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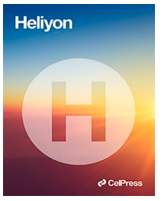

Research article

Will customer change affect enterprise innovation efficiency? A study from the perspective of social networks

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ABSTRACT

An enterprise innovation strategy is the driving force for the healthy and sustainable development of enterprises, and high-quality, efficient innovation is important for improving enterprises' market value and promoting their high-quality development. Customer relationships are an important factor affecting enterprise product technology and enterprise innovation; however, few studies have evaluated the impact of customer change on innovation efficiency. Therefore, from the perspective of social capital, we use China's listed manufacturing companies' data from 2013 to 2020 to systematically examine how customer changes affect enterprise innovation performance, and test the impact of social networks on the relationship between customer change and enterprise innovation efficiency. The empirical research shows that customer change reduces enterprises' innovation efficiency, and that social network relationships have an intermediary effect on the relationship between customer change and innovation efficiency; that is, the social network relationships reduce the negative impact of customer change on enterprise innovation efficiency. Further analysis shows that this mediating effect is not obvious for enterprises experiencing large customer changes but is prominent for nonstate-owned or nontechnology-intensive enterprises. Our study enriches and expands the research on how customer relationships influence enterprise innovation efficiency, clarifies different mechanisms due to various "networks", and provides new empirical evidence to enable enterprises to improve their competitiveness.

1. Introduction

The manufacturing industry is the industrial pillar and material foundation of the national economy and is an important symbol of the national science and technological level and comprehensive national strength, and the leading force of international competition. According to data from the China Statistical Yearbook from 2012 to 2021, the R&D intensity (ratio) of Chinese manufacturing enterprises rose from 0.85 % to 1.54 % or more than 80 % in ten years. The transition from "made in China" to "created in China" was significantly accelerated. An increase in R&D investments has driven the sustainable development of China's manufacturing industry. However, given increasingly limited resources and growing international tensions, various manufacturing enterprises in China seek effective ways to effectively transform R&D investment into innovation results in order to realize value added in a fiercely competitive environment [1–4]. Among them, customers, as an important part of manufacturing companies' supply chain, are directly related to the business performance of these companies [5]. Moreover, the relationships that customers and companies form together have

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become an important social capital for companies [6]. As a result, customer relationships have become an important source of competitive advantage for various organizations and have received increased amounts of attention from scholars.

Existing studies on the economic consequences of customer relationships show that customer concentration has a significant impact on enterprise performance, capital structure, cash holdings and other corporate behaviors [7–12]. Relevant studies have noted that customers' demand for products is an important reason for enterprises to improve their technical levels and promote innovation [13, 14]. Gnyawali and Park (2011) claim that some enterprises have participated in customers' internal technological innovation to enhance their overall competitiveness [15]. Thus, network capital at the supply chain level is formed through long-term, inter-penetrating business activities between firms and their customers, bringing direct or indirect economic value to the firms [16]. Moreover, Ak and Patatoukas have noted that to attract or retain customers, enterprises will increase their investments in innovation [17]. Similarly, Jansen et al. concluded similarly that firms use social capital, such as customers, to gain access to resources such as information on market demand and to incentivize themselves to develop new products and improve their technological capabilities [18]. Other studies have used a static perspective of customer transaction ratios, i.e., customer concentration, to measure customer relationships; however, the conclusions have not been consistent. For example, Ernst et al. note that customer concentration hinders enterprises' investments in innovation from the perspective of financing constraints and operational risks, while Chu et al. note that from the perspective of knowledge sharing, greater customer concentration is associated with greater enterprises technological innovation performance [19,20].

According to these findings, we can intuitively understand the cooperation relationship between the enterprise and the customer and the degree of cooperation; however, this static relationship ignores the dynamic fluctuation of the transaction between the enterprise and the customer - customer changes, which is the main aspect of the business risk. The impact on the development of the enterprise business cannot be ignored. Moreover, how customer change affects enterprise operational behavior is bound to be different from the effects of customer concentration. In addition, Ak and Patatoukas also points out that social capital, which is centered around the customer and the business, also has an impact on business decisions [17]. However, few studies have explored this issue in depth. Based on this, we explore the impact of customer relationships on enterprise innovation efficiency from the perspective of customer change and to discuss the functional mechanism of customer change on enterprise innovation efficiency from the perspective of social network relationships.

Based on the above discussions, we pose three main questions: 1) Are firms that experience customer change less innovatively efficient than firms that do not? 2) Is it true that the greater the customer change is associated with a less innovatively efficient a firm is? and 3) What is the effect of social networks on firms' innovation efficiency? Does it mediate between customer change and innovation efficiency? Therefore, we select a sample of the Chinese manufacturing industry from 2013 to 2020, and propose to address these issues by exploring the impact of customer relationships on firms' innovation efficiency from the perspective of customer change. We also explore the mechanism through which customer change affects firms' innovation efficiency from the perspective of social network relationships. Fig. 1 illustrates the main logical structure of our study.

The contribution of this paper is threefold. First, different from prior studies, that characterize the impact of customer relationships on enterprise innovation from a static perspective, we measure the impact of customer relationships from customer changes and explore the output efficiency of innovation input, shedding new light on the literature on the economic consequences of customer relationships. Second, new empirical evidence is provided on social networks, and the impact of different networks on enterprises is further investigated. Third, by discussing enterprise innovation behavior from the perspective of enterprise heterogeneity, we can help managers allocate resources reasonably according to the nature of enterprise ownership.

The remainder of this paper is organized as follows. Section 2 presents the theoretical analysis and hypothesis development. Section 3 presents the methodology. Section 4 presents our result analysis, section 5 presents the discussion, and section 6 concludes the paper.

2. Theoretical analysis and hypothesis development

Enterprise innovation is the key to sustainable and high-quality enterprise development. Different from other investment activities, innovation activities have the characteristics of a large investment scale, long cycle, high uncertainty, risk points and high adjustment costs. In the early stage of the research, most scholars started with innovation investments, namely, research and development intensity, to explore the factors affecting enterprises' research and development costs, including enterprise scale [21–23], manager

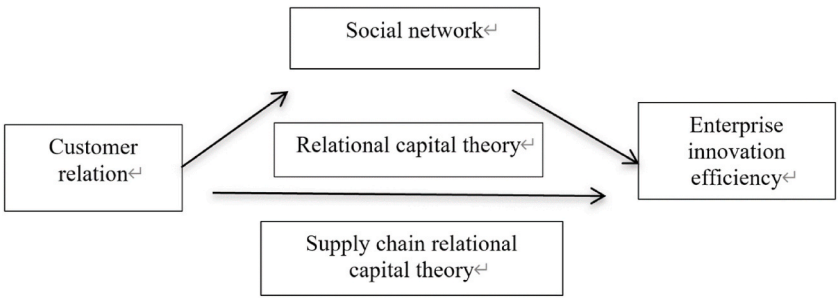

Fig. 1. Logical structure.

behavior [24], financing constraints [25–27], and CEO characteristics [28], etc. As the research deepened, scholars gradually began to pay attention to the scientific and technological achievements produced by innovation investments—the factors influencing innovation performance—and the research results became relatively rich [29–32]. As market competition has increasingly intensified, given the rapid increase in innovation investments, whether the technology level has been significantly improved and how to improve the utilization rate of research and development resources and reduce waste have become hot topics for scholars in recent years [33, 34].

Based on the research purpose of this paper, the relevant literature was screened on the factors influencing innovation efficiency was screened from three aspects, namely, micro enterprise factors, meso market factors and macro institutional factors, as shown in Table 1. Thompson also demonstrates that social capital is a network based on trust that which helps enterprises to identify innovation opportunities and provide scarce resources through the relationship network, providing an adequate resource base for enterprise innovation and stimulating innovative activities [35]. Consequently, exploring the relationships among different forms of social capital, customer relationships, social network relationships and innovation efficiency is necessary to improve the efficiency of enterprise resource utilization and enhance the sustained competitive advantage of enterprises. In light of the above analysis, this paper proposes the first hypothesis.

H1. The innovation efficiency of enterprises experiencing customer change is lower than that of enterprises not experiencing customer change. And the greater the change, the lower the firm's innovation efficiency.

Social capital, as one of the three basic forms of capital, is a collection of resources constituted by social relations and as an intangible asset generated during activities; it can be transformed into economic capital under certain conditions [46,47]. American sociologist Coleman also defined social capital as the social resources owned by individuals and influenced by many factors, such as ideology, the stability of the social structure, government funding, and social network closure [48]. Campbell et al. Lin analyzed social capital from the perspective of social resources, i.e., that social resources are individual resources embedded in social networks composed of social resources. Through the frameworks of classical capital theory and neo-capital theory, they analyse the significance of social capital in the interaction between individual behavior and social structure and put forward the theory of social capital [49–51]. Social capital theory emphasizes the importance of using social connections and social relations to achieve goals. Enterprises' social status and core management team can play a decisive roles in decisions related to enterprise behavior [52]. Given the widespread use of social capital in the field of economics, social capital is viewed as the horizontal relationship among enterprises, which is the longitudinal relationship between the enterprise and each link in the supply chain, and represents the sum of the social relationships among enterprises, related groups, external organization suppliers, customers and other cooperative parties with respect to access to external information and resources [53].

As important enterprise resources, customers can not only help enterprises reduce various costs and improve inventory management efficiency and receivable recovery rates but also provide effective market information and influence their innovation performance [54,55]. Along with the trend of continuous new product development and increased customer choices, the market is becoming more customer-centered, and the goal of innovation is to satisfy the personalized demands of customers. Since enterprises need to understand the need for customers to develop new products, customers guide enterprise innovation. Moreover, the convergence of the interests of enterprises and customers helps firms obtain market information and understand trends in industry technology. In addition, by utilizing customer information, firms save the cost of market research for new products and effectively reduce the risk of innovation failure by making technological innovations based on customer needs. The above discussion suggests that a stable cooperative relationship between firms and customers is crucial for firms to understand the market and reduce the risk of innovation failure.

Management networking, as an important form of corporate capital, has a profound impact on corporate development. A prior study documented the relationship between the personal characteristics of executives (i.e., CEOs, directors) and the innovation performance of enterprises [56,57]. Others have found that the number of shared directors on a board significantly improves enterprises' patent output [58,59]. Hambrick and Mason stated that organizational outcomes—strategies and performance levels—are partially predicted by managerial background characteristics [60]. Prior research has also suggested that overconfident CEOs invest more in innovation and obtain more patents and patent citations. Wen et al. found that managerial overconfidence partially mediates the relationship between customer stability and innovation investments [61]. In general, social networking relationships enable executives to obtain effective access to information and resources and a better understanding of companies. Business ties that serve as "catalysts" lead entrepreneurs to use effectual approaches by promoting their overconfidence.

Table 1
Literature review.

Enterprise innovation	Influence factor	Authors
Micro enterprise factors	Equity checks and balances	Zhu and Zhou [36]
	Employee stock ownership plan, employee diversification	Zhou et al. [37], Mayer et al. [38]
	Research and development team	Xie et al. [39]
Meso market factors	Hedge fund	Brav et al. [40]
	Market sentiment	Dang and Xu [41]
	Regional synergy	Fan et al. [42]
Macro institutional factors	Government subsidies	Hong et al. [43]
	Degree of intellectual property rights protection	Li and Zhang [44]
	Environmental legislation	Zhang et al. [45]

Form the perspective of management capability, competent management improves innovation efficiency by reducing information asymmetry and alleviating agency problems [62]. As an important social capital of enterprises, to some extent, management competence can help enterprises carefully choose innovative investment projects and avoid wasting R&D resources on ineffective or inefficient projects to improve the enterprise innovation efficiency [63,64]. Therefore, capable management pursues high efficiency, preventing the waste of innovation resources and innovation investments. Strong social networks increase manager overconfidence, leading to greater initiative for enterprises to change customers and managers' willingness to seek stable and close partners. Based on the above discussion, the second hypothesis is proposed：

H2. A social network has a significantly positive effect on enterprise innovation efficiency and mediates the relationship between customer change and innovation efficiency.

3. Methodology

3.1. Sample data

We use a sample of listed manufacturing companies from 2013 to 2020 are obtained. All the data are from the annual reports of companies and from the CSMAR database. Missing variables and ST companies are excluded, resulting in 2215 final sample observations. To eliminate the effects of extreme values, the continuous variables are winsorized at the 1 % level, and some variables are lagged to year t-1 to avoid endogeneity.

3.2. Explanatory and control variables

(1) Innovation efficiency (*Inno Efficiency*)

Since not all patents declared by enterprises can be successfully certified or authorized, the proportion of authorized patents out of the number of enterprise patent applications (*Apply (*Grant*)/Apply*) is used as an indicator of innovation efficiency. A higher proportion means higher innovation efficiency.

Additionally, a larger number of patents produced by R&D input per unit indicates higher enterprise innovation efficiency from the input−output perspective [65,66]. Following Hirshleifer et al., *Apply*/*R&D* is defined as the ratio of firm i's patents granted in year t scaled by its R&D capital (5-year cumulative R&D expenses assuming an annual depreciation rate of 20 %). For example, the weight of R&D input on patent output is 1 and is 0.8, 0.6, 0.4, and 0.2 in years t-1 to t-5, respectively. Five Apply/R&D variables are used as proxies for innovation over five years. Five years is used because the impact of an R&D investment is approximately five years. Since the amount of R&D investments is much larger than the number of patent applications, the index is enlarged by 106 to improve the observations. That is, *Apply*/*R&D* is a proxy for the number of patent applications transformed to R&D expenditures per million RMB. Eqs. (1)–(5) express this relationship in the following robustness test.

$$Apply/R\&D1_t = \frac{Apply_t \times 10^6}{R\&D_t} \tag{1}$$

$$Apply/R\&D2_t = \frac{Apply_t \times 10^6}{R\&D_t + 0.8R\&D_{t-1}} \tag{2}$$

$$Apply/R\&D3_t = \frac{Apply_t \times 10^6}{R\&D_t + 0.8R\&D_{t-1} + 0.6R\&D_{t-2}} \tag{3}$$

$$Apply/R\&D4_t = \frac{Apply_t \times 10^6}{R\&D_t + 0.8R\&D_{t-1} + 0.6R\&D_{t-2} + 0.4R\&D_{t-3}} \tag{4}$$

$$Apply/R\&D5_t = \frac{Apply_t \times 10^6}{R\&D_t + 0.8R\&D_{t-1} + 0.6R\&D_{t-2} + 0.4R\&D_{t-3} + 0.2R\&D_{t-4}} \tag{5}$$

(2) Customer change (*CustomerVary*)

Customer names are collected for a single company that has a customer concentration greater than or equal to 10 %. Customer I and customer j in the current year are compared with those in the previous year, and any changes are defined as customer changes. The proxy is set to 1 if the customer changes and 0 otherwise. Considering the different impacts of the extent of customer concentration on the enterprise, interaction variables are used for customer sales and customer change. Eq. (6) is as follows:

$$CustomerVary\begin{cases} change: & 1 * CustomerSales \\ no\ \ change: & 0 \end{cases} \tag{6}$$

(3) Social networks

If core management personnel (directors, supervisors, senior executives) work in two listed companies simultaneously, these two companies are considered to have social connections [58,67]. Prior studies have used social network centrality as a proxy for social networks. Following Freeman and Bonacich, we also note that degree, closeness, betweenness and eigenvectors are good measures of network status, influence and importance [68]. We use degree as a proxy for social networks and closeness as an alternative proxy in the robustness test. The formula is as follows:

$$Degree_i = \frac{\sum_{j \neq i}^{n} x(i,j)}{n-1} \ (\mathrm{i} \neq \mathrm{j}) \tag{7}$$

As shown in Eq. (7), enterprises I and j are two different enterprises in a social node. If there is a social connection between enterprises I and j, x(I, j) is 1; otherwise, it is 0. The degree reflects the number of connections of the enterprises in a social node. To eliminate the scale effect, we use the total number of connections of node enterprise I divided by n-1.

$$Closeness_i = \frac{n-1}{\sum_{j \neq i}^{n} d(i,j)} \ (i \neq j) \tag{8}$$

In Eq. 8, d(I,j) represents the length of the shortest path between node enterprises I and j. Closeness is the reciprocal of the sum of the shortest path length between two enterprises in the social network and is a proxy for the closeness of two enterprises in the network. In this paper, n-1 is used to eliminate the scale effect and obtain the standardized near-centrality index. For enterprises without any connections, that is, those that do not have the shortest path to any other enterprises in the network, closeness equals 0.

(4) Control variable (*Ctrls*).

According to previous scholarly research on enterprise innovation efficiency, large scale enterprises experience relatively mature development and have a strong influence on enterprise growth, innovation ability and the market, enabling them to further improve their innovation efficiency [69,70]. Enterprise profitability, solvency and operating capacity are all related to enterprise risks that significantly affect enterprise innovation efficiency [71,72]. Cash flow, as the enterprise capital buffer pool, helps ease the pressure of innovation financing and improve innovation performance [73]. Increasing investments in R&D can significantly improve innovation performance and is critical to enterprise innovation [74–75]. Therefore, we control for multiple variables that may affect the efficiency of enterprise innovation, including enterprise size (*Size*), leverage (*Lev*), profitability (*Roa*), growth capacity (*Growth*), R&D investment intensity (*R&D*), the tangible assets ratio (*Tar*), operating income per share (*Sales*) and free cash flow per share (*Fcf*). The annual virtual variables (Year) are set for different years to control for macroeconomic conditions.

3.3. Regression model

Eq. (9) is used to test the impact of an enterprise's customer changes on innovation efficiency (hypothesis H1), where $InnoEfficiency_{i,t}$ is the innovation efficiency of enterprise i in year t; $CustomerVary_{i,t-1}$ is the customer change in year t-1, including whether the enterprise changes the customers (*CustomerVary1*) and the degree of the customer change (*CustomerVary2*); $Ctrls_{i,t-1}$ represents the control variable in year t-1; vt represents year fixed effects; and $\varepsilon_{i,t}$ is a random error term.

$$InnoEfficiency_{i,t} = \alpha_0 + \alpha_1 CustomerVary_{i,t-1} + \sum Ctrls_{i,t-1} + v_t + \varepsilon_{i,t} \tag{9}$$

To address the influence mechanism of customer change on enterprise innovation efficiency (hypothesis H2), Eqs. (9)–(11) are used to investigate the mediating effects of social networks on the relationship between customer change and enterprise innovation efficiency. Eq. (9) represents the total effect of customer change on enterprise innovation efficiency (coefficient α_1); Eq. (10) represents the influence of customer change on the mediating variable, social network (coefficient β_1); coefficient γ_1 in Eq. (11) represents the direct effect of customer change on enterprise innovation efficiency after controlling for the mediating variable; and γ_2 represents the effect of the social network on enterprise innovation efficiency after controlling for customer change. If coefficients $\alpha_1, \beta_1,$ and γ_2 are all significant, a mediation effects exist between customer change and enterprise innovation efficiency, that is, the interaction of coefficient $\beta_1 \times \gamma_2$. If coefficient γ_1 is significant, a partial mediating effect exists. If coefficient γ_1 is not significant, a complete mediating effect exists (Baron and Kenny, 1986).

$$SocialNetwork_{i,t-1} = \beta_0 + \beta_1 CustomerVary_{i,t-1} + \sum Ctrls_{i,t-1} + v_{t-1} + \varepsilon_{i,t-1} \tag{10}$$

$$InnoEfficiency_{i,t} = \gamma_0 + \gamma_1 CustomerVary_{i,t-1} + \gamma_2 SocialNetwork_{i,t-1} + \sum Ctrls_{i,t-1} + v_{t-1} + \varepsilon_{i,t-1} \tag{11}$$

4. Result analysis

4.1. Summary statistics of variables

Table 2 reports the summary statistics for the variables used in this paper. Table 1 shows that, on average, 44.8 % of the patent applications in the sample are authorized (*Apply (*Grant*)/Apply* = 0.448). The average number of patent applications per million in the R&D investment portfolio is 0.834 each year. Similarly, the average values are 0.442, 0.344, 0.300, and 0.279 from years 2–5, respectively.

The mean of *CustomerVary1* is 0.418, suggesting that the rate of change in the customers of the sample companies is relatively high, while the mean of *CustomerVary*2 is 10.7 %, indicating that most of the customer changes are from nonmajor clients. The mean of *Degree* is 0.180, which means that each sample company is connected to 18 % of all listed companies in the same year. The mean of *Closeness* is 0.468. The sum of the average minimum path for one company to reach every other company throughout the social network is 213.68 steps.

For the control variables, the average asset size of the sample company is 21.953, the average return on equity is 3.2 %, the average operating income growth rate is 23.3 %, the average asset-liability ratio is 43.9 %, the average R&D expenditure is 3.9 % of operating income, the average tangible asset ratio is 92.7 %, the average operating income per share is 5.778 RMB, and the average free cash flow per share is −0.214 RMB. The variance inflation factor (VIF) of the variables in the regression analysis is less than 2, indicating no multicollinearity in the regression model.

4.2. Univariate analysis

To show differences in innovation efficiency between enterprises that do and do not change customers, the Ttset3 command in Stata is used to compare the means and medians of customers not changed versus customers changed and the results are provided in Table 3. Both the mean and the median of the customer change subsample are lower than those of the unchanged customer subsample. The results of the *t*-test for the means and the Z test for the medians are positively significant, suggesting that customer relationships significantly affect innovation performance.

4.3. Empirical results

Table 4 reports the results of customer changes (*CustomerVary, CustomerVaryFlu*) and innovation efficiency (*Apply (*Grant*)/Apply*) relations. Columns (1) and (4) show the results of the first step of the mediating effect test, reflecting the relationship between customer change and innovation efficiency after controlling for size, profitability, the leverage ratio, growth, R&D investments, firm-level cash flow, other related factors and year fixed effects. The coefficients of *CustomerVary* and *CustomerVaryFlu* are both significantly negative, suggesting that customer change reduces patent output per unit of R&D input. These results are consistent with the logic of testable hypothesis 1.

Columns (2) and (5) show the results of the second step of the mediating effect test. This step tests the effect of the independent variable (*CustomerVary, CustomerVaryFlu*) on the mediation variable (*Degree*). The coefficients of *CustomerVary* and *CustomerVaryFlu* are significantly positive at the 1 % level, indicating that managers of enterprises with customer change, in contrast to managers of enterprises without customer change, have a stronger social network, enabling them to engage in more initiatives and have more bargaining power to choose customers who are beneficial to them.

Columns (3) and (6) show the results of the third step of the mediating effect test. The coefficient of *Degree* is significantly positive,

Table 2
Descriptive statistics of the variables.

Variable name	mean	sd	min	p25	p50	p75	max	VIF
Apply(Grant)/Apply	0.448	0.192	0.000	0.333	0.486	0.531	1.000	–
Apply/ R&D 1	0.834	1.443	0.000	0.133	0.389	0.912	12.730	–
*Apply/ R&D*2	0.442	0.620	0.000	0.076	0.229	0.525	3.748	–
*Apply/ R&D*3	0.344	0.474	0.000	0.060	0.183	0.402	2.717	–
*Apply/ R&D*4	0.300	0411	0.000	0.0153	0.160	0.356	2.383	–
*Apply/ R&D*5	0.279	0.373	0.000	0.050	0.151	0.336	2.122	–
CustomerVary1	0.418	0.493	0.000	0.000	0.000	1.000	1.000	1.04
CustomerVary2	0.107	0.166	0.000	0.000	0.000	0.174	1.000	1.05
Degree	0.180	0.118	0.000	0.085	0.171	0.256	0.726	1.04
Closeness	0.468	0.149	0.000	0.441	0.499	0.578	0.589	1.04
Size	21.953	1.131	18.524	21.158	21.838	22.603	25.079	1.50
Roe	0.032	0.056	−0.188	0.008	0.029	0.058	0.200	1.19
Growth	0.233	0.569	−0.689	−0.047	0.106	0.337	3.396	1.08
Lev	0.439	0.208	0.055	0.277	0.432	0.597	0.941	1.50
R&D	0.039	0.039	0.000	0.015	0.033	0.049	0.265	1.11
Tar	0.927	0.082	0.535	0.916	0.953	0.973	0.999	1.10
Sales	5.778	5.517	0.237	2.144	4.181	7.356	31.345	1.42
Fcf	−0.214	2.649	−13.254	−0.383	0.300	0.891	4.645	1.05

Table 3
Results of the univariate analysis.

Variable	Customer not changed			Customer changed			Difference test	
	Observations	mean	median	Observations	mean	median	T test	Z test
Apply(*Grant*)/ *Apply*	1209	0.454	0.429	893	0.398	0.415	0.056***	4.227***
Apply/ *R&D 1*	1272	0.889	0.413	913	0.758	0.364	0.132**	3.412*
Apply/ *R&D*2	1258	0.503	0.286	910	0.417	0.208	.0052*	6.761***
Apply/ *R&D*3	1249	0.363	0.201	908	0.325	0.166	0.038*	6.298***
Apply/ *R&D*4	1219	0.318	0.180	904	0.285	0.147	0.033*	10.429***
Apply/ *R&D*5	1216	0.298	0.172	903	0.268	0.140	0.030*	10.164***

Table 4
Empirical results.

Variable	Interpreter variable: $CustomerVary_{t-1}$			Interpreter variable: $CustomerVary\ Flu_{t-1}$		
	Apply (*Grant*)/*Apply* $_t$	$Degree_{t-1}$	*Apply* (*Grant*)/*Apply* $_t$	*Apply* (*Grant*)/*Apply* $_t$	*Degreet-1*	*Apply* (*Grant*)/*Apply* $_t$
-cons	0.842*** (7.23)	−0.274*** (−4.01)	0.871*** (7.47)	0.775*** (6.77)	−0.279*** (−4.13)	0.914*** (8.05)
$CustomerVary_{t-1}$	−0.018** (−2.12)	.0021*** (4.06)	−0.021** (−2.37)			
$CustomerVary\ Flu2_{t-1}$				−0.088*** (−3.33)	0.065*** (4.24)	−0.096*** (−3.72)
$Degree_{t-1}$			0.107*** (2.80)			0.135*** (3.50)
$Size_{t-1}$	−0.017*** (−3.63)	.0017*** (6.18)	−0.019*** (−3.99)	−0.011** (−2.29)	0.017*** (6.07)	−0.018*** (−3.59)
Roe_{t-1}	−0.112*** (−2.96)	.0027 (1.20)	.1–015*** (−3.04)	−0.121*** (−3.28)	.0036* (1.67)	−01.13*** (−3.59)
$Growth_{t-1}$	−0.21*** (−2.69)	03.00 (0.71)	−01.02*** (−2.74)	−0.015* (−1.94)	01.00 (1.03)	−07.01** (−2.21)
Lev_{t-1}	0.032 (1.35)	08.00 (0.55)	.0031 (1.22)	0.0015 (0.57)	.0010 (0.66)	.0018 (0.71)
$R\&D_{t-1}$	−0.500*** (−4.14)	0.199*** (2.81)	−0.522*** (−4.32)	−0.493*** (−4.23)	0.222*** (3.21)	−0.559*** (−4.79)
Tar_{t-1}	0.016 (0.29)	.0060* (1.82)	.0010 (0.87)	−0.071 (−0.30)	.0070** (2.18)	.0–043 (−0.79)
$Sales_{t-1}$	−0.001* (−1.72)	−0.001* (−1.74)	−0.002 (−1.73)	−0.002* (−1.73)	−0.003* (−1.682)	−0.001* (−1.673)
Fcf_{t-1}	0.001 (0.75)	0.001 (1.22)	0.001 (0.95)	0.001 (0.73)	0.002* (1.77)	0.002 (0.82)
Year	Yes	Yes	Yes	Yes	Yes	Yes
F	7.82	7.89	7.85	7.58	8.79	8.09
Adj-R^2	0.035	00.04	0.037	0.038	.0036	.0036
Sobel test	0.021**(Z = 2.306)			0.007***(Z = 2.7)		
Goodman test 1	0.024**(Z = 2.26)			0.008***(Z = 2.656)		
Goodman test 2	0.019**(Z = 2.355)			0.006***(Z = 2.746)		
Mediating effect ratio	12.05 %			10.04 %		

Note: * * *, * *, and * indicate that the regression coefficients are significant at the 1 %, 5 % and 10 % levels, respectively.

indicating that the social network is an important factor that affects enterprise innovation efficiency. The coefficients of *CustomerVary* and *CustomerVary Flu* are significant, and their absolute values and significance increase substantially compared with those in Columns (1) and (4). The results show that social network relations (*Degree*) have mediating effects on customer change and innovation efficiency. The above discussion suggests a mechanism of customer change and enterprise innovation efficiency, that is, a mechanism of customer change–social network relationship–innovation efficiency. As shown in Table 4, the proportions of Degree to *CustomerVary*

Table 5
Group tests.

Variable	Degree of customer change < mean			Degree of customer change > mean		
	Apply (*Grant*)/*Apply* $_t$	$Degree_{t-1}$	*Apply* (*Grant*)/*Apply* $_t$	$\frac{Apply\ (Grant)}{Apply}_t$	$Degree_{t-1}$	*Apply* (*Grant*)/*Apply* $_t$
-cons	0.832	−0.269	0.885	0.533	−0.378	0.601
$CustomerVary\ Flu_{t-1}$	−0.485*** (−3.19)	0.330*** (3.78)	−0.551*** (−3.60)	−0.178** (−2.274)	−0.015 (−0.346)	−0.175** (−2.244)
$Degree_{t-1}$			0.200*** (29).6			0.229** (2.139)
Ctrls	Yes	Yes	Yes	Yes	Yes	Yes
F	3.40	4.33	3.80	2.62	1.92	2.93
Adj -R^2	02.04	0.035	054.0	0.038	0.027	0.030
Sobel test	0.032**(Z = 2.148)			0.733(Z = 0.342)		
Goodman test 1	0.036**(Z = 2.096)			0.756(Z = 0.310)		
Goodman test 2	0.028**(Z = 2.203)			0.700(Z = 0.385)		
Mediating effect ratio	13.61 %			–		

and *CustomerVaryFlu* are −12.05 % and −10.04 %, respectively, suggesting that social network relations weaken the negative impact of customer change on innovation efficiency. The Sobel, Goodman 1, and Goodman 2 tests using the sgmediation command were applied. All of the results are significant, which is consistent with the logic in testable hypothesis 2.

A comparison of the coefficients of *CustomerVary* (−0.018) and that of *CustomerVaryFlu* (−0.088) leads to the conclusion that the extent of a customer change has a greater impact on enterprise innovation efficiency than does whether customers change. However, comparing the relationship between the extent of customer change (*CustomerVaryFlu*) and innovation efficiency shows that social networks have a stronger mediating effect on the relationship between whether enterprises change customers (*CustomerVary)* and innovation efficiency. To further investigate the relationships among the extent to which customers change, social networks and innovation efficiency, the sample enterprises with customer change are divided into two groups according to the mean degree of customer change. The differences between the two groups are shown in Table 5.

Table 5 Columns (1), (2) and (3) show that social networks have a stronger mediating effect on the group with a smaller degree of customer change (for a mediating effect ratio of −13.61 %). However, in Column (5), the coefficient of *CustomerVaryFlu* is not significant in the group with a greater degree of customer change. The Sobel test shows that the mediating effect is not valid since the Z statistic is greater than 0.05. We find a significant mediating effect of social networks on customer change and innovation efficiency when enterprises' small-scale customers change. We explain that social networks do not have a significant impact when enterprises experience large-scale customer changes because the loss of relationships with large customers cannot be offset by management's social networks. Customers are important stakeholders of enterprises, and those who closely cooperate with enterprises give them resources that provide a competitive advantage. The relationship capital brought by main customers to enterprises has not only has a significant impact on their operations and long-term performance but also has direct or indirect effects on enterprises' financing capacity, cash holdings, etc. Financing and cash holdings provide funds for enterprises' operations and are key to enterprise innovation and losing main customers creates operational and financial risks for enterprises. Therefore, changes in main customers may represent passive behavior for enterprises rather than representing the will of management. Losses from major customer churn cannot be compensated for through other capital obtained from other social networks.

4.4. Additional analysis: mediating effect based on the perspective of enterprise heterogeneity

The above discussion indicates that customer change affects enterprise innovation efficiency, and that social networks have a mediating effect on this relation. In general, material resources and competitive environments differ between state-owned enterprises and nonstate-owned enterprises and between technology-intensive and nontechnology-intensive enterprises. Enterprise heterogeneity has a significant impact on social networks and innovation performance. Therefore, the relevance of enterprise heterogeneity to customer change and innovation performance is examined, as well as is the moderation of the mediating effects.

4.4.1. Ownership property

State-owned enterprises (SOEs) have more political resources, facilitating their acquisition of additional competitive advantages. Compared with SOEs, non-SOEs must use social networks to obtain more resources, reducing the gap with SOEs through enterprise innovation in a competitive market. Based on the ultimate controlling shareholder, our sample is divided into two groups: 1) SOEs and 2) non-SOEs. The same test as for Table 4 is used to obtain the results for these two subsamples, which are shown in Table 6.

In Table 6, the mediating effect ratio of a social network (*Degree*) in the non-SOEs subsample is 14.61 %, which is significantly greater than the 9.14 % for the SOEs subsample. The results suggest that when enterprises change customers, non-SOEs rely more on social networking to select their customers and ensure their innovation efficiency. Moreover, the mediating effect ratio of SOEs is less than 10 %, suggesting that social networking is not SOEs' major social resource.

4.4.2. Factor intensity

Research on innovation investment generally shows that there are differences in enterprise innovation among industries. For

Table 6
Empirical results of ownership differences.

Variable	State-owned enterprises			Non-state-owned enterprises		
	$Apply\frac{(Grant)}{Apply}_t$	$Degree_{t-1}$	$Apply\frac{(Grant)}{Apply}_t$	$Apply\frac{(Grant)}{Apply}_t$	$Degree_{t-1}$	$Apply\ (Grant)/Apply_t$
-cons	−0.012	−0.467	0.052	0.922	−0.230	0.954
$CustomerVary_{t-1}$	−0.041*** (−2.67)	0.026*** (2.87)	−0.044*** (−2.91)	−0.025** (−1.98)	0.026*** .1(36)	−0.028** (−2.26)
$Degree_{t-1}$			0.142** (2.30)			0.140*** (2.94)
Ctrls	Yes	Yes	Yes	Yes	Yes	Yes
F	3.84	4.37	3.95	3.30	3.92	3.65
Adj-R^2	0.055	0.064	0.060	0.038	0.039	06.03
Sobel test	0.073*(Z = 1.795)			0.026**(Z = 2.22)		
Goodman test 1	0.083*(Z = 1.732)			0.030**(Z = 2.167)		
Goodman test 2	0.062*(Z = 1.854)			.0023**(Z = 2.278)		
Mediating effect ratio	9.14 %			14.61 %		

example, the innovation needs of high-tech industries are significantly different from those of traditional industries. However, given the advancements in the manufacturing industry in the direction of "intelligence", traditional industries are gradually transforming and upgrading with the support of technology to meet diversified and personalized market demands. The full sample is divided into technology-intensive and nontechnology-intensive industries according to factor intensity. In contrast to those of technology-intensive industries, innovation activities in nontechnology-intensive industries are more likely to be limited by business conditions, capital, customer needs and other aspects. The same model as used for Table 5 is used to test the two subsamples. The results are shown in Table 7.

The results in Table 7 show that the mediating effect ratio of the social network (*Degree*) in the nontechnology-intensive enterprise subsample is 12.57 %, which is greater than the 10.27 % of the technology-intensive enterprise subsample. Furthermore, the coefficient of *CustomerVary* is −0.038 for the nontechnology-intensive enterprise group, which is larger than the absolute value of that for the technology-intensive enterprise group, −0.031. Therefore, although nontechnology-intensive enterprises are not equipped with high-tech production, the conclusion reached is that their transformation and upgrading are more closely related to customers. For these enterprises, the motivation for innovation is to satisfy diversified and personalized demands in the markets.

4.5. Robustness test

For robustness, alternative dependent and mediating variables are used to further test our baseline results.

(1) Alternative dependent variable

R&D inputs per unit divided by output patents (*Apply/R&D*) are used as an alternative dependent variable and a proxy for enterprise innovation efficiency. The results are shown in Tables 8 and 9. The results in Table 8 show that customer change (*CustomerVary*) has a significant negative effect on innovation efficiency (*Apply/R&D*). The results in Table 9 show that the social network (*Degree*) still has a mediating effect on the relationship between customer change and innovation performance. The empirical conclusion has not changed substantially.

(2) Alternative mediating variable

Proximity centrality (*Closeness*) is used as an alternative mediating variable to measure social networking. The results, shown in Table 10, suggest that social networks (*closeness*) have a mediating effect on the relationship between customer change and innovation performance. The empirical conclusion has not changed substantially.

5. Discussion

Previous studies have analyzed the impact of supply chain resource integration on corporate innovation [20, 76], but have not explored the relationship between customers and corporate innovation efficiency from the perspective of supply chain social capital. In the post-COVID-19 era, various risks are intertwined and thus have a impact on the stability of the supply chain and its upstream and downstream relationships. For example, in February 2020, Hyundai, Mazda, Apple, Starbucks, IKEA, Uniqlo and other brands temporarily closed their stores in China [77]. From this perspective, this study fills a gap in the existing literature. This article explores the relationship between customers and corporate innovation efficiency through supply chain social capital. If we can discover the hidden information in the results, we may provide useful advice to business operators, policy makers, and consumers. By focusing on the quality of enterprise innovation, this paper first finds that social networks have a significant impact on enterprise innovation efficiency, mainly providing enterprises with high-quality information and market opportunities, and improving the success rate of innovation. In addition, this article also finds that social capital such as customer relationships is conducive to the development of

Table 7
Empirical results of differences in factor density.

Variable	skill-intensive			Nontechnology intensive		
	$Apply\frac{(Grant)}{Apply}_t$	$Degree_{t-1}$	$Apply\frac{(Grant)}{Apply}_t$	$Apply\frac{(Grant)}{Apply}_t$	$Degree_{t-1}$	$Apply\ (Grant)/Apply_t$
-cons	0.398	−0.458	0.450	0.445	−0.435	.5033
$CustomerVary_{t-1}$	−0.031*** (−2.64)	08.0*** (3.38)	−0.034*** (−2.91)	−0.038** (−2.46)	0.028*** .1(36)	−0.043*** (−2.76)
$Degree_{t-1}$			.1014*** (2.58)			.1071*** (2.94)
Ctrls	Yes	Yes	Yes	Yes	Yes	Yes
F	3.34	5.36	36.9	3.28	6.02	3.82
Adj-R^2	.0033	.0059	.0048	03.03	.0082	.0041
Sobel test	.0040**(Z = 2.051)			.0035**(Z = 2).105		
Goodman test 1	.0046**(Z = 1.996)			.0041**(Z = 2.048)		
Goodman test 2	.0035**(Z = 2.11)			.0030**(Z = 2.166)		
Mediating effect ratio	10.27 %			12.57 %		

Table 8
Alternative dependent variable: baseline results.

Variable	$Apply/R\&D1_t$	$Apply/R\&D2_t$	$Apply/R\&D3_t$	$Apply/R\&D4_t$	$Apply/R\&D5_t$
-cons	2.586	1.330	1.006	0.707	0.701
$CustomerVary_{t-1}$	−0.254*** (−3.60)	−0.117** (−3.92)	−0.093*** (−4.07)	−0.072*** (−3.64)	−0.068*** (−3.81)
Year	control	control	control	control	control
F price	9.00	7.48	6.50	5.75	5.29
Adj.R^2	0.032	07.02	04.02	01.02	0.019

Table 9
Alternative dependent variable-mediating effects.

Variable	$Degree_{t-1}$	$Apply/R\&D1_t$	$Apply/R\&D2_t$	$Apply/R\&D3_t$	$Apply/R\&D4_t$	$Apply/R\&D5_t$
-cons	−0.318	2.853	1.452	1.103	0.792	0.788
$CustomerVary_{t-1}$	0.017*** (3.09)	−0.269*** (−3.81)	−0.123*** (−4.14)	−0.098*** (−4.29)	−0.075*** (−3.85)	−0.072** (−4.00)
$Degree_{t-1}$		0.841*** (3.10)	0.407*** (3.59)	01.3*** (3.62)	00.28*** (3.75))	0.247*** (3.62)
Year	Yes	Yes	Yes	Yes	Yes	Yes
F	7.34	8.41	7.45	6.14	5.58	5.11
Adj.R^2	0.042	0.036	04.03	09.02	07.02	.0025
Sobel test	–	0.029**(Z = 2.189)	0.028**(Z = 2.198)	.0028**(Z = 2.192)	0.043**(Z = 2.024)	0.041**(Z = 2.042)
Goodman test 1	–	0.033**(Z = 2.134)	0.032**(Z = 2.146)	.0032**(Z = 2.141)	0.048**(Z = 1.975)	0.046**(Z = 1.991)
Goodman test 2	–	0.024**(Z = 2.248)	0.024**(Z = 2.253)	.0025**(Z = 2.247)	0.038**(Z = 2.077)	0.036**(Z = 2.097)
Mediating effect ratio	–	5.77 %	5.52 %	5.39 %	5.36 %	5.10 %

Table 10
Results of the robustness test using alternative mediating variables.

Variable	*Apply (Grant)/Apply*	*Closeness*	*Apply (Grant)/Apply*	*Apply (Grant)/Apply*	*Closeness*	*Apply (Grant)/Apply*
-cons	0.587	0.069	0.583	0.598	0.015	0.597
$CustomerVary_{t-1}$	−0.027*** (−2.93)	0.054*** (8.49)	−0.030** (−3.21)			
$CustomerVary\ Flu_{t-1}$				−0.027*** (−2.91)	0.054*** (8.45)	−0.030** (−3.23)
$Closeness_{t-1}$			0.058* (1.82)			0.065** (2.04)
Ctrls	control	control	control	control	control	control
F	5.60	30.48	6.85	5.72	30.51	6.87
Adj.R^2	0.039	0.112	0.042	0.041	0.113	0.052
Sobel test	0.075*(Z = 1.778)			0.048**(Z = 1.98)		
Goodman test 1	0.077*(Z = 1.766)			0.049**(Z = 1.967)		
Goodman test 2	0.074*(Z = 1.789)			0.046**(Z = 1.993)		
Mediating effect ratio	11.54 %			12.69 %		

corporate innovation. Therefore, this article is of critical significance for establishing customer trust, strengthening the relationship between customers and enterprises, and improving enterprise innovation efficiency.

6. Conclusion

Based on the logical starting point of "relationship" capital, the mechanisms of customer change and enterprise innovation efficiency are examined. The empirical results show that customer change has a significantly negative impact on enterprise innovation efficiency, and social networking as a mediating variable moderates this negative impact.

The analysis has several important implications for the influence mechanism of enterprise innovation efficiency. First, customer relations with enterprises are "external" and an important resource for enterprises. The relationship between customers and enterprise innovation efficiency is investigated from the perspective of supply chain social capital. Enterprises are concerned with not only innovation quantity but also innovation quality. The keys to the sustainable development of enterprises include understanding customers' needs, seizing market opportunities, creating new products, scaling up production processes and mastering core technologies. If enterprises change customers, they lose the resources brought about by external cooperation and synergism. This loss reduces enterprises' access to market information and technical knowledge and negatively affects their business capital and performance. Thus, the quality of enterprises' innovation activities is directly or indirectly affected. Therefore, reducing the possibility of customer change and maintaining long-term, stable and cooperative relationships between enterprises and customers are more conducive to the sustainable and healthy development of enterprises. If an enterprise takes the initiative to replace customers due to customer financial risks, business changes and other reasons, by improving product technology and market competitiveness, it is bound to make better customer choices and should seize the opportunity to establish long-term, strategic cooperative relationships with customers. However, from the perspective of the competitive environment, the buyer still occupies a strong position, and the customer is likely to relinquish cooperation. Therefore, it is necessary to integrate the supply chain relationship into the enterprise's social capital, build

trust with customers, strengthen the interests between the enterprise and its customers, carry out targeted technological innovation, strengthen customers' participation in enterprise innovation, make full use of resource advantages, ensure research and development resource utilization efficiency, and actively meet customers' personalized demand for the purpose of offering a full service as the key to maintaining long-term cooperation with customers.

Moreover, the "internal" and "external" relationships of an enterprise are combined in a complete research framework. On the one hand, as an important internal resources, social networks have a significant relationship with enterprise innovation efficiency. The reason for this strong relationship is that social networks can be considered a "group" that reduces information costs, helps facilitate information exchange, and provides enterprises with more high-quality information and market opportunities, improving the success rate of innovation. However, this "internal" relationship is different from the "external" relationship with customers. We believe that social networking represents connections among core managers; thus, it can be called the manager network. By facilitating the sharing and exchange of resources and complementing external and internal knowledge, a manager network promotes firm innovation. On the other hand, the relationship with customers is "external" and represents another type of social capital formed by customers' penetration of business activities over the long term. This relationship contributes to the sustainable and healthy development of enterprises. Enterprise innovation needs to be built on customer demands. Cooperation is the key to enterprise innovation. This social capital cannot be replaced by that of the manager network.

Third, the findings suggest that enterprise heterogeneity has a significant impact on the relationship between customers and innovation efficiency. Prior research on enterprise innovation documents that innovation activities are affected by operational and financing abilities. Since enterprises with different ownership structures may be exposed to different market environments and financing channels, their heterogeneity may affect innovation activities.

Nevertheless, barring data limitations and other reasons, future research may further the progress of this study in the following aspects. First, patent data are used to measure enterprise innovation efficiency. These data can measure R&D ability but cannot directly reflect the economic value contributed by R&D. Therefore, the measure of enterprise innovation efficiency may have limitations, and future studies may introduce product innovation or new product sales as proxies for enterprise innovation efficiency. Second, in contrast to customer relationships, supplier or competitor relationships may have far-reaching impacts on enterprise innovation. Future research may further explore the impact of these various networks on enterprise innovation.

Authorship statement

The authors declare no competing financial interests or personal relationships that could influence this work.

Data availability statement

Data will be made available on request.

Additional information

No additional information is available for this paper.

CRediT authorship contribution statement

Wen Xuqian: Writing – original draft, Data curation, Conceptualization. **Wang Hui:** Writing – review & editing, Data curation. **Zhou Wei:** Writing – review & editing.

Declaration of competing interest

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