How to configure the supply chain to stimulate firm innovation performance?

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Abstract

Supply chain characteristics are an important driving force for innovation at the focal firm. Previous research has separately examined the impact of structural, relational, and capability dimensions of the supply chain on firm innovation. Relying on the structure-relationship-capability framework, this study explores the configurational impact of geographical distance, business concentration, and partner innovation of both the supplier-base and the customer-base on firm innovation. Necessary causality analysis (NCA) and fuzzy-set qualitative comparative analysis (fsQCA) are employed. Based on a dataset of 123 Chinese listed firms in high-tech manufacturing sectors, we provide novel insights on the antecedent configurations of the partner characteristics in both ends of supply chains for facilitating firm innovation. Our findings indicate that there are no necessary conditions for high firm innovation performance. We identify three distinct paths - namely, innovation-driven, customer-dominated, and relationship-driven configurations - that consistently lead to high firm innovation performance. From a configurational perspective, this research contributes to the innovation and supply chain literature and provides practical implications for managers to facilitate firm innovation.

Keywords: Supplier-base, customer-base, geographical distance, business concentration, innovation, NCA, fsQCA

1. Introduction

The supply chain, consisting of both suppliers and customers, is the primary field for firms to build external connections and to search for resources for innovation (Tomlinson and Fai, 2016). The characteristics of the supply chain reflect the quantity and quality of resources available to the focal firm, directly impacting its innovation performance (Zimmermann, *et al*., 2016). For example, Bosch, a leading manufacturing firm in the automotive sector, has significantly advanced its innovation in automotive sensors and safety systems through strategic partnerships with specialized suppliers of electronic components and close collaboration with automotive manufacturers like Daimler (Grimm and Walz, 2024). Given that supply chains are complex ecosystems involving suppliers and customers, selecting good supply chain partners to address complexity presents a significant challenge to firm innovation (Griffis *et al*., 2017). Practical evidence shows that serval prerequisites in supply chains, regarding structural, relational and organizational dimensions, are prioritized at the expense of innovation work (Anderson *et al*., 2023). Academic studies have identified three types of supply chain characteristics that influence firm innovation: network structure (Pillai and Bindroo, 2020; Sharma *et al.*, 2020), inter-organizational relationships (Jer *et al.*, 2017; Cheng *et al.*, 2014), and organizational capabilities (Oke *et al.*, 2013; Lin *et al.*, 2010). These studies consistently highlight the involvement of supply chain partners in the focal firm's innovation activities. However, both managers and researchers know far less about what kinds of supply chains are most beneficial to firm-level innovation, i.e., how to select supply chain partners to

enhance firm innovation performance. Addressing this topic can be related to initial work by Chandler (1962) highlighting issues of aligning incentives within the supply chain to achieve throughput and assured supply, the influence of vertical integration (and disintegration) decisions on the internal operation of the firm and its future path, and finding a balance between a need for coordination and information overload, which are still of actual practical importance for the management of innovation in the supply chain (Helper and Sako, 2010).

Supply chains can be divided into upstream and downstream segments. Numerous studies have investigated the heterogeneous roles of suppliers and customers in facilitating focal firm's innovation, in line with the complementary role of supply chain partners (Lau *et al*., 2010; Lee and Schmidt, 2017; Menguc *et al*., 2014; Roy and Sivakumar, 2010). On the one hand, firms rely on the manufacturing competence of upstream suppliers and recognize that suppliers are an increasingly important source of innovativeness (Azadegan and Dooley, 2010). Under collaborative innovation situations, suppliers actively promote the application of their successful innovations to the focal firm, which is conducive to focal firms' process and product innovation (Wagner and Bode, 2014). On the other hand, downstream customers are also essential sources of information and knowledge for firm innovation (Taghizadeh *et al*., 2018). Customer firms have a better understanding of market demand and have rich product ideas and design creativity (Greer and Lei, 2012). In short, upstream and downstream segments play distinct roles in shaping operational processes along supply chains.

A seminal study established a structure-relationship-capability (SRC) framework to elucidate the innovation performance of a focal firm through the integration of accessibility, interconnectedness, and partner innovativeness within its supply network (Bellamy *et al*.,

2014). In this approach, we introduce geographical distance, business concentration, and partner innovation from the supply chain complexity literature to capture the key inter-organizational characteristics of supply chains. Prior studies suggest that high performance may be a function of key complexity characteristics between supply chain partners. Specifically, the SRC framework, represented by geographical distance, business concentration, and partner innovation, plays a crucial role in searching for knowledge, cultivating relationship capital and facilitating inter-organizational learning (Sharma *et al*., 2020; Krolikowski and Yuan, 2017; Wagner, 2012). Geographical distance, as an essential indicator of the spatial complexity of supply chains, reflects the distance in geography dimension between focal firms and supply chain partners, and the extent to which each supply chain partner contributes heterogeneous resources related to locations to create new value (Bellamy *et al*., 2014; Chu *et al.*, 2019). Business concentration reflects the dependence of two parties in vertical partnerships, and the extent to which this collaboration influences operation processes, coordination efforts, and organizational learning (Krolikowski and Yuan, 2017). Partner innovation refers to the ability of a supply chain partner to generate, adopt, and implement new ideas, processes, products, or services to improve its performance (Bellamy *et al*., 2014; Kibbeling *et al.*, 2013).

The impact of the three key supply chain characteristics on firm innovation has garnered significant attention. Prior studies have shown positive, negative and U-shaped effects of geographical distance from supply chain partners on innovation performance (Sharma *et al*., 2020; Presutti *et al*., 2019; Wei and Sheng, 2023). Business concentration changes the power dynamics and dependence between focal firms and supply chain partners, thereby affecting the transfer of information and knowledge (Jiang *et al*., 2023). While some studies report positive

or negative impacts of business concentration on innovation performance (Krolikowski and Yuan, 2017; Kim and Zhu, 2018), Chen *et al*. (2022) argue for a nonlinear effect. The spillover effect of innovativeness from supply chain partners is notably amplified in the context of vertical relationships (Isaksson *et al*., 2016; Ojha *et al.*, 2018), though this effect varies depending on organizational contexts (Wang and Hu, 2020; Stanko and Olleros, 2013). Such mixed evidence suggests that the efficacy of each supply chain characteristic may depend on its interplay with other characteristics (Bellamy *et al*., 2014). However, the combined impact of these key supply chain characteristics has been largely neglected in the existing innovation literature.

In this study, we follow the SRC framework and link geographical distance, business concentration, and partner innovation from upstream and downstream segments with focal firms' innovation. By considering these three characteristics simultaneously, we aim to identify advantageous configurations that facilitate firm-level innovation. We propose that firms are embedded in supply chain networks with different SRC configurations, and that these configurations are crucial for innovation performance. More specifically, based on a configuration approach, this study aims at identifying the focal firm's SRC configurations with its suppliers and customers, and at investigating whether firms with different SRC configurations would attain different levels of innovation performance.

This study contributes to the literature in three significant ways. Firstly, existing research on the impact of supply chain characteristics on innovation primarily focuses on supplier characteristics (Sharma *et al.*, 2020; Bellamy *et al.*, 2014; Choi and Krause, 2006) or customer characteristics (Guerola-Navarro *et al.*, 2021; Chu *et al.*, 2019; Krolikowski and Yuan, 2017).

While Shou *et al*. (2018) briefly touched upon both ends of the supply chain concurrently using cluster analysis, they largely overlooked the combined influence of suppliers and customers. Secondly, most research examines the individual effects of geographical distance, business concentration, and organizational innovativeness on firm innovation (Pillai and Bindroo, 2020; Krolikowski and Yuan, 2017; Kibbeling *et al*., 2013). However, these studies neglect to unveil the combined impact of these three partner characteristics within the SRC framework. We empirically develop a configurational taxonomy of geographical distance, business concentration and partner innovation, identifying three distinct configurations that facilitate the innovation of the focal firm. Thirdly, most research indicates a conflicting linear relationship between individual partner characteristics and firm innovation performance, lacking a consistent conclusion based on econometric analysis (Chu *et al*., 2019; Presutti *et al*., 2019). The methodology used in these studies overlooks the interplay among various supply chain characteristics. We introduce an asymmetric logic (Ragin, 2008) to investigate the intertwined effect of geographical distance, business concentration, and partner innovation on firm innovation.

2. Literature review and theoretical framework

The supply chain management literature unanimously acknowledges the importance of supply chain collaboration to firm innovation (Solaimani and van der Veen, 2022; Soosay *et al.*, 2008; Simatupang and Sridharan, 2005). Supply chain collaboration refers to the joint planning and execution of operations among two or more firms in a vertical partnership, creating competitive advantages to satisfy market demands through information sharing, joint decision-making and benefit sharing (Simatupang and Sridharan, 2005). Therefore, supply chain collaboration needs

systematic cooperation between focal firms, upstream suppliers and downstream customers to foster innovation and improve performance (Cassivi, 2006). This insight argues for integrating both ends of supply chains. Many studies consider suppliers and customers separately and identify their characteristics that affect the focal firm's innovation (e.g., Sharma *et al.*, 2020; Dai *et al.*, 2015; Peng *et al*., 2013; Ozer and Zhang, 2015). Shou *et al*. (2018) constructed a taxonomy of focal firms' configurations, assessing complementarity and compatibility with both suppliers and customers through cluster analyses. The authors further investigated the relationship between these configurations and environmental innovation using ANOVA tests. However, there remains a lack of research that simultaneously considers configurations of multiple characteristics of the two ends of the supply chain, in view of facilitating innovation of the focal firm.

Research on innovation management in the supply chain context mainly focuses on the impact of partner characteristics on firm innovation. Bellamy *et al*. (2014) delved into the impact of supply network accessibility and interconnectedness on firm innovation output, while also considering the moderating effect of supply network partner innovativeness. This study examined the interactions among these three distinct characteristics of the supply network - structural, relational and capability dimensions - shedding light on the formation of the SRC framework. A stream of literature focuses on the impact of geographical distance, business concentration, and organizational innovativeness on firm innovation in the supply chain context within the SRC framework (Pillai and Bindroo, 2020; Jer *et al.*, 2017; Ozer and Zhang, 2015). The geographical distance of supply chain partners affects the costs and benefits of focal firms' resource search for innovation (Pillai and Bindroo, 2020; Chu *et al.*, 2019). Some studies

have found that business concentration in vertical relationships affects the focal firm's innovation outcome (Krolikowski and Yuan, 2017). In addition, organizational capabilities of partners reflected in supply chain innovation install a creative atmosphere with knowledge spillovers in joint operations, thereby enhancing the motivation of firms to innovate (Narasimhan and Narayanan, 2013; Kibbeling *et al.*, 2013). Although the interaction between two characteristics within the SRC framework has been explored by using a moderating approach (Wei and Sheng, 2023; Elking *et al*., 2022; Chu *et al*., 2019), the three characteristics from both ends of supply chains have not been considered simultaneously. Unlike existing studies that mainly examine the independent impact of a single characteristic, we focus on the configurational role of geographical distance, business concentration, and partner innovation in both the supplier-base and in the customer-base, in relation to firm innovation performance.

Considering the above facts, we construct six characteristics in both ends of supply chains as conditions: supplier-base geographical distance, supplier-base business concentration, supplier-base innovation, customer-base geographical distance, customer-base business concentration and customer-base innovation, and investigate their combined impact on firm innovation performance in a configurational approach. Below, aligning with the SRC framework, we elaborate on the main insights from the literature regarding the association of each characteristic with focal firm innovation and highlight the need to consider each of the characteristics in conjunction with the other characteristics.

2.1 Supplier-base characteristics

The supplier-base refers to the principal actors in the supply network that the focal firm can directly manage through contracts and purchase ties (Choi and Krause, 2006). Compared to the

supply network, the supplier-base presents the crucial traits of the supply chain upstream and has a more direct and substantial impact on the focal firm's decision-making and performance (Lu and Shang, 2017). Compared to the indirect connection, the direct connection between the focal firm and its supply network is an efficient channel for knowledge sharing, which is closely related to the innovation activities of the focal firm (Narasimhan and Narayanan, 2013). Therefore, we choose the supplier-base to represent the supply chain upstream.

2.1.1 Supplier-base geographical distance

Supplier-base geographical distance refers to the average geographical distance between the focal firm and suppliers in the supplier-base. Innovation studies have examined the relationship between supplier geographical distance and innovation performance from different theoretical perspectives (Sharma *et al.*, 2020; Pillai and Bindroo, 2020; dos Santos Silvestre and Dalcol, 2009; Schiele, 2006; Frigant and Lung, 2002). As an essential source of innovation, suppliers' location determines the diversity of resources that focal firms can search for innovation. Generally, the farther away the supplier is, the greater the variety of resources (Chakrabarti and Mitchell, 2013). As the supplier distance increases, focal firms can search for and integrate more diverse resources to promote innovation activities (Leiponen and Helfat, 2010; Frigant and Lung, 2002). On the other hand, some studies suggest that spatial agglomeration can lead to more frequent and efficient interactions among supply chain partners, increasing communication and knowledge transfer (Boschma, 2005; Pillai and Bindroo, 2020). Therefore, suppliers co-locating with the focal firm have more knowledge resources and thus facilitate innovation activities.

From the perspective of transaction cost theory, if a supplier is geographically far away,

the possibility of its opportunistic behavior will increase, which will lead to an increase in transaction costs (Obloj and Zemsky, 2015). Geographically distant suppliers embody diverse technical and cultural backgrounds. For focal firms, managing and coordinating interactions and knowledge transfer with distant suppliers can be challenging, taking great efforts with high costs (Sharma *et al.*, 2020). In addition, geographically dispersed supply chains have higher uncertainties and more potential risks, such as natural disasters and epidemics. Therefore, integrating knowledge of distant suppliers, in general, generates high costs, deteriorating firm innovation performance (Sharma *et al.*, 2020). In summary, the literature has not yet reached a consensus on the relationship between supplier-base geographical distance and firm innovation performance.

Although the impact of supplier-base geographical distance at the upstream end of the supply chain has been studied, few studies have explored how other supply chain characteristics moderate the relationship between this distance and a firm's innovation performance. A firm's network influence and strategic emphasis, as organizational capabilities, have been shown to negatively and positively moderate the connection between supplier geographical distance and innovation performance, respectively (Sharma *et al*., 2020). Additionally, at the interorganizational level, network ties with suppliers and customers may also moderate the relationship between cluster membership and innovation performance (Ozer and Zhang, 2015). However, this moderating approach often overlooks the combined influence of multiple characteristics across the structural, relational, and capability dimensions of supply chains.

2.1.2 Supplier-base business concentration

Supplier-base business concentration can be defined as the proportion a focal firm purchase from the supply base, which is reflected by the data distribution of the purchase share (Schwieterman *et al*., 2018; Sako *et al*., 2016). Previous studies put forward positive and negative views on the relationship between supply chain concentration and performance (Schwieterman *et al.*, 2018). The advantage of high business concentration is to provide focal firms with relational value creation and efficient collaboration. The disadvantage of high business concentration is that it brings high risks and uncertainties to the operation and production of focal firms.

We further investigate the relationship between supplier-base business concentration and firm innovation performance based on the above presented contradictory insights. Supplier-base business concentration determines the scope and depth of external knowledge from the upstream supply chain, relating to the outcome of the focal firm's search activities (Dong *et al.*, 2021; Chen *et al.*, 2022). Thus, low concentration is conducive for focal firms to acquire complementary knowledge and to progress their technological update. From a social network perspective, low concentration means that focal firms have high independence and low switching costs in the purchase relationship (Sako *et al.*, 2016; Kim and Choi, 2015).

High supplier-base business concentration may also promote firm innovation. High supplier-base business concentration indicates that the purchase of focal firms is concentrated in a small number of suppliers, so the searchable knowledge scope is narrow, and the diversity of knowledge resources is limited. However, high business concentration indicates plenty of relational resources generated from consistent commission, mutual trust and common cognition. There is potential for relational value creation. This strategic relationship guarantees

the depth of searchable knowledge and continuity of search activities, thereby promoting firm innovation (Chen *et al.*, 2022). However, high business concentration brings more risks and high switching costs in operations to focal firms, hindering innovation persistence (Kim and Choi, 2015). These opposite views call for a more exploratory study of the association between supplier-base concentration and firm innovation performance.

The influence of supplier-base concentration on innovation performance can be shaped by the structural characteristics of the supplier-base and the organizational capabilities of the focal firm. For example, Sharma *et al*. (2024) suggested that factors such as the breadth, depth, and geographical dispersion of the supplier-base can moderate the relationship between supplier-base concentration and innovation performance (Sharma *et al*., 2024). Additionally, Chen *et al*. (2022) highlighted that a firm's financial slack and growth opportunities can also affect this relationship. In line with the SRC framework, further research should explore how structural and capability characteristics interact with relational factors to impact innovation performance.

2.1.3 Supplier-base innovation

Many studies have recognized the crucial role of suppliers as a key source of knowledge and technology for focal firm innovation (Azadegan and Dooley, 2010; Narasimhan and Narayanan, 2013; Wagner, 2012; Cassiman and Veugelers, 2006; Elking *et al.*, 2022), and of innovation learning in the supply chain (Hazen *et al.*, 2012).

On the one hand, suppliers actively participate in focal firms' innovation activities, and supplier innovation can be transmitted to focal firms through collaborations (Schiele, 2006). Collaborative innovation involved by suppliers can improve innovation quality and speed with fewer costs and facilitates the success of new product development (Menguc *et al.*, 2013;

Johnsen, 2009; Luzzini *et al.*, 2015). However, managing collaborative innovation with suppliers depends on supplier selection and effectively managing their participation in the innovation process (Modi and Mabert, 2007).

On the other hand, focal firms actively absorb upstream innovation, thereby enhancing their product and process innovation (Wagner, 2012; Narasimhan and Narayanan, 2013; Trautrims *et al.*, 2017). Pihlajamaa *et al.* (2019) proposed a stimulation model for supplier innovation explaining how a focal firm enhances the suppliers' innovativeness, guides the suppliers' innovation process, and encourages the suppliers to share innovations and creativity. Although firms tend to select high-innovation suppliers, the effective absorption of supplier innovation by focal firms depends on the involved operational complexity.

The impact of supplier innovation on the focal firm's innovation performance is shaped by various factors within the supplier base. For instance, Elking *et al*. (2022) explored how geographical distance, financial interdependence, and technical similarity influence the connection between supplier innovation and a buyer firm's innovation outcomes. Additionally, Oke *et al*. (2013) suggested that a strong innovation climate and strategic relationships can amplify the positive effects of supplier innovation on a firm's performance. However, the combined impact of structural and relational factors within the supplier-base on the link between supplier-base innovation and a firm's innovation performance remains underexplored.

2.2 Customer-base characteristics

The customer-base refers to the principal customers who have established direct business connections with the focal firm. Downstream customers are an important source of focal firms' innovation. However, their role differs from upstream suppliers' (Roy and Sivakumar, 2010;

Cui and Wu, 2016; Hora and Dutta, 2013). Compared with the upstream, customer firms are closer to the market and have more demand knowledge (Taghizadeh *et al.*, 2018). Customer firms work as intermediaries in the value chain from the material supply to the end-user demand. They have more knowledge about product usage that must be converted into the new product design to support the focal firm's innovation generation (Roy and Sivakumar, 2010). Therefore, we consider downstream customer characteristics as potential factors influencing the focal firm's innovation generation, mirroring the counterpart effect of upstream characteristics.

2.2.1 Customer-base geographical distance

Customer-base geographical distance means the average geographical distance between principal customers in the customer-base and focal firms. Geographical distance affects the effectiveness and efficiency of knowledge transfer and also determines the cost of collaborative innovation to a great extent (Presutti *et al.*, 2011; Bindroo *et al.*, 2012). Two contradictory views on the relationship between customer-base distance and firm innovation come up in the literature (Chu *et al.*, 2019; Bindroo *et al.*, 2012; Presutti *et al.*, 2019; Wei and Sheng, 2023). Some studies suggest that close geographical proximity of the customer-base to the focal firm is conducive to information sharing and knowledge transfer, thereby promoting firm innovation. For example, Chu *et al.* (2019) argue that customer-base geographical proximity facilitates firm innovation through feedback and demand channels. Specifically, downstream feedback generates and transmits tacit knowledge, which is crucial to firm innovations. The demand volume is related to transaction costs constrained by geographical distance; thus customer proximity motivates firm innovation through increased demand scale. Similarly, Bindroo *et al.* (2012) suggested that customer-base geographical distance is negatively correlated with the

focal firm's innovation speed and radical innovation. The logic behind this argument is that more timely and frequent information sharing and (tacit) knowledge transfer accelerates the speed of (radical) innovation, as more face-to-face interactions come up in a setting of close geographical proximity. However, Corrocher *et al.* (2009) found that the customer-base distance is not significantly related to product innovation of the focal firm. Presutti *et al.* (2019) argued that small geographical distance of the customer-base impairs firm innovation. The reason is that local interactions brought by close geographical proximity cause a lock-in effect, isolating more geographically distant external resources and deteriorating interorganizational learning. Based on the knowledge-based view and transaction cost theory, Wei and Sheng (2023) suggested an inverted U-shaped relationship between customer-base geographical distance and innovation performance because a distant customer-base brings diverse knowledge for the focal firm but also goes with high costs in collaborative innovation. In a nutshell, the relationship between customer-base geographical distance and innovation performance is still inconclusive.

Relational and capability factors can influence how customer-base geographical distance affects innovation performance. For example, Wei and Sheng (2023) found that customer concentration can weaken the inverted U-shaped relationship between customer-base geographical distance and innovation performance. Similarly, Chu *et al*. (2019) observed that customer innovation and business concentration positively influence the benefits of close customer proximity on supplier innovation. However, exploring the combined effects of geographical distance and other relational and capability factors on innovation is limited. Given the inconclusive findings and the lack of studies on these interaction effects, further research on the impact of customer-base geographical distance on innovation performance in a

configurational approach is required.

2.2.2 Customer-base business concentration

Customer-base business concentration is denoted by the share of focal firms' sales to principal customer firms in the customer-base. The higher the share of sales to the customer-base in total sales of the focal firm, the higher the customer-base business concentration. Customer-base business concentration influences the focal firm's independence and the customer-base's bargaining power (Kamath and Liker, 1990; Pan *et al.*, 2020; Jean *et al.*, 2012). As mentioned above, concentration is a double-edged sword. Some studies suggest that high customer-base business concentration favors firm innovation (Kamath and Liker, 1990; Krolikowski and Yuan, 2017). On the one hand, firms with high customer-base business concentration are less independent and tend to increase investment in specific assets and R&D (Cohen and Frazzini, 2008; Krolikowski and Yuan, 2017). On the other hand, high customer-base business concentration means high switching costs to find new customers, which motivates focal firms to invest more in R&D to pursue premium and plentiful innovation outputs (Krolikowski and Yuan, 2017).

However, other studies suggest that an intensively concentrated customer-base may negatively impact firm innovation (Pan *et al.*, 2020; Kim and Zhu, 2018). High customer-base concentration brings in its wake heavy customer switching costs and operational risks, resulting in declined willingness and capability to invest in innovation activities. In addition, high customer-base concentration enhances customers' bargaining power, which leads to hold-up problems. The hold-up costs brought by a highly concentrated customer-base can outweigh the benefit of economies of scale (this is for example the case in a Chinese context, Pan *et al.*,

2020).

These inconclusive findings mentioned earlier may stem from the impact of various organizational or customer-related factors. For example, Kim and Zhu (2018) explored how network centrality and interconnectedness affect the relationship between supplier dependence and R&D intensity. Similarly, Pan *et al*. (2020) suggested that major customer stability influences the link between customer concentration and corporate innovation. Despite these insights, the role of structural and capability factors within the customer base in shaping the relationship between customer concentration and innovation performance remains largely unexplored. The conflicting perspectives and uncertainty surrounding this relationship suggest the need for a more open and nuanced examination of customer-base business concentration's impact on innovation performance.

2.2.3 Customer-base innovation

Customer-base innovation measures the average level of innovation in the customer base. The impact of customer innovation on firm innovation has been studied from different theoretical perspectives (Pihlajamaa *et al.*, 2019; Desouza *et al.*, 2008; Nambisan and Nambisan, 2008; Li *et al.*, 2018; Jean *et al.*, 2012). Based on organizational learning, focal firms learn from innovative customers in a process in which knowledge acquisition, assimilation and transformation generate more knowledge resources, thereby improving innovation performance (Jean *et al.*, 2012; Pihlajamaa *et al.*, 2019). From the perspective of knowledge spillovers, innovative customers tend to provide market knowledge, demand information and usage ideas to focal firms. Thus, downstream knowledge has a positive spillover effect along the supply chain, contributing to the firm’s innovation performance (Li *et al.*, 2018). From the

innovation diffusion perspective, focal firms can obtain application feedback on new technologies from innovative customers, which establishes a reverse mechanism of downstream innovativeness to motivate upstream innovations (Aversa *et al.*, 2015).

While customer innovation has the potential to enhance a firm's innovation efforts, inter-organizational relationships can limit the impact of this innovation on the firm's overall performance (Nambisan and Nambisan, 2008). Oke *et al*. (2013) suggested that strategic relationships with customers can modify how customer-base innovation affects a firm's innovation outcomes. Beyond relational dynamics, structural factors within the customer base may also play a role in shaping this relationship. However, within the SRC framework, the combined influence of customer innovation, along with structural and relational factors, on a firm's innovation remains underexplored.

2.3 Research framework

Based on the above insights on the influence of geographical distance, business concentration, and partner innovation of both the upstream and downstream segments on focal firms' innovation, this study focuses on answering two questions.

Research question 1: Are, and to what extent, geographical distance, business concentration, and partner innovation of both the upstream and downstream segment of the supply chain necessary for firms to achieve high innovation performance?

Research question 2: How do geographical distance, business concentration, and partner innovation of both the upstream and downstream segments interplay to help focal firms achieve high innovation performance?

Since the literature is not clear on the individual role of these characteristics and remains

limited regarding the interplay between these characteristics, we will in a rather exploratory way investigate associations between these characteristics in both ends of supply chains and firm-level innovation performance. Utilizing insights from the supply chain collaboration literature and the SRC framework, we illustrate the theoretical framework in Figure 1.

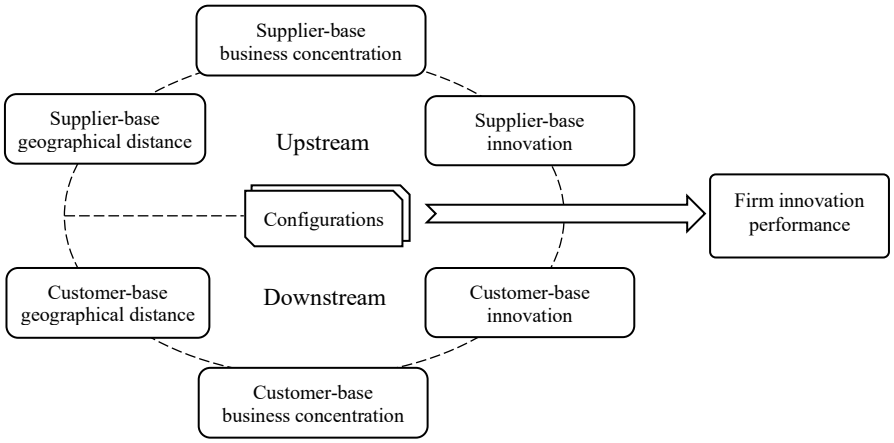


Figure 1 Theoretical framework

3. Methodology

The non-linear relationship and interaction between many variables cannot be tested in traditional regression techniques due to too low degrees of freedom or multilinearity in multiple econometrics analysis (Vis, 2012). Therefore, we rely on necessary condition analysis and fuzzy-set qualitative comparative analysis.

3.1 NCA and fsQCA

Necessary causality denotes that if a specific condition is not present, the outcome will not exist (Dul *et al.*, 2016). Necessary condition analysis (NCA) methods are used to identify necessary but insufficient conditions for a desired outcome and test their statistical significance (Dul *et al.*, 2020). The advantage of NCA is that it can identify whether a condition is necessary at a statistical significance level and examine the extent to which this condition is necessary for the outcome. Therefore, we first use R software to implement NCA to identify whether a

single supply chain characteristic is necessary for high firm-level innovation performance through testing the statistical significance. Secondly, the bottleneck technique is employed to measure which level of the necessary conditions is needed for high innovation performance.

Sufficient causality denotes that if a specific condition exists, the outcome will inevitably exist; if this condition does not exist, the outcome may also exist (Dul *et al.*, 2016). Fuzzy-set qualitative comparative analysis (fsQCA) is a set-theoretic technique that uses Boolean algebra, counterfactual analysis, and logistic minimization to analyze causal complexity (Ragin, 2008). The general fsQCA is apt for analyzing cross-sectional data. Unlike the marginal effect of the regression method, fsQCA analyzes the complex causality between the interplay of multiple conditions and the outcome in a configuration approach (Fiss, 2007). In addition, fsQCA combines the advantages of qualitative and quantitative analysis without the missing variable bias, and there is no need to consider control variables (Fainshmidt *et al.*, 2020). Therefore, this method is suitable for exploring the complex causality between supply chain characteristics and firm innovation performance. fsQCA also identifies the necessary causality, but it cannot test the statistical significance or measure the necessary causality level. Thus, we combine NCA and fsQCA to test the necessary causality and mutually validate the results. In addition, we use R software to implement fsQCA to identify potential configurations in which characteristics of the supplier-base and the customer-base jointly promote firm innovation.

3.2 Sample and data

As a target population, Chinese high-tech manufacturing firms are selected to test the conjunctural effect of supply chain base characteristics on firm innovation performance. The rationale for this choice is twofold. Firstly, China is an emerging economy with a mature

manufacturing sector, offering (to some extent) a valuable benchmark for other emerging economies. Secondly, Chinese high-tech manufacturing firms boast complete supply chains spanning from raw materials to final products, with a strong incentive to engage in collaborative efforts within their supply chains. The sample of this study consists of Chinese firms in the high-tech manufacturing sector listed on the Shanghai and Shenzhen stock exchanges in 2016. We focus on the year 2016 for three reasons. First, China's macroeconomic situation was stable without systematic fluctuation in China in 2016. Second, while analyzing supply chain data during 2011-2019, we found that the data in 2016 exhibited the highest quality in terms of sample size and industry diversity. Moreover, the panel dataset from 2011 to 2019 is strongly unbalanced, such that the within consistency index in panel fsQCA might have low validity and reliability. Therefore, we adopt cross-sectional fsQCA rather than panel fsQCA. Third, the industry distribution of sample firms in 2016 appears more random based on statistical examinations. In general, sample firms are growth-oriented and middle-aged, with an average growth rate of assets at about 33% and an average age of about 18 years. These are also large and innovation-orientated Chinese firms with an average number of employees reaching about 3360, and an average R&D intensity at about 3.81%.

Since supply chain characteristics are conditions, we first clarify their measurement. As mentioned above, this study measures supply chain characteristics at the supplier-base and customer-base level. Following the operationalization of Han *et al.* (2022) and Yang *et al*. (2023), we selected the largest five suppliers and customers in terms of the transaction volume as the supplier-base and customer-base, respectively. These suppliers and customers primarily consist of not publicly listed companies.

Supplier - focal firm - customer relationships came from the China Stock Market and Accounting Research (CSMAR) database. We screened the sample data as follows. First, we focused on the high-tech manufacturing industry including industry codes C25-C41, except for C30 and C33[1]. Second, we excluded companies that disclose fewer than five suppliers and customers and unrecognizable supplier or customer names. Third, we exclude companies with special treatment (ST) (i.e., firms facing a high probability of delisting because of consistent loss) and companies with an asset-liability ratio greater than 1. Fourth, we excluded companies with cross-border supply chain partners because crossing borders creates cultural, economic and political barriers to supply chain operations (Bray *et al.*, 2019). Finally, we got 123 listed companies and their supply chain data.

We obtained the geographical location of focal firms from CSMAR and manually collected the addresses of suppliers and customers in the Qichacha system (https://www.qcc.com/), a convincible and popular tool to search enterprises' credit information. We developed an algorithm program to obtain the latitude and longitude of suppliers' and customers' addresses. The data on supply chain concentration come from the purchase share in CSMAR. Based on Chu *et al*. (2019) and Sharma *et al*. (2020) caring about the innovation output，we operationalized innovation with patent data. The data of supplier and customer innovation were based on the patent search and analysis database of the China National Intellectual Property Administration (CNIPA). The data of the focal firm innovation performance came from the Chinese Research Data Service Platform (CNRDS).

3.3 Variable measurements

3.3.1 Conditions

Geographical distance. The geographical distance between the supplier/customer and the focal firm is calculated using the earth's great circle distance formula based on the latitude and longitude. The formula is as follows:

$$GD = 6378 \times arccos\left[sin(lat_f) * sin(lat_{s/c}) + cos(lat_f) * cos(lat_{s/c})\, cos(lon_{s/c} - lon_f)\right] \quad (1)$$

where lat_f、lon_s are the latitude and longitude (in radians) of the focal firm address; $lat_{s/c}$、$lon_{s/c}$ are the latitude and longitude (in radians) of the supplier/customer address, respectively. The corresponding radians are obtained by dividing the longitude and latitude by 180/π. Supplier-base and customer-base geographical distance are measured as the average distance to suppliers within the supplier-base and customers within the customer-base, respectively.

Business concentration. We took the Herfindahl-Hirschman Index (HHI) of the largest five suppliers and customers measures supplier-base and customer-base business concentration, respectively. Concentration was calculated as follows:

$$Concentration_{it} = \sum_{j=1}^{J}\left(\frac{Purchase/Sales_{ijt}}{Purchase/Sales_{it}}\right)^2 \quad (2)$$

where $Purchase/Sales_{ijt}$ is the sales of company *i* to *j* suppliers/customers (J≤5) in period t, and $Purchase/Sales_{it}$ is the total purchase/sales of company *i* in period *t*.

Partner innovation. To measure supplier or customer innovation, we used the total number of patent applications regardless of granting status (Liang *et al*., 2024; Yang *et al*., 2010; Ahuja and Katila, 2001). This approach provides a more immediate and comprehensive assessment of a firm's innovation efforts (Griliches *et al*.,1986). Supplier-base and customer-base innovation are measured as the average number of patent applications of suppliers within the supplier-base and customers within the customer-base, respectively.

3.3.2 Outcome

Firm innovation performance. Innovation performance can be measured through patents and new products. However, due to the difficulty of obtaining comprehensive data on new products across different industries, patent-based measures are often more practical and reliable (Sharma *et al*., 2024). We used the number of patent applications regardless of granting status as an indicator of firm innovation performance (Liang *et al*., 2024; Yang *et al*., 2010; Ahuja and Katila, 2001). While some studies have measured innovation performance using the total number of patents granted (Bellamy *et al*., 2014; Sharma *et al*., 2020), these measures, although reflecting confirmed and legally protected innovations, often involve lengthy approval processes that delay the assessment of innovation. In contrast, the total number of patent applications captures both successful and ongoing innovation activities, providing a more timely and comprehensive indicator of a firm's inventive output (Griliches *et al*., 1986). As a robustness check, we used the number of patents granted as an alternative outcome variable.

3.4 Calibration

Calibration is the first step in qualitative comparative analysis. The direct calibration method is based on statistical principles with high objectivity (Ragin, 2008). Thus, using the direct method, we calibrated the six conditions and one outcome as fuzzy-set data. Due to a lack of theoretical and practical evidence, we followed existing studies to set calibration thresholds (Fiss, 2011; Fainshmidt *et al.*, 2019). Because the data of the innovation variable is seriously left-skewed, in line with Pappas *et al.* (2017), we set the 75th percentile and 25th percentile as the fully in and fully out thresholds of set membership, respectively, and the mean of these two values as the crossover point. For other variables, we set the 75th percentile, median, and 25th percentile as the fully in, crossover and fully out thresholds of the set membership, respectively.

The descriptive statistics, calibration thresholds and rationale are presented in Table 1.

Table 1 Descriptive statistics, calibration thresholds and rational

Conditions & outcome	*Descriptive statistics*				*Calibration anchors*			*Calibration rational*
	Min	*Mean*	*Max*	*SD*	*In*	*Crossover*	*Out*	
Supplier-base geographical distance *supdis*	2.576	609.202	1764.672	411.251	849.241	536.083	301.983	Data distribution. 75th percentile, median, and 25th percentile as the fully in, crossover, and fully out anchors
Supplier-base business concentration *supcon*	0.001	0.076	0.867	0.133	0.078	0.024	0.011	Data distribution. 75th percentile, median, and 25th percentile as the fully in, crossover, and fully out anchors
Supplier-base innovation *supino*	0.000	120.358	3303.000	423.055	61.000	30.750	0.500	Data distribution with a negative skewness. 75th percentile and 25th percentile as the fully in and fully out anchors. Mean of the 75th percentile and 25th percentile as the crossover anchor
Customer-base geographical distance *cusdis*	6.579	808.622	3339.137	498.309	1031.869	734.303	460.517	Data distribution. 75th percentile, median, and 25th percentile as the fully in, crossover, and fully out anchors
Customer-base business concentration *cuscon*	0.001	0.042	0.547	0.067	0.056	0.017	0.006	Data distribution. 75th percentile, median, and 25th percentile as the fully in, crossover, and fully out anchors
Customer-base innovation *cusino*	0.000	385.528	8798.000	1163.002	212.500	106.500	0.500	Data distribution with a negative skewness. 75th percentile and 25th percentile as the fully in and fully out anchors. Mean of the 75th percentile and 25th percentile as the crossover anchor
Firm innovation performance *firino*	0.000	15.512	176.000	31.495	15.000	7.500	0.000	Data distribution with a negative skewness. 75th percentile and 25th percentile as the fully in and fully out anchors. Mean of the 75th percentile and 25th percentile as the crossover anchor

4. Empirical analysis

4.1 Analysis of necessary conditions

We comprehensively judged the necessity of conditions considering the effect size, statistical significance, and bottleneck level. In the NCA technique, the effect size range is [0,1], and the effect increases as the value increases. The p-value of the effect size is calculated by a permutation test based on Monte Carlo simulation. Both ceiling envelopment (CE) and ceiling regression (CR) techniques are employed to estimate the effect size.

The results of the necessary condition analysis are shown in Table 2. When the effect size is higher than 0.1 and the significance (p-value) is less than 0.05, we considered this condition necessary for the outcome (Dul, 2016; Dul *et al*., 2020). The effect size of supplier-base geographical distance, supplier-base business concentration, supplier-base innovation, customer-base business concentration and customer-base innovation are insignificant ($p>0.05$), indicating that these conditions are not necessary for firm innovation performance. Although the effect size of customer-base geographical distance is significant ($p<0.05$), the effect size is small (far less than 0.1). Therefore, customer-base distance as well is not a necessary condition for firm innovation performance.

Table 2 Separate necessary conditions analysis based on NCA

Conditions	*Method*	*c-accuracy*	*Ceiling zone*	*Scope*	*Effect size*	*p-value*
supdis	CR	100%	0.000	0.949	0.000	1.000
	CE	100%	0.000	0.949	0.000	1.000
supcon	CR	100%	0.000	0.945	0.000	0.513
	CE	100%	0.000	0.945	0.000	0.509
supino	CR	100%	0.000	0.904	0.000	1.000
	CE	100%	0.000	0.904	0.000	1.000
cusdis	CR	99.2%	0.002	0.950	0.002	0.114
	CE	100%	0.003	0.950	0.003	0.045
cuscon	CR	100%	0.000	0.937	0.000	1.000
	CE	100%	0.000	0.937	0.000	1.000
cusino	CR	100%	0.000	0.903	0.000	1.000
	CE	100%	0.000	0.903	0.000	1.000

Note: We use calibrated variables to conduct analyses; Permutation test generates 10000 random samples; CE is a piecewise linear line on the basis of data envelopment analysis (DEA) techniques. CR is a continuous linear line (OLS regression line) on the basis of the outcomes of a CE analysis (CE with varying return to scale or CE with free disposal hull).

In addition, we used the CR with free disposal hull (CR-FDH) technique to analyze the bottleneck level of each condition. The bottleneck level refers to 'for which level of outcome, which level of a condition is necessary' (Dul, 2016). As Table 3 shows, only supplier-base business concentration (*supcon*) and customer-base geographical distance (*cusdis*) have bottlenecks. Specifically, *supcon* must be ≥ 0.4 for a desired outcome of *firino* = 1. *cusdis* must be ≥ 0.1 for a desired outcome of *firino* = 0.4. Similarly, *cusdis* must be ≥ 0.2 for 0.5 ≤ *firino* ≤ 0.6; cusdis must be ≥ 0.3 for 0.7 ≤ *firino* ≤ 0.8; *cusdis* must be ≥ 0.4 for 0.9 ≤ *firino* ≤ 1. These specific thresholds of *supcon* and *cusdis* help mangers understand the minimum requirements that must be met to achieve specific outcomes.

Table 3 NCA bottleneck level for single necessary conditions

firino	*supdis*	*supcon*	*supino*	*cusdis*	*cuscon*	*cusino*
0	NN	NN	NN	NN	NN	NN
0.1	NN	NN	NN	NN	NN	NN
0.2	NN	NN	NN	NN	NN	NN
0.3	NN	NN	NN	NN	NN	NN
0.4	NN	NN	NN	0.1	NN	NN
0.5	NN	NN	NN	0.2	NN	NN
0.6	NN	NN	NN	0.2	NN	NN
0.7	NN	NN	NN	0.3	NN	NN
0.8	NN	NN	NN	0.3	NN	NN
0.9	NN	NN	NN	0.4	NN	NN
1	NN	0.4	NN	0.4	NN	NN

Note: The CR with free disposal hull (CR-FDH) technique is used; NN= Not Neccesary

We also used the fsQCA method to identify potential necessary conditions; the results are shown in Table 4. The range of consistency is [0.471, 0.642]. The consistency level of single supply chain characteristics for high firm innovation performance is low (consistency < 0.9). Thus, no singly supply chain characteristic is necessary for high firm innovation performance. In a nutshell, the fsQCA confirms the results of NCA with regard to the necessity test.

4.2 Analysis of sufficient conditions

In line with prior studies, we set the raw consistency threshold at 0.75, the PRI consistency threshold at 0.7, and the case frequency cut-off at 2 (Ragin, 2008; Tekic and Tekic, 2021; Xie and Wang, 2020). According to previous studies, supplier-base and customer-base innovation

are conducive to firm innovation performance (Solaimani and van der Veen, 2022; Narasimhan and Narayanan, 2013; Pihlajamaa *et al.*, 2019). Therefore, in the counterfactual analysis, we assume that the presence of supplier-base and customer-base innovation can contribute to high firm innovation performance regardless of impacts of the other four conditions.

Table 4 Necessity analysis in fsQCA

Conditions	Consistency	Coverage
supdis	0.545	0.483
~supdis	0.546	0.471
supcon	0.471	0.417
~supcon	0.642	0.554
supino	0.550	0.554
~supino	0.559	0.432
cusdis	0.552	0.486
~cusdis	0.560	0.486
cuscon	0.538	0.482
~cuscon	0.589	0.502
cusino	0.536	0.660
~cusino	0.559	0.379

According to the methodological practice, we analyzed the conjunctural causality based on the intermediate solution, and then identified the core or peripheral conditions by combining the parsimonious solutions[2]. The configurations generated in both parsimonious solutions and intermediate solutions include core conditions, and the remaining conditions in intermediate solutions are deemed as peripheral conditions (Ragin, 2008; Fiss, 2011). According to the strength of the evidence relative to the outcome, a core condition plays a decisive role in the presence of the outcome and a peripheral condition only has a supporting role.

Table 5 shows that three sufficient configurations can lead to high firm innovation performance. Customer-base innovation exists in the three paths as a core condition, indicating the importance of customer-base innovation to the focal firm's innovation performance. Absence of high supplier-base geographical distance is also present in the three paths, indicating that more geographical proximity of the supplier-base benefits firm innovation performance. The bottleneck levels of supplier-base business concentration and customer-base

geographical distance as possible necessary conditions have to be considered in elaborating upon the three sufficient configurations.

Table 5 Sufficient configurations for high firm innovation performance

Casual conditions	High firm innovation performance		
	A	B	C
Upstream			
Supdis	⊗	⊗	⊗
supcon	⊗	⊗	●
Supine	●		⊗
Downstream			
Cusdis	●	●	⊗
cuscon		●	●
Cusino	●	●	●
Consistency	0.874	0.941	0.921
Raw coverage	0.110	0.105	0.118
Unique coverage	0.034	0.023	0.081
Overall consistency		0.881	
Overall coverage		0.221	

Note: Black circles indicate the presence of a condition, and circles with "×" indicate its absence. Large circles indicate core conditions; smaller ones indicate peripheral conditions. Blank spaces indicate irrelevant conditions.

Configuration A shows that the absence of high supplier-base geographical distance and business concentration, the presence of high supplier-base innovation, high customer-base geographical distance and high customer-base innovation, regardless of high or low customer-base business concentration, combinedly lead to high firm innovation performance. This path features the absence of supplier-base geographical distance and supplier-base business concentration and the presence of customer-base innovation as core conditions. It is worth noting that supplier-base business concentration must reach a specific bottleneck before expecting the highest innovation performance to occur, regardless of other favorable conditions. We name this configuration as "*innovation-driven*". This configuration exhibits a fairly high level of consistency (0.87) and covers 11% of the membership in the outcome. In other words,

when supplier-base geographical distance and business concentration are not high, customer-base geographical distance and innovation can facilitate the focal firm's innovation activities. Meanwhile, an innovative supplier-base meets the resource needs of focal firms to innovate. This configuration evidences the combined role of both ends of the supply chain rather than only the upstream or downstream segments.

Configuration A confirms insights from the downstream part of the supply chain as described in the literature overview. Some studies argue that downstream customers' knowledge is central to innovation generation (e.g., Pihlajamaa *et al.*, 2019; Li *et al.*, 2017), partly because relying on customers leads to more market knowledge (Greer and Lei, 2012). However, empirical evidence shows that relying too heavily on customers may harm innovation because over-embeddedness prevents firms from searching for new directions (Tomlinson and Fai, 2016). A high search breadth in relation to external knowledge sources (e.g., search from distant customers) can offset the negative results of relying heavily on customers (Laursen, 2011). Configuration A also confirms insights from the upstream in the literature. Supplier geographical distance is negatively associated with the firm's innovation performance (Sharma *et al.*, 2020; Pillai and Bindroo, 2020); Supplier business concentration also negatively relates to the firm's innovation performance (Sako *et al.*, 2016). This confirms their core role in high innovation performance. Eliking *et al.* (2022) hypothesized that supplier innovation and geographical proximity can mutually support firm innovation, proved by Configuration A.

There are two representative companies figuring in Configuration A. For example, Company X covered by Configuration A centers on the manufacturing of connectors and related parts and is active in the sectors of rail transit, vehicle and special equipment. Company X establishes strategic partnerships with innovative customers (e.g., communication equipment and automobile manufacturer) at an average distance of about 750 km and embeds supply chain

relationships to a slight degree (the average purchase share of the five largest suppliers is only about 14%) with innovative material providers nearby (about 370 km away). The company takes advantage of the pulling of customers' needs for innovations and the push of suppliers' innovation of materials and parts.

Configuration B shows that the absence of high supplier-base geographical distance and business concentration, the presence of high customer-base geographical distance, business concentration and innovation, regardless of high or low supplier-base innovation, can lead to high firm innovation performance. This configuration features the absence of supplier-base geographical distance and business concentration and the presence of customer-base geographical distance and innovation as core conditions, with customer-base business concentration as an additional peripheral condition. Supplier-base business concentration at low/medium level must reach specific bottleneck thresholds to achieve the highest firm innovation performance. This configuration can be named as "*customer-dominated*". Both the solution coverage (0.11) and consistency (0.94) indicate that this configuration systematically leads to high firm innovation performance. This configuration stresses the leading role of the customer-base. Limited supplier-base geographical distance and business concentration, combined with greater customer-base geographical distance, business concentration and innovation can be associated with strengthened focal firm innovation performance. This finding reveals that the customer-base guides the innovation activities of the focal firm through its innovation and relational dominance (Chu *et al.*, 2019), but only in a supplier-base constellation characterized by close geographical proximity and limited business concentration. Configuration B confirms the driving role of customer innovation regardless of the level of supplier innovation (Laursen, 2011), the dark sides of geographical proximity (Presutti *et al.*, 2019), the supportive role of customer concentration in alleviating the proximity-innovation paradox (Wei and Sheng, 2023), and the mutual support between geographical proximity and

business concentration of suppliers in relation to the increase of diverse resources and the reduction of search costs (Pillai and Bindroo, 2020).

Two companies represent Configuration B. As an example, we take Company Y with its principal suppliers all located in the home city. The purchase business is relatively dispersed, because the total purchase share from the five largest suppliers accounts for only one fourth of the annual total purchase. Its principal customers are large automobile manufacturers with excellent innovation capabilities, and they are located in the east and northeast regions of China, far away from its home city at an average distance of more than 1800 km. Moreover, the sales to its five largest customers accounts for three fifths of the annual sales in total. Highly concentrated customer relationships and stable needs for innovation from customer firms, accompanied by the low cost the crowded and diverse suppliers bring, encourage focal firms to increase R&D investment and generate more innovation outcomes.

Configuration C shows that the absence of high supplier-base geographical distance, high supplier-base innovation and high customer-base geographical distance, and the presence of high supplier-base and customer-base business concentration and high customer-base innovation, configurationally lead to high firm innovation performance. Among these conditions, the absence of supplier-base innovation, presence of customer-base business concentration and customer base innovation are core conditions. Customer-base geographical distance at low/medium level must reach specific bottleneck thresholds to achieve the desired innovation performance. We name this configuration as "*relationship-driven*". This solution presents a high level of consistency (0.92) and covers about 12% of the membership in the outcome. This configuration highlights the advantage of the concentrated relationships along supply chains (upstream and downstream). When the supply chain presents a limited geographical centralization and the innovation capability, and business concentration of the customer-base is high, focal firms are pushed to increase investment to satisfy the innovation

needs from the downstream. In this configuration, relational assets brought by the concentrated supply chain, accompanied by high customer innovation and limited supplier innovation, seem to facilitate innovation activities (Chen *et al.*, 2022). In a concentrated supply chain (supplier - focal firm - customer), in terms of both relationship and location, the effect of learning by supply from the upstream would be damaged by the lock-in issue in a more concentrated relationship from the downstream (Hsu *et al.*, 2022). Under this situation, a high level of customer innovation and a limited level of supplier innovation can stimulate technology spillover along the supply chain (Hsu *et al.*, 2022), thereby facilitating the focal firm's innovation performance.

There are four representative companies covered by Configuration C. For example, Company Z's purchases from the five largest suppliers account for a little over half of the total purchase, while the sales to the five largest customers account for three fifths of the total sales. In addition, its supplier-base and customer-base are about 520km away on average. In this constellation, its principal customer firms are innovative pharmaceutical firms, and supplier firms are not so innovative, belonging to traditional manufacturing sectors, which stimulate technology spillover and facilitate innovation along the supply chain.

We also investigate sufficient configurations for the negation of high firm innovation performance (i.e., the low/medium firm innovation performance). Three sufficient configurations in Table 6 are identified with an overall coverage of 0.35 for low/medium firm innovation performance. Upon comparing configurations associated with high and low/medium innovation performance, we observe no mirror opposites among the identified configurations, aligning with the asymmetry principle. Notably, configurations favoring high firm innovation performance entail a combination of the absence of high supplier-base geographical distance and the presence of high customer-base innovation. Configurations linked to low/medium firm innovation performance consistently involve greater supplier-base

business concentration and limited customer-base innovation. This underscores the significant role of customer innovation in driving firm-level innovation. However, high supplier-base business concentration and limited customer-base innovation are insufficient individually. They are found to be sufficient only when combined with specific conditions, such as high supplier-base geographical distance and high customer-base business concentration (Configuration D); limited supplier-base geographical distance, limited supplier-base innovation, and limited customer-base geographical distance (Configuration E); high supplier-base geographical distance, high supplier-base innovation, and limited customer-base geographical distance (Configuration F).

Table 6 Sufficient configurations for low/medium firm innovation performance

Casual conditions	Low/medium innovation performance		
	D	E	F
Upstream			
Supdis	●	⊗	●
supcon	●	●	●
Supine		⊗	●
Downstream			
Cusdis		⊗	⊗
cuscon	●		
Cusino	⊗	⊗	⊗
Consistency	0.803	0.847	0.773
Raw coverage	0.169	0.105	0.118
Unique coverage	0.112	0.154	0.020
Overall consistency		0.829	
Overall coverage		0.350	

Note: Black circles indicate the presence of a condition, and circles with "×" indicate its absence. Large circles indicate core conditions; smaller ones indicate peripheral conditions. Blank spaces indicate irrelevant conditions.

4.3 Robustness checks

We conduct additional analyses to ensure the robustness of our conclusions. First, a t-test was conducted to alleviate the concern of selection bias in the sample. We found that the means of

firm innovation performance in the group with excluded firms and the retained sample is not significantly different (H: difference=0, p=0.780). Second, we changed the fuzzy score that equals 0.5 after calibration to 0.499 (Fainshmidt *et al.*, 2019). We also excluded CSA from the logistic minimization, and the main results are unchanged (see Table 7).

Table 7 Enhanced solutions after excluding CSA (change the fuzzy score 0.5 into 0.499)

Casual conditions	High firm innovation performance			
	G	H	I	J
Upstream				
Supdis	⊗	⊗	⊗	●
supcon	⊗	⊗	●	⊗
Supine	●		⊗	●
Downstream				
Cusdis	●	●	⊗	⊗
Cuscon		●	●	●
Cusino	●	●	●	●
Consistency	0.874	0.941	0.921	0.963
Raw coverage	0.110	0.105	0.118	0.095
Unique coverage	0.034	0.023	0.074	0.040
Overall consistency	0.888			
Overall coverage	0.261			

Note: Black circles indicate the presence of a condition, and circles with "×" indicate its absence. Large circles indicate core conditions; smaller ones indicate peripheral conditions. Blank spaces indicate irrelevant conditions.

Third, we changed the calibration method: the fully in, crossover, and fully out thresholds of the innovation variable were reset as the 75% percentile, median, and 25% percentile of the membership, respectively; the fully in, crossover and fully out thresholds of the remaining variables are reset as the 95% percentile, median and 10% percentile of the membership respectively. The results remained consistent (see Table 8). Fourth, we used the number of granted patents as an alternative outcome variable. We found largely consistent sufficient configurations. Fifth, we took a one-year lag for firm innovation performance to address potential simultaneity. Only two configurations – similar to Configurations A and B in the main

analysis - are identified in relation to high lagged firm innovation performance. Sixth,we utilized the 2015 dataset, which includes 93 firms out of the sample of 123 firms in the main analysis, to identify sufficient configurations, and the results were highly consistent. Similarly, we also analyzed the 2017 dataset, comprising 91 firms out of the sample in the main analysis, with 71 firms overlapping between the 2015 and 2017 datasets. We found largely consistent results, particularly with the innovation-driven, customer-dominated, and relationship-driven configurations.. Seventh, we increased the consistency threshold to 0.8 (Fiss, 2011; Tekic and Tekic, 2021), and the results remained completely consistent. Finally, we excluded the contradictory simplifying assumptions (CSA) from the process of logical minimization, and the enhanced solutions stayed unchanged. CSA occurs when the same logical remainder row is included in the logical minimization for the occurrence of the outcome and its non-occurrence (Oana *et al.*, 2021).

Table 8 Sufficient solutions with alternative calibrations

Casual conditions	High firm innovation performance			
	H	I	J	K
Upstream				
Supdis	⊗	⊗	⊗	●
supcon	⊗	⊗	●	●
supino	●		⊗	●
Downstream				
cusdis	●	●	⊗	●
cuscon		●	●	●
cusino	●	●	●	●
Consistency	0.855	0.919	0.922	0.871
Raw coverage	0.162	0.175	0.156	0.154
Unique coverage	0.031	0.022	0.053	0.039
Overall consistency		0.836		
Overall coverage		0.302		

Note: Black circles indicate the presence of a condition, and circles with "×" indicate its absence. Large circles indicate core conditions; smaller ones indicate peripheral conditions. The fully in, crossover, and fully out thresholds of the innovation variable are reset as the 75% percentile, median, and 25% percentile of the membership; the fully in, crossover and fully out thresholds of the remaining

variables are reset as the 95% percentile, median and 10% percentile of the membership. Blank spaces indicate irrelevant conditions.

5. Conclusions

This study adopted necessary condition analysis and fuzzy-set qualitative comparative analysis to explore the combined impact of supplier-base characteristics (geographical distance, business concentration, and innovation) and the counterpart of customer-base characteristics on firm innovation performance. The target population consisted of Chinese firms in the high-tech manufacturing industry.

We found that single supply chain characteristics are not necessary for achieving high firm innovation performance. Bottleneck thresholds of supplier-base business concentration and customer-base geographical distance at low/medium level should be considered in view of high firm-level innovation performance. Configurations of limited supplier-base geographical distance and high customer-base innovation are more likely to be associated with high innovation performance. *Innovation-driven*, *customer-dominated* and *relationship-driven* are three distinct configurations that contribute to high firm innovation performance. The findings highlight that downstream characteristics, especially customer-base innovation, combined with a geographically concentrated supplier-base, are more likely to facilitate firm innovation in the supply chain context. Alternatively, high supplier-base geographical distance and limited customer-base innovation is more likely to lead to low/medium innovation performance. This highlights the significant role of customer innovation in facilitating firm innovation. Our findings emphasize the importance of jointly considering supplier-base and customer-base characteristics and confirm the vital role of customer-base characteristics in firm innovation performance.

Our study contributes to the literature in three ways. First, our findings directly contribute to the operations management field, particularly in supply chain combination studies. Previous research has extensively explored the relationship between partner characteristics at single ends

of supply chains and focal firm innovation (Chen *et al*., 2022; Chu *et al*., 2019; Wagner, 2012). Unlike those studies focusing solely on the separate impact of upstream or downstream characteristics on firm innovation, this study identified multiple combinations of these partner characteristics from both ends of the supply chain, thereby extending the perspective of supply chain combination in innovation studies (Shou *et al*., 2018). Our findings provide evidence of how different combinations and interactions of partner characteristics in the supplier-base and customer-base can better explain high firm innovation performance.

Second, this study contributes to the innovation management literature by exploring the combined antecedents in supply chains, offering a deeper understanding. Previous studies have identified the supply chain characteristics that influence the focal firm's innovation performance, including geographical distance (Wei and Sheng, 2023; Pillai and Bindroo, 2020), business concentration (Sharma *et al*., 2024), and partner innovation (Kibbeling *et al*., 2013). We contribute to the literature by providing profound insights into how the combinations of such supply chain characteristics (SRC framework – Bellamy et al. (2014)) may explain high or low/medium firm innovation performance, transcending the prevalent discussion on the most important factors and the single best solution of symmetric analyses.

Third, most studies employ variance-based methods to examine the impact of supply chain characteristics on firm innovation performance (Sharma *et al*., 2020; Shou *et al*., 2018; Krolikowski and Yuan, 2017). Unlike those methods suggesting symmetric relations among variables, our study combines NCA and fsQCA methods to explore the asymmetric causality between supply chain characteristics and firm innovation performance. This approach allows for the identification of equifinal configurations of a range of supply chain characteristics that can be associated with high firm innovation performance, aligning with the notion that not one solution fits all. By doing so, our study offers deeper insights into the asymmetric relations between configurations of supply chain characteristics and firm innovation performance.

Specifically, the findings reveal three distinct configurations of supply chain characteristics that can produce the same innovation outcome, indicating the asymmetric relations.

This study offers several managerial implications for innovation project managers. First, managers are advised to formulate explicit supply chain strategies to align with the innovation strategy. Our findings suggest that configurations of supply chain characteristics should be matched with specific innovation goals. Supply chain managers should actively adjust and transform the composition of their supply chain partners, combining the upstream and downstream segments, to achieve the desired innovation performance. Second, the innovation of supply chain partners plays a crucial role in facilitating firm innovation. Managers should consider establishing or reconfiguring their supply chain relationships with innovative partners through expanded external collaborations. For example, a firm with clustered suppliers characterized by lower business concentration (reaching a specific threshold) and dispersed customers may focus on meeting market demand at a lower cost. However, such a firm could excel in process or product innovation if its suppliers and customers demonstrate strong innovativeness in developing new products. Third, while customer-base characteristics may appear more prominent in driving firm innovation, the potential role of the supplier-base should not be neglected. Our findings reveal that geographically dispersed innovative customers with high business concentration benefits firm innovation performance. However, clustered suppliers with low business concentration (reaching specific thresholds) also play an essential role in this positive relationship. In a downstream-led supply chain, managers should pay balanced attention to both ends of the supply chain in terms of structure, relationship, and capability. Fourth, managers could consider establishing a concentrated supply chain in terms of business shares to facilitate firm innovation. According to our findings, highly concentrated supplier and customer bases are more likely to facilitate firm innovation, particularly when combined with a clustered supply chain and innovative downstream partners. In a cluster region,

if firms aim to enhance firm innovation with a limited number of less innovative suppliers, they can strategically focus on serving a limited number of innovative customers.

This study has some limitations. First, we selected the largest five suppliers and customers to define the supplier-base and customer-base, respectively. The disadvantage is that relatively few supply chain members embody supply chain characteristics. Future research could investigate supply chain characteristics with more participates and in other contexts than the Chinese one. Second, this study uses cross-sectional data without considering dynamic effects. With high-quality longitudinal data, the panel QCA technique could be used to capture dynamic impact in the future. Third, apart from the supply chain characteristics of structural, relational, and capability dimensions, future research could take other dimensions into consideration, such as network centrality. Fourth, as the propensity of patent applications differs and the value of patents might broadly differ according to the sector, future research could find an alternative proxy of firm innovation performance not based on patent data. Finally, future research can combine fsQCA and case study methods to provide more in-depth insights into the asymmetric relationship between supplier-base and customer-base characteristics in view of firm innovation performance.

Endnotes:

1. The industries in our sample include C25- Petroleum processing, coking and nuclear fuel processing industries, C26-Chemical raw materials and chemical products manufacturing, C27-Pharmaceutical manufacturing, C28-Chemical fiber manufacturing, C29-Rubber and plastic products industry, C31-Ferrous metal smelting and rolling industry, C32-Non-ferrous metal smelting and rolling processing industry, C34-General equipment manufacturing, C35-Special equipment manufacturing, C36-Automotive manufacturing, C37-Railway, ship, aerospace and other transportation equipment manufacturing, C38-Electrical machinery and equipment manufacturing, C39-Computer, communications and other electronic equipment manufacturing, C40-Instrumentation Manufacturing, and C41-Other manufacturing.
2. For reasons of clarity, more explanations for terminology are needed. Counterfactual analysis has advantages in categorizing the causal conditions into core and peripheral causes, but challenged by the problem of limited diversity. Limited diversity refers to “situations in which one or more logically possible combinations of conditions are void of (enough) empirical evidence” (Schneider and

Wagemann, 2013). In fsQCA, this kind of combinations is defined as logical remainders. The conservative solution does not include any of the logical remainders into the minimization, but the parsimonious solution includes all of the logical remainders. The intermediate solution includes the logical remainders that are in line with the proposed directional expectations on single conditions to get the most appropriate solutions for interpretation (Onna *et al.*, 2021).

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