF_26)). For manufacturing firms, RDI is the foundation for maintaining sustainable development capabilities in the fierce market, which positively affects the speed and quality of innovation, and further leads to higher operational performance ([Guo et al. 2020](#_ENREF_25)). It is therefore vital for manufacturing firms to ensure the efficiency of RDI, which is helpful in improving their level of innovation and sustainable development capabilities ([Ozturk 2018](#_ENREF_42), [Alam et al. 2020](#_ENREF_2)).

* Given the importance of manufacturing firms’ RDI, it is important to explore the potential factors that affect such investment. As a primary source of innovation, the basic characteristics are as follows: (1) RDI occupies long-term cash flows with high risk, (2) the specificity of assets formed by RDI is strong, and (3) it is difficult to completely possess the benefits of assets formed by RDI ([Driver and Guedes 2012](#_ENREF_18)). Based on the basic understanding of the characteristics, the internal and external factors that affect manufacturing firms’ RDI have been discussed. Some internal factors mainly include corporate governance and ownership ([Driver and Guedes 2012](#_ENREF_18)), board monitoring ([Guldiken and Darendeli 2016](#_ENREF_24)), and financial slack and constraints ([Broome et al. 2018](#_ENREF_9), [Shaikh et al. 2018](#_ENREF_49)). External factors mainly include contract enforcement ([Seitz and Watzinger 2017](#_ENREF_48)), cross-border capital ([Kwon and Park 2018](#_ENREF_33)), supplier dependence ([Kim and Zhu 2018](#_ENREF_28)), and a trust-intensive environment ([Ndubuisi 2020](#_ENREF_40)). Although the aforementioned literatures have explored the heterogeneous effect of RDI in different operational environments, an important branch of the supply chain network structure has been ignored, especially for manufacturing firms.
* The supply chain network indicates all firms that are directly or indirectly involved in the focal firm with or without their knowledge of them ([Choi and Krause 2006](#_ENREF_16)). From the perspective of the supply chain network, manufacturing firms are more closely associated with partners due to the complex manufacturing process. In particular, the globalisation of manufacturing production indicates that the formation of supply chain networks is complicated ([Seiler et al. 2020](#_ENREF_47)). Although research on supply chain networks has grown considerably in the past few years, the supply chain network constructed in previous research on innovation communities is incomplete; to some extent, the role of supply chain networks is not be extended into the scope of RDI.
* However, as an effective way to heighten a firm’s innovation and sustainable development capabilities, it is vital to consider RDI from the perspective of supply chain networks. The rationale for considering supply chain network structures is straightforward. On the one hand, previous studies have investigated firms’ RDI primarily focusing on linear or dyadic perspectives ([Kim and Zhu 2018](#_ENREF_28)), which draws our attention to the direct effect of supply chain network structure on a firm’s RDI. On the other hand, previous literatures focus more on R&D output from the perspective of network. Undoubtedly, network structures formed by supply relationships provide potential access to diverse resources ([Wen et al. 2021](#_ENREF_55)), and thus, network resources are vital in improving innovation ([Kim et al. 2020](#_ENREF_29)). However, less attention has been paid to whether network resources will be invested in R&D. Furthermore, organisations have increasingly realised that relying solely on internal resources for innovation is not sufficient to cope with dynamic markets and it is important to leverage network resources to continue R&D activities. Therefore, the above-mentioned reasons inspired us to investigate a firm’s RDI from a broad perspective of supply chain networks.
* Based on the aforementioned analysis, we suppose that a firm’s RDI may be closely related to its supply chain network structure. Thus, we address the following questions:
* *Q1:* Does a firm’s supply network structure affect its RDI?
* *Q2:* How does a firm’s supply network structure affect its RDI?
* Given the fact that manufacturing firms with different KTI have diverse innovation performance, [Duan et al. (2020)](#_ENREF_19) confirm that manufacturing firms with high KTI usually have technical advantages to respond to the dynamic market. The firm’s characteristics are therefore also an important factor that cannot be ignored when we consider a firm’s RDI involved in supply chain network environments. Thus, we further investigate the moderating effect of KTI on the relationships between supply chain network structure and RDI. According to the KTI, we divide the empirical sample into high-tech enterprises (HTEs) and non-high-tech enterprises (non-HTEs). Generally speaking, the identification of HTEs includes many aspects, such as R&D funds, R&D personnel, the new product sales revenue, and so on. The fact that a manufacturing firm can be recognised as an HTE affirms its innovation performance. Moreover, as a primary source of innovation, the overall innovation performance of HTEs is better than that of non-HTEs, which is the difference between HTEs and non-HTEs regarding the impact of supply chain network structure on RDI? We therefore formulate the following research question:
* *Q3:* How does KTI moderate the relationship between supply chain network structure and RDI?
* To answer these questions, we should first have an in-depth understanding of the concept of the supply chain network structure, which refers to the connections among firms and their positions in the network ([Borgatti and Li 2009](#_ENREF_8)). There are two fundamental structures to this study that emerge from the literature reviewd above-network power and network cohesion ([Carnovale et al. 2019](#_ENREF_11), [Wang et al. 2021](#_ENREF_53)). Network power, refers to the interdependence inherently exists and governs the behaviors among actors of network. Network cohesion is related to the ability of guiding network connections. Specifically, we utilize degree to represent network power, and betweenness centrality to represented network cohesion.
* To comprehensively explore the impact of supply chain network structure on manufacturing firms’ RDI, we next construct a large-scale supply chain network including the focal firms with their two-tier suppliers and customers (directly and indirectly). The process of constructing a supply chain network mainly comprises two steps: (1) obtaining the supply relationship of manufacturing firms and (2) constructing the network based on the obtained supply relationships. In the first step, we collect all the A-share listed firms in the manufacturing industry on the Shanghai and Shenzhen Stock Exchange over the period of 2014–2019 and collect the information of their two-tier suppliers and customers. In the second step, we use Pajek, a type of social network analysis software that can handle hundreds of millions of network nodes, to construct a network based on the supply relationships. We then calculate the firms’ network structural characteristics and visualise the supply chain network relationships. Finally, we obtain 2390 observations from 20,483 nodes in the six years of supply chain networks. Surprisingly, the firm’s supply chain network structure really has a negative effect on its RDI, and KTI positively moderates the relationship between network cohesion and RDI.
* Our study makes three primary contributions to the innovation stream of supply chain network management. First, it fills a gap in the relationship between supply chain network structure and RDI, and theoretically explains why network structure negatively affects RDI for the first time, which responds to the call for more attention to manufacturing innovation. Second, this study explores the contingency conditions of this effect. Specifically, KTI positively moderates the relationship between network cohesion and RDI, thus extends the literature by examining how supply chain network structure and the firm’s characteristics jointly form the RDI of Chinese manufacturing firms. Lastly, our study adds to the literature on supply chain network management by providing a large number of real datasets. Our empirical sample contains focal firms associated with their two-tier suppliers and customers, which are beneficial for considering a firm’s network structure comprehensively and reveal firm’s RDI, thus providing a valuable reference for the innovation development of emerging economies.
* The remainder of this paper is organised as follows. Section 2 provides the theoretical development of the research questions and hypotheses. The methodology adopted in this study is presented in section 3. Section 4 presents the empirical analysis and the results. Our research findings and implications for theory and practitioners are discussed in section 5. Finally, we conclude our study and discuss future research opportunities in section 6.

# Theoretical background and hypotheses development

## Social capital theory

Social capital, which recognized as worthy resources available through the network of relationships possessed by an individual or organisation, and cannot be formed in a short time, which is different from physical capital and human capital. Thus, it has a far-reaching impact on actors in networks ([Ceci et al. 2019](#_ENREF_14)). Generally speaking, Social capital is considered according to three dimensions: cognitive, relational, and structural. The cognitive dimension comprises the significance and understanding of mutual sharing among actors in network, the relational dimension represents the reliance, cooperation, and reciprocity among actors in network, and the last is structural dimension, which involves communication patterns of actors in network ([Villena et al. 2011](#_ENREF_51), [M.Whipple and Wiedmer 2015](#_ENREF_39)). According to the basic understanding of the three dimensions of social capital, some significant benefits or damage of social capital can be drawn from a social network perspective.

* Previous literature on innovation of manufacturing firms focuses more on the positive aspects of social capital ([Basole et al. 2018](#_ENREF_6)); however, the risks and potential negative consequences cannot be ignored. For example, the loss of objectivity due to strong attachment to network partners, opportunistic behaviours due to lack of monitoring or too much belief in network partners ([Alletto et al. 2017](#_ENREF_3)), and poor decision-making caused by obtaining redundant information ([Pillai et al. 2015](#_ENREF_44)). In particular, when we consider a firm’s R&D activities, adverse consequences should be given more attention. Specifically, cognitive social capital may cause homogeneity in firms’ thinking, which reduces the motivation for independent innovation. Relational social capital may lead to firms in the supply chain network to over-identify each other, and be satisfied with current performance rather than to pursue high-level performance, which is detrimental to innovation and change. In particular, RDI is a useful way to improve a firm’s response to change. Structural social capital may cause firms to have difficulty in making decisions, and it may lead to less valuable learning from the overloading of information and the increased expenditure of energy to sustain frequent interactions ([Villena et al. 2011](#_ENREF_51)).
* On the whole, social capital is brought about by the tight connections of firms in the supply chain network, which makes firms likely to accept established patterns of thinking and behaviour, and ignore the importance of major innovation ([Florida et al. 2002](#_ENREF_21)). While firms with better network structure have an advantage to obtain network resources that are available for RDI, at the same time, they do not easily to adopt more novel ideas to support innovation. Thus, we suspect that firms with better supply chain network structure may not be keen on RDI that is characterised as costly and risky; in contrast, they may prefer short-term profitable projects given the relatively minimal risk and ease of securing.

## Hypotheses development

### Network power and firm’s RDI

In the context of supply chain network, a firm’s network power is derived from the attractiveness of its own resources to obtain resources by contacting with other network actors ([Carnovale et al. 2019](#_ENREF_11)). Thus, we adopt degree to capture firms’ network power. Degree describes the influential scope, which refers to the extent to which a firm affects other firms’ operational decisions or strategic behaviour ([Kim et al. 2011](#_ENREF_30)). With a high degree, the firms have the capability to affect the decisions and behaviours of other supply chain partners, which is helpful for obtaining network resources for RDI.

* However, firms with better network power in extended networks results in the exclusion of potentially beneficial ideas ([Locke 1999](#_ENREF_37)), and then reduction of network resources in beneficial innovation projects. In particular, considering that RDI is characterised by costly and risky, firms may not give up their short-term interests for the sake of uncertainty in the future, since RDI does not necessarily conform to cost efficiency. Thus, even if firms with better network power have the advantage to obtain network resources, these resources may be invested in projects that make profits quickly or may not be used to avoid losses due to innovation. Therefore, we suggest the following hypotheses:
* H1a: Network power has a negative effect on the firm’s RDI.

### Network cohesion and firm’s RDI

* Although network power is crucial in explaining RDI, the network cohesion should be noticeable as well. Network cohesion refers to the navigation of these network connections. In order to represent such cohesion, we examine the firms’ betweenness centrality. Betweenness centrality also has been studied in various related contexts such as financial performance ([Lau et al. 2019](#_ENREF_34)), joint ventures ([Carnovale and Yeniyurt 2014](#_ENREF_12)) and firm innovativeness ([Andrade Rojas et al. 2018](#_ENREF_4)).
* Betweenness centrality describes relational mediation, which refers to the extent to which a firm intervenes in or controls the process of dealing with other network partners. With a high betweenness centrality, the firms have the capability to control over other firms by accessing less redundant information. Such capability makes the firm a broker to mediate dealing among network members to strengthen the network cohesion. However as the cohesion of network increases, on one hand, the firms are likely to accept established patterns of thinking and behaviour, which can cause them to decrease the enthusiasm and facilicate reductions in RDI; on the other hand, firms have to increased expenditure of energy to sustain frequent interactions, which inevitably reduce some network resources for long-term projects. Thus we expect that:

H1b: Network cohesion has a negative effect on the firm’s RDI.

### Moderating role of KTI

HTEs generally refer to the firms that continually participate in R&D activities and conduct business activities based on core independent intellectual property rights, while non-HTEs are not. To encourage firms to participate in innovation activities, governments publish HTE programmes, and many tax relief policies have been implemented for HTEs. Furthermore, Dai and Wang ([2019](#_ENREF_17)) confirm that the HTE programme promotes the innovation performance of Chinese listed firms pursuant to R&D intensity and productivity. Thus, the HTE programme can serve as an incentive for manufacturing firms to pay attention to innovation. Recognised HTEs can enjoy preferential tax policies and government financial allocation for innovation, and non-HTEs also benefit from the HTE programme. Thus, it is meaningful to investigate the differences between HTEs and non-HTEs in terms of innovation performance.

* As a primary source of innovation, RDI plays a vital but different role in HTEs and non-HTEs. The differences between HTEs and non-HTEs regarding RDI have been discussed from different aspects, the firms’ growth in [Nunes et al. (2012)](#_ENREF_41), the speed and quality of innovation in Guo *et al*. ([2020](#_ENREF_25)), and the top management quality in [Zhao et al. (2021)](#_ENREF_58). Furthermore, [Lin et al. (2020)](#_ENREF_36) find that the central position of the network is conducive for HTEs to obtain resources and valuable information, which significantly improves a firm’s innovation performance. However, [Lin et al. (2020)](#_ENREF_36) construct a network of directors and focus on innovation output, which is different from our study in that it focuses on supply chain network structure and firms’ RDI by introducing the social capital, especially its negative effects.
* According to social capital theory, we suppose that the negative effect of supply chain network structure on RDI can be enhanced in HTEs compared to non-HTEs. On the one hand, the certification conditions of HTEs are extremely strict; therefore, being identified as HTEs is a positive signal for network partners to cooperate and accelerate acquisition of social capital, as HTEs with better network structure may have other better investment opportunities and have a channel that is beneficial to knowledge accumulation. However, it may also cause them to be satisfied with their current innovation performance, instead of having more drive to increase the RDI. On the other hand, HTEs with better network structure may have an advantage in RDI efficiency than non-HTEs, which naturally reduces RDI but enjoys a great return on innovation. Therefore, whether it is due to better investment opportunities or higher investment efficiency, we suppose that the KTI positively moderate the relationship between network structures and RDI. Therefore, we hypothesise the following:
* H2a: The relationship between network power and RDI is more negative in HTEs than non-HTEs.
* H2b: The relationship between network cohesion and RDI is more negative in HTEs than non-HTEs.

The research framework of this study is presented in Figure I.

**--- Insert Figure I here ---**

# Methodology

## Supply chain network construct

Manufacturing firms are the core body of the national innovation system, including various types of firms such as HTEs and non-HTEs, which should attach importance to RDI ([Wei et al. 2020](#_ENREF_54)). To explore the potential relationship between supply chain network structure and firms’ RDI, we first collect the empirical data from A-share listed firms in the manufacturing industry on the Shanghai and Shenzhen Stock Exchanges over the period 2014–2019. We construct a supply chain network of Chinese manufacturing firms using Pajek and then measure the network structural characteristics of manufacturing firms in terms of various network centralities. The basic information of manufacturing firms (i.e., age, size, and debt ratio) is collected from the China Stock Markets and Accounting Research (CSMAR) database. In summary, the data collection and supply chain network construction process are summarised in five steps. The construction steps of the supply chain network are presented in Figure II, and the corresponding 6-year supply chain networks of manufacturing firms are illustrated in Figure III.

* Step 1: We first select the A-share listed firms in the manufacturing industry from 2014 to 2019, then collect the names of the top five suppliers and customers of listed manufacturing firms by hand, and finally delete the listed firms that do not disclose the names of the main suppliers and customers.
* Step 2: We next ensure the disclosed top five suppliers and customers, whether listed firms or not. If the suppliers or customers are listed firms, then the stock code is recorded; otherwise the process ends.
* Step 3: We continue to collect disclosed information of listed firms of the top five suppliers and customers by hand. If their suppliers or customers are listed firms, then the stock code is recorded; otherwise the process ends.
* Step 4: We establish the tables that include ‘the names of firms-the name of main suppliers (customers)’ and replace them by stock code if they are listed firms. We then feed the tables into Pajek and generate supply chain networks among manufacturing firms.
* Step 5: Finally, we calculate the network structural characteristics of each manufacturing firm, including network power and network cohesion, then merge the basic financial information and supply chain network structural characteristics based on the listed firm’s stock code.
* It is worth noting that some main suppliers or customers of listed firms are non-listed Chinese firms, and the disclosed information of such firms is different from listed firms; thus, this study first omits these non-listed firms. Second, although the branches of listed firms do not have an independent legal personality, but they are closely related to the interests of their parent firms, this research uses the parent firms of these firms to replace branches. Based on the aforementioned steps and standards, we finally obtain 2390 observations from 20,483 nodes in the supply chain network.

**--- Insert Figure II here ---**

**--- Insert Figure III here ---**

## Characterises measure

### Dependent variables

RDI: RDI is used as an agent of a firm’s investment in innovation by previous research ([Parast 2020](#_ENREF_43)), and R&D intensity represents the level of investment ([Kim and Zhu 2018](#_ENREF_28)). In line with other research, we calculate RDI by the ratio of a firm’s R&D expenditure to sales per year ([Purkayastha et al. 2018](#_ENREF_46)).

### Explanatory variables

* (1) Network power
* For the operationalization of network power, we use Degree () which is the number of incident ties of a node, and is measured using the following formula:

|  |  |  |
| --- | --- | --- |
|  |  | * (1) |

* where  is the total of nodes in the network; we take  node  has connection with , otherwise . A firm with a high  has connections with more suppliers and customers thus can be considered as an influential actor in its network.
* (2) Network cohesion
* To operationalize network cohesion of firms in supply chain network, we use betweenness centrality () which is the number of paths a node lies on the shortest paths between other nodes, and is measured using the following formula:

|  |  |  |
| --- | --- | --- |
|  |  | * (2) |

* where  refers to the number of shortest paths from node  to node , and is the number of shortest paths from node  to node  through . A firm with high  plays a pivotal role in bridging the disconnected nodes in the network.

### Control variables

To seclude the marginal effects of the independent variable, several variables are controlled in our study: firm size, firm age, asset-liability ratio, industry concentration, firm performance, and the rationality are sufficient. Firm size (SIZE) is measured as the logarithm of total assets ([Lv et al. 2020](#_ENREF_38)). The debt ratio (LEV) is measured as total debt over total assets ([Lv et al. 2020](#_ENREF_38)). We calculate firm age (AGE) by the number of years from the firm’s establishment to the focal year ([Caselli et al. 2009](#_ENREF_13)). Considering that a firm with better financial performance will have more resources to devote to innovation activities, we control performance with ROA, which is measured as the ratio of net income to total assets ([Shaikh et al. 2018](#_ENREF_49)). Industry concentration is captured by the Herfindahl-Hirschman Index (HHI) in [Bellamy et al. (2014)](#_ENREF_7).

# Empirical analysis

## Sample selection and Data description

We collect the data of A-share listed firms in the manufacturing industry over the period of 2014–2019, and the information of two-tier suppliers and customers is also collected manually. According to the relationship between suppliers and customers, we then construct supply chain networks and calculate the network structural characteristics of firms in Pajek. The corresponding financial data are collected from China Stock Market & Accounting Research Database (CSMAR).

The descriptive statistics and correlations of the major variables are reported in Table I. The mean of RDI in our sample is approximately 3.68%, which is in a moderate position ([Guldiken and Darendeli 2016](#_ENREF_24), [Kim and Zhu 2018](#_ENREF_28)). The mean of network power is 7.3950, network cohesion is 0.0006, respectively. In addition, the correlation coefficients of major variables deserve further attention. The correlation coefficients between network power and RDI are significantly negative at the 10% level, and the correlation coefficients between network cohesion and RDI are significantly negative at the 1% level, which indicates that supply chain network structures are significantly negatively affect RDI. Therefore, the results are consistent with H1a and H1b.

**--- Insert Table I here ---**

## Empirical results

To better understand the relationship between supply chain network structure and firms’ RDI, the following model is constructed to analyse this relationship:

|  |  |
| --- | --- |
|  | (4) |

where the dependent variable  represents a firm’s intensity of RDI, the independent variable  represents network power and network cohesion, which makes for two separate models to be estimated. Adopting separate models is helpful for analysing the impact of supply chain network structure on the firm’s RDI. Furthermore, the estimated approach is in line with [Potter and Wilhelm (2020)](#_ENREF_45). The control variables composed of , , , , and , which consist of a series of variables that may affect a firm’s RDI,  account for any unobserved time-specific effects,  is the residual error,  to  are the estimated parameters in Eq. (4).

The results of Models 2-1 to 2-3 are presented Table II. We first examine the effects of the basic control variables on RDI (Model 2-1), and the regression results are presented in column 2. Then, we test the effect of network power on a firm’s RDI (Model 2-2), the results of which are provided in column 3. The estimated coefficient of network power is -0.0006 and significant at the 1% level, indicating that the network power negatively and significantly affects a firm’s RDI, thereby supporting H1a.We then test the effect of network cohesion on firm’s RDI (Model 2-3), the results are presented in column 4. The coefficient of network cohesion is -0.7576 and statistically significant at the 5% level, indicating that the network cohesion negatively and significantly affects RDI; thus, H1b is supported.

**---Insert Table II here---**

To explore the moderating effect of KTI, we divide manufacturing firms into HTEs and non-HTEs. The results of Eq. (5) below are reported in Table III.

|  |  |
| --- | --- |
|  | * ((5) |

* where  is a dummy variable.  takes the value of 1 if a firm  has high-tech enterprise certification in year , otherwise 0.  to  are the parameters.
* The results of Models 3-1 to 3-2 are presented in Table III . First, the results of Model 3-1 are provided in column 2. The coefficient is -0.0002 but not statistically significant at the 10% level, indicating that the moderating effect of KTI is absent between network power and RDI; thus, H2a is not supported. The results of Model 3-2 are presented in column 3. Then, the results of Model 3-2 are reported in column 3. The coefficient is -1.9369 and statistically significant at the 5% level, indicating that the negative relationship between network cohesion and RDI is stronger in HTEs than non-HTEs; thus, H2b is supported. To illustrate the moderating effect of KTI between network cohesion and RDI, we created a conditional effects graph. The negative relationship between network cohesion and RDI in HTEs and non-HTEs is illustrated in Figure IV, and the negative network cohesion-RDI is strengthened when the firms are HTEs.

**---Insert Table III here---**

**---Insert Figure IV here---**

## Robustness test

To test the robustness of the above results on how supply chain network structures decrease RDI in manufacturing firms and the contingency conditions of this effect, we adopt two approaches that replace the missing value of R&D expenditure with different levels of expense in R&D, including 0.5% and 0.75% of sales ([Purkayastha et al. 2018](#_ENREF_46)). It is necessary that firms with missing R&D expenditure do not have expenses in R&D, possibly because a small proportion of sales are used to invest in R&D, or the disclosure of expenses is not standard and sufficient. Therefore, we use 0.5% and 0.75% of sales, respectively, to test our hypotheses when R&D expenditures are missing in our sample.

* First, we re-test our hypotheses using 0.5% of sales to replace missing R&D expenditure, and the results are presented in Tables IV–V. We then re-test our hypotheses using 0.75% of sales to replace missing R&D expenditure; the results are presented in Tables VI–VII. Finally, we further control the industry according to the secondary classification of manufacturing industry. Considering the problems of heteroscedastic and serial correlation, we use the robust standard errors and standard errors which are clustered by firms to re-test our hypotheses respctively, the results are presented in Tables VIII-IX. All the robustness results are consistent with our previous analyses, and the hypotheses in this research are supported again.

**---Insert Table IV here---**

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# Discussion

This study examines the impact of supply chain network structure (i.e.,network power and network cohesion) on a firm’s RDI and explores the contingency conditions of this effect. The results distinctly show that supply chain network structure negatively affects firms’ RDI, and KTI positively moderate the relationship between network cohesion and RDI.

## Theoretical implications

Our study thus contributes to the innovation stream of supply chain management by examining the impact of supply chain network structure on manufacturing firms’ RDI. First, the whole of empirical findings demonstrate that a firm’s supply chain network structure has a negative effect on RDI. The rationale for these negative effects is straightforward, firms with a high level of social capital are possibly to accept established patterns of thinking and behaviour and ignore the importance of major innovation. The acquisition of external information and knowledge is not used in innovation activities, and flexible supply chain networks have been recognised in the transformation of external information and knowledge into innovation ([Liao and Marsillac 2015](#_ENREF_35), [Adebanjo et al. 2018](#_ENREF_1)). We further extend the literature on manufacturing firm’s RDI by introducing social capital theory to explain why the acquisition of network resources decreases RDI. Therefore, our research is the first to provide a nuanced understanding of how supply chain network structure decreases RDI, which contributes to the innovation community from the perspective of supply chain network management.

* Second, we find a lack of supporting evidence that KTI moderates the relationships between network power and RDI. The findings are in line with [Stam et al. (2014)](#_ENREF_50), who confirm that the moderating effect of KTI is absent between strong/weak ties and firm performance. We further expect the reason is that HTEs do not reduce R&D expenditure and may even be more cautions in R&D activities. Furthermore, [Yu et al. (2020)](#_ENREF_57) find that HTEs have a strong developmental potential in improving innovation quality, and a large profit ratio comes from few radical innovations ([Foss et al. 2011](#_ENREF_22), [Chang et al. 2012](#_ENREF_15)). In other words, HTEs with high network power have a clear understanding of RDI, and thus do not reduce expenditure for general innovation, as R&D expenditure affects the identification of HTEs. Thus, our research may be the first to introduce a moderating mechanism into RDI involved in the supply chain network environment.
* Third, as expected, the negative relationship between network cohesion and RDI is stronger in HTEs. On the one hand, HTEs with high network cohesion always contact with disconnected partners; thus, they may not be trusted by connected partners ([Lau et al. 2019](#_ENREF_34)). In other words, they may spend more extensive efforts to cope with quantities of diverse information in innovation activities and may not possess the benefits of novel information to rely on network cohesion ([Stam et al. 2014](#_ENREF_50)). However, Chinese manufacturers highlight the importance of trust ([Xiao and Tsui 2007](#_ENREF_56)), as trust is central to most theories of supply chain network effectiveness ([Galaskiewicz 2011](#_ENREF_23)). On the other hand, HTEs that enjoy more social capital with high network cohesion can also bear stronger financial pressure to compensate for previous RDI and maintain the current relationship with disconnected partners; thus, the negative effect of network cohesion on RDI can be enhanced in HTEs compared to non-HTEs. In addition, because the scale of innovation activities of HTEs is usually larger than that of non-HTEs, the negative effect is magnified.

## Managerial implications

Our findings also have noteworthy implications for manufacturing firms’ innovation activities in operation practice. First, managers should make better use of network structures to cultivate their advantage, which is helpful for them to obtain critical information and knowledge ([Finne et al. 2015](#_ENREF_20), [Wen et al. 2021](#_ENREF_55)). We further suggest that managers identify what kinds of information and knowledge are favourable, and then improve the utilisation of resources, which is beneficial to the firm’s innovation ([Bagheri et al. 2020](#_ENREF_5)). In particular, in the era of increasing globalisation, it is vital for firms to improve their innovation capability, and the efficient utilisation of network resources can be considered as a supportive role in the global supply chain ([Carnovale et al. 2016](#_ENREF_10), [Wang et al. 2021](#_ENREF_52)).

* Second, the empirical results indicate that the allocation of network resources may directly affect innovation performance. We therefore suggest that managers should allocate network resources effectively to maximise the value of such resources for innovation. This suggestion was developed by Huo et al. ([2020](#_ENREF_27)), who confirmed that the process of supply chain learning is beneficial for assimilating and leveraging knowledge from network partners. We further suppose that firms should effectively allocate resources obtained from network partners to diminish the negative effect of social capital and focus on innovation activities, such as more highly differentiated products. It is generally believed that such products provide firms with sustainable competitive advantage.
* Finally, considering the fact that individual-level innovation behaviour plays a significant role in the system of a firm’s innovation practice, managers should maintain a positive attitude toward innovation, instead of being satisfied with the status quo. [Kör et al. (2021)](#_ENREF_31) suggest managers should improve self-leadership skills and create an atmosphere conducive to firm members’ innovation. Furthermore, [Lin et al. (2020)](#_ENREF_36) suggest that firms should increase the amount of equity for managers, as managers with more shareholdings typically make decisions from the long-run perspective of firms and devote themselves to the maximal value creation of the firm. We further suggest that managers should seek and adopt beneficial novel ideas and be sensitive to the changeable environment, especially in the period of economic transition.

# Conclusions and limitations

This study provides supporting evidence that a firm’s supply chain network structure has a negative effect on its RDI and provides a nuanced perspective on how to best use supply chain network resources for innovation activities based on social capital theory. This study first collects A-share listed firms in the manufacturing industry with two-tier suppliers and customers to construct a supply chain network, and then identifies constructed network power and network cohesion that are closely related to firms’ innovation capabilities. However, as managers ignore the importance of major innovation caused by a high level of social capital, manufacturing firms with high-level network structures will reduce RDI in practical operations. Our findings therefore indicate that supply network structures have a negative effect on firms’ RDI; KTI positively moderates the relationship between network cohesion and RDI. Our empirical findings thus are the first to explore the role of supply network structure on Chinese manufacturing firms’ RDI. In essence, this study contributes to the innovation streams of supply chain management by underlining the negative role of supply chain network structures in manufacturing firms’ R&D activities.

* While this study has provided a nuanced understanding that the supply chain network structure negatively affects manufacturing firms’ RDI, several limitations should be noted. First, our sample is from listed manufacturing firms over the period of 2014–2019. However, some firms do not disclose the firm names of main suppliers and customers completely, and we have to delete these firms. This may be one potential reason that some of our hypotheses were not significant. Therefore, future research can expand the scope of the empirical sample by adding listed firms from other industries. Second, we establish the connection between firms based on the relationship between supplier and consumer, and the connection strength among firms is not considered. Thus, future research can consider the connection strength among firms according to cash flow. Finally, although we have identified different types of firms, the types of RDI still vary, such as internal or external, and public or private RDI; future research can explore the relationship between supply chain network structure and the types of RDI.

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Table I. Descriptive statistics and correlations

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Variables | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
| (1) RDI | 1 |  |  |  |  |  |  |  |
| (2) Network power | -0.0507\* | 1 |  |  |  |  |  |  |
| (3) Network cohesion | -0.1035\*\*\* | 0.2608\*\*\* | 1 |  |  |  |  |  |
| (4) SIZE | -0.1723\* | -0.1770\* | 0.1608\*\*\* | 1 |  |  |  |  |
| (5) LEV | -0.2422\* | -0.0320 | 0.1002\*\*\* | 0.4601\* | 1 |  |  |  |
| (6) AGE | -0.1620\* | 0.0138 | 0.0254 | 0.1032\* | 0.1472\* | 1 |  |  |
| (7) ROA | -0.0225 | -0.1104\* | 0.0117 | 0.0856\* | -0.4072\* | -0.0634\* | 1 |  |
| (8) HHI | -0.1146\* | 0.0531\* | 0.1305\*\*\* | 0.0778\* | 0.0291 | 0.0657\* | 0.0338\* | 1 |
| Mean | 0.0368 | 7.3950 | 0.0006 | 22.1583 | 0.4303 | 17.8736 | 0.0286 | 0.1149 |
| S.D. | 0.0345 | 4.3932 | 0.0019 | 1.3112 | 0.2072 | 5.1765 | 0.0716 | 0.0909 |
| Minimum | 0.0000 | 1.0000 | 0.0000 | 19.5397 | 0.0675 | 7.0000 | -0.3457 | 0.0239 |
| Maximum | 0.2088 | 21.0000 | 0.0129 | 25.9096 | 0.9849 | 31.0000 | 0.1930 | 0.4305 |

Note: (a) The sample includes firm-year observations from 2014-2019, n=2390. (b) \* denotes statistical significance at the 10% level.

Table II. Impact of supply chain network structure on RDI

|  |  |  |  |
| --- | --- | --- | --- |
| Independent variable | Model 2-1 | Model 2-2 | Model 2-3 |
| Network power |  | -0.0006\*\*\* |  |
|  |  | (-3.6195) |  |
| Network cohesion |  |  | -0.7576\*\* |
|  |  |  | (-2.0763) |
| SIZE | -0.0010\* | -0.0013\*\* | -0.0008 |
|  | (-1.6499) | (-2.1663) | (-1.3714) |
| LEV | -0.0404\*\*\* | -0.0403\*\*\* | -0.0403\*\*\* |
|  | (-9.5134) | (-9.5153) | (-9.4970) |
| AGE | -0.0011\*\*\* | -0.0010\*\*\* | -0.0011\*\*\* |
|  | (-7.8018) | (-7.6724) | (-7.7581) |
| ROA | -0.0583\*\*\* | -0.0615\*\*\* | -0.0585\*\*\* |
|  | (-5.3603) | (-5.6527) | (-5.3823) |
| HHI | -0.0382\*\*\* | -0.0364\*\*\* | -0.0361\*\*\* |
|  | (-5.1800) | (-4.9392) | (-4.8584) |
| Constant | 0.0930\*\*\* | 0.1037\*\*\* | 0.0898\*\*\* |
|  | (7.3406) | (7.9934) | (7.0447) |
| Year | YES | YES | YES |
| Observations | 2,390 | 2,390 | 2,390 |
| R-squared | 0.1202 | 0.1250 | 0.1218 |
| Adj\_R2 | 0.1165 | 0.1210 | 0.1177 |

Note: (a) Dependent variable: RDI; (b)\*p<0.1, \*\*p<0.05, \*\*\*p<0.01.

Table III. Moderating effect of KTI

|  |  |  |
| --- | --- | --- |
| Independent variables | Model 3-1 | Model 3-2 |
| Network power | -0.0005\*\*\* |  |
|  | (-2.7442) |  |
| Network power\*KTI | -0.0002 |  |
|  | (-0.7233) |  |
| Network cohesion |  | -0.2606 |
|  |  | (-0.6093) |
| Network cohesion \*KTI |  | -1.9369\*\* |
|  |  | (-2.1040) |
| HTE | 0.0159\*\*\* | 0.0152\*\*\* |
|  | (5.9598) | (10.0215) |
| SIZE | -0.0018\*\*\* | -0.0013\*\* |
|  | (-2.8994) | (-2.1004) |
| LEV | -0.0405\*\*\* | -0.0403\*\*\* |
|  | (-9.7726) | (-9.7092) |
| AGE | -0.0009\*\*\* | -0.0009\*\*\* |
|  | (-6.9665) | (-7.0270) |
| ROA | -0.0687\*\*\* | -0.0648\*\*\* |
|  | (-6.4291) | (-6.0720) |
| HHI | -0.0318\*\*\* | -0.0313\*\*\* |
|  | (-4.4025) | (-4.2842) |
| Year | YES | YES |
| Constant | 0.1081\*\*\* | 0.0941\*\*\* |
|  | (8.4912) | (7.5295) |
| Observations | 2,390 | 2,390 |
| R-squared | 0.1608 | 0.1581 |
| Adj\_R2 | 0.1563 | 0.1535 |

Note: (a) Dependent variable: RDI; (b) \*p<0.1, \*\*p<0.05, \*\*\*p<0.01.

Table IV. Replace missing R&D expenditure with R&D expenditure=0.5% of sales

|  |  |  |  |
| --- | --- | --- | --- |
| Independent variable | Model 4-1 | Model 4-2 | Model 4-3 |
| Network power |  | -0.0006\*\*\* |  |
|  |  | (-3.6513) |  |
| Network cohesion |  |  | -0.7784\*\* |
|  |  |  | (-2.1460) |
| SIZE | -0.0011\* | -0.0015\*\* | -0.0010 |
|  | (-1.8864) | (-2.4056) | (-1.5973) |
| LEV | -0.0397\*\*\* | -0.0396\*\*\* | -0.0396\*\*\* |
|  | (-9.4192) | (-9.4212) | (-9.4026) |
| AGE | -0.0010\*\*\* | -0.0010\*\*\* | -0.0010\*\*\* |
|  | (-7.5799) | (-7.4492) | (-7.5349) |
| ROA | -0.0584\*\*\* | -0.0617\*\*\* | -0.0587\*\*\* |
|  | (-5.4064) | (-5.7017) | (-5.4295) |
| HHI | -0.0379\*\*\* | -0.0361\*\*\* | -0.0358\*\*\* |
|  | (-5.1807) | (-4.9380) | (-4.8502) |
| Constant | 0.0951\*\*\* | 0.1059\*\*\* | 0.0919\*\*\* |
|  | (7.5551) | (8.2104) | (7.2500) |
| Year | YES | YES | YES |
| Observations | 2,390 | 2,390 | 2,390 |
| R-squared | 0.1201 | 0.1250 | 0.1218 |
| Adj\_R2 | 0.1164 | 0.1210 | 0.1178 |

Note: (a) Dependent variable: RDI; (b) \*p<0.1, \*\*p<0.05, \*\*\*p<0.01.

Table V. Replace missing R&D expenditure with R&D expenditure=0.5% of sales

|  |  |  |
| --- | --- | --- |
| Independent variables | Model 5-1 | Model 5-2 |
| Network power | -0.0005\*\*\* |  |
|  | (-2.7352) |  |
| Network power \*KTI | -0.0002 |  |
|  | (-0.7728) |  |
| Network cohesion |  | -0.2902 |
|  |  | (-0.6821) |
| Network cohesion \*KTI |  | -1.9028\*\* |
|  |  | (-2.0781) |
| HTE | 0.0157\*\*\* | 0.0149\*\*\* |
|  | (5.9346) | (9.8933) |
| SIZE | -0.0019\*\*\* | -0.0014\*\* |
|  | (-3.1348) | (-2.3205) |
| LEV | -0.0399\*\*\* | -0.0397\*\*\* |
|  | (-9.6721) | (-9.6076) |
| AGE | -0.0009\*\*\* | -0.0009\*\*\* |
|  | (-6.7453) | (-6.8071) |
| ROA | -0.0687\*\*\* | -0.0648\*\*\* |
|  | (-6.4670) | (-6.1095) |
| HHI | -0.0317\*\*\* | -0.0311\*\*\* |
|  | (-4.4041) | (-4.2816) |
| Year | YES | YES |
| Constant | 0.1102\*\*\* | 0.0961\*\*\* |
|  | (8.7016) | (7.7306) |
| Observations | 2,390 | 2,390 |
| R-squared | 0.1600 | 0.1573 |
| Adj\_R2 | 0.1554 | 0.1527 |

Note: (a) Dependent variable: RDI; (b) \*p<0.1, \*\*p<0.05, \*\*\*p<0.01.

Table VI. Replace missing R&D expenditure with R&D expenditure=0.75% of sales

|  |  |  |  |
| --- | --- | --- | --- |
| Independent variable | Model 6-1 | Model 6-2 | Model 6-3 |
| Network power |  | -0.0006\*\*\* |  |
|  |  | (-3.6662) |  |
| Network cohesion |  |  | -0.7889\*\* |
|  |  |  | (-2.1806) |
| SIZE | -0.0012\*\* | -0.0015\*\* | -0.0010\* |
|  | (-2.0050) | (-2.5255) | (-1.7107) |
| LEV | -0.0394\*\*\* | -0.0393\*\*\* | -0.0393\*\*\* |
|  | (-9.3687) | (-9.3707) | (-9.3520) |
| AGE | -0.0010\*\*\* | -0.0010\*\*\* | -0.0010\*\*\* |
|  | (-7.4655) | (-7.3342) | (-7.4199) |
| ROA | -0.0585\*\*\* | -0.0618\*\*\* | -0.0587\*\*\* |
|  | (-5.4278) | (-5.7244) | (-5.4514) |
| HHI | -0.0378\*\*\* | -0.0360\*\*\* | -0.0357\*\*\* |
|  | (-5.1793) | (-4.9357) | (-4.8443) |
| Constant | 0.0962\*\*\* | 0.1070\*\*\* | 0.0929\*\*\* |
|  | (7.6609) | (8.3172) | (7.3512) |
| Year | YES | YES | YES |
| Observations | 2,390 | 2,390 | 2,390 |
| R-squared | 0.1201 | 0.1250 | 0.1218 |
| Adj\_R2 | 0.1164 | 0.1210 | 0.1178 |

Note: (a) Dependent variable: RDI; (b) \*p<0.1, \*\*p<0.05, \*\*\*p<0.01.

Table VII. Replace missing R&D expenditure with R&D expenditure=0.75% of sales

|  |  |  |
| --- | --- | --- |
| Independent variables | Model 7-1 | Model 7-2 |
| Network power | -0.0005\*\*\* |  |
|  | (-2.7296) |  |
| Network power\*KTI | -0.0002 |  |
|  | (-0.7977) |  |
| Network cohesion |  | -0.3050 |
|  |  | (-0.7186) |
| Network cohesion \*KTI |  | -1.8858\*\* |
|  |  | (-2.0645) |
| HTE | 0.0156\*\*\* | 0.0147\*\*\* |
|  | (5.9202) | (9.8257) |
| SIZE | -0.0020\*\*\* | -0.0015\*\* |
|  | (-3.2524) | (-2.4307) |
| LEV | -0.0396\*\*\* | -0.0394\*\*\* |
|  | (-9.6183) | (-9.5532) |
| AGE | -0.0009\*\*\* | -0.0009\*\*\* |
|  | (-6.6315) | (-6.6939) |
| ROA | -0.0688\*\*\* | -0.0649\*\*\* |
|  | (-6.4838) | (-6.1263) |
| HHI | -0.0316\*\*\* | -0.0310\*\*\* |
|  | (-4.4033) | (-4.2787) |
| Year | YES | YES |
| Constant | 0.1113\*\*\* | 0.0971\*\*\* |
|  | (8.8048) | (7.8295) |
| Observations | 2,390 | 2,390 |
| R-squared | 0.1596 | 0.1568 |
| Adj\_R2 | 0.1550 | 0.1522 |

Note: (a) Dependent variable: RDI; (b) \*p<0.1, \*\*p<0.05, \*\*\*p<0.01.

Table VIII. Add control variable and adopt robust standard errors

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Independent variables | Model 8-1 | Model 8-2 | Model 8-3 | Model 8-4 | Model 8-5 |
| Net power |  | -0.0004\*\*\* |  | -0.0003\* |  |
|  |  | (-2.7340) |  | (-1.9573) |  |
| Network power\*KTI |  |  |  | -0.0002 |  |
|  |  |  |  | (-0.7688) |  |
| Net cohesion |  |  | -0.9193\*\*\* |  | -0.5246\* |
|  |  |  | (-4.0069) |  | (-1.8990) |
| Network cohesion\*KTI |  |  |  |  | -1.4477\*\* |
|  |  |  |  |  | (-2.5135) |
| HTE |  |  |  | 0.0132\*\*\* | 0.0123\*\*\* |
|  |  |  |  | (5.3501) | (7.9865) |
| SIZE | -0.0011\*\* | -0.0013\*\* | -0.0009\* | -0.0016\*\*\* | -0.0012\*\* |
|  | (-2.0182) | (-2.4385) | (-1.6457) | (-3.1733) | (-2.3582) |
| LEV | -0.0434\*\*\* | -0.0433\*\*\* | -0.0433\*\*\* | -0.0433\*\*\* | -0.0431\*\*\* |
|  | (-9.5483) | (-9.5299) | (-9.5433) | (-9.7535) | (-9.7414) |
| AGE | -0.0008\*\*\* | -0.0008\*\*\* | -0.0008\*\*\* | -0.0007\*\*\* | -0.0007\*\*\* |
|  | (-5.8859) | (-5.8280) | (-5.8344) | (-5.3440) | (-5.3493) |
| ROA | -0.0478\*\*\* | -0.0502\*\*\* | -0.0480\*\*\* | -0.0569\*\*\* | -0.0540\*\*\* |
|  | (-2.9124) | (-3.0389) | (-2.9276) | (-3.5043) | (-3.3558) |
| HHI | -0.0543\*\*\* | -0.0527\*\*\* | -0.0515\*\*\* | -0.0482\*\*\* | -0.0468\*\*\* |
|  | (-8.5463) | (-8.2843) | (-8.0523) | (-7.5620) | (-7.2654) |
| Year | Yes | Yes | Yes | Yes | Yes |
| Industry | Yes | Yes | Yes | Yes | Yes |
| Constant | 0.0745\*\*\* | 0.0817\*\*\* | 0.0703\*\*\* | 0.0873\*\*\* | 0.0759\*\*\* |
|  | (6.8015) | (7.3787) | (6.3958) | (8.0240) | (7.0804) |
| Observations | 2,390 | 2,390 | 2,390 | 2,390 | 2,390 |
| R-squared | 0.1974 | 0.1995 | 0.1997 | 0.2230 | 0.2232 |
| Adj\_R2 | 0.1930 | 0.1948 | 0.1950 | 0.2178 | 0.2180 |
| Note: (a) Dependent variable: RDI; (b) \*p<0.1, \*\*p<0.05, \*\*\*p<0.01.(c) Robust t-statistics in parentheses, | | | | | |
|  | |  |  |  |  |

Table IX. Add control variable and adopt cluster robust standard errors

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Independent variables | Model 9-1 | Model 9-2 | Model 9-3 | Model 9-4 | Model 9-5 |
| Network power |  | -0.0004\* |  | -0.0003 |  |
|  |  | (-1.7385) |  | (-1.4351) |  |
| Network power\*KTI |  |  |  | -0.0002 |  |
|  |  |  |  | (-0.6988) |  |
| Network cohesion |  |  | -0.9193\*\* |  | -0.5246 |
|  |  |  | (-2.5525) |  | (-1.4712) |
| Network cohesion\*KTI |  |  |  |  | -1.4477\*\* |
|  |  |  |  |  | (-2.2434) |
| HTE |  |  |  | 0.0132\*\*\* | 0.0123\*\*\* |
|  |  |  |  | (5.0932) | (7.1832) |
| SIZE | -0.0011 | -0.0013 | -0.0009 | -0.0016\*\* | -0.0012 |
|  | (-1.2592) | (-1.5096) | (-1.0306) | (-2.0027) | (-1.5090) |
| LEV | -0.0434\*\*\* | -0.0433\*\*\* | -0.0433\*\*\* | -0.0433\*\*\* | -0.0431\*\*\* |
|  | (-6.2182) | (-6.1894) | (-6.2139) | (-6.4060) | (-6.4249) |
| AGE | -0.0008\*\*\* | -0.0008\*\*\* | -0.0008\*\*\* | -0.0007\*\*\* | -0.0007\*\*\* |
|  | (-3.5231) | (-3.4838) | (-3.4929) | (-3.2487) | (-3.2592) |
| ROA | -0.0478\*\* | -0.0502\*\* | -0.0480\*\* | -0.0569\*\*\* | -0.0540\*\*\* |
|  | (-2.4418) | (-2.5474) | (-2.4512) | (-2.9447) | (-2.8195) |
| HHI | -0.0543\*\*\* | -0.0527\*\*\* | -0.0515\*\*\* | -0.0482\*\*\* | -0.0468\*\*\* |
|  | (-5.4453) | (-5.2612) | (-5.1773) | (-4.8813) | (-4.7415) |
| Year | Yes | Yes | Yes | Yes | Yes |
| Industry | Yes | Yes | Yes | Yes | Yes |
| Constant | 0.0745\*\*\* | 0.0817\*\*\* | 0.0703\*\*\* | 0.0873\*\*\* | 0.0759\*\*\* |
|  | (4.2988) | (4.6247) | (4.0599) | (5.1159) | (4.5756) |
| Observations | 2,390 | 2,390 | 2,390 | 2,390 | 2,390 |
| R-squared | 0.1974 | 0.1995 | 0.1997 | 0.2230 | 0.2232 |
| Adj\_R2 | 0.1930 | 0.1948 | 0.1950 | 0.2178 | 0.2180 |
| Note: (a) Dependent variable: RDI; (b) \*p<0.1, \*\*p<0.05, \*\*\*p<0.01.(c) Robust t-statistics in parentheses, and clustered at firm level. | | | | | |



Figure I. Research framework



Figure II. Steps involved in constructing supply chain networks



Figure III. Supply chain networks in the period 2014–2019



Figure IV. Moderating effect of KTI