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# How Does Relationship Embeddedness affect Firm Resilience: The Role of Digitalization



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# How Does Relationship Embeddedness affect Firm Resilience: The Role of Digitalization


## Abstract

In the context of the profound restructuring of the global semiconductor supply chain, firm resilience has become a critical issue in supply chain management (SCM). The globalization of supply and the increasing demand for customer customization in the semiconductor industry have led to significant variations in the supply chain structures of different firms. This study employs social network analysis (SNA) as a theoretical framework to examine the impact of relationship embeddedness in supply chains on firm resilience, alongside the multidimensional moderating role of digitalization. Using secondary data from 477 listed companies in China's semiconductor industry between 2017 and 2023, we employ multiple econometric models to test our hypotheses. The results reveal that both supplier concentration (SC) and customer concentration (CC) exert significant positive effects on firm resilience. Moreover, the degree (DT) and speed (DTV) of digital transformation within focal firms significantly strengthen the positive impact of supplier concentration on resilience. These findings underscore the critical role of relationship embeddedness in enhancing firm resilience and provide empirical evidence on the role of digitalization in this relationship. Finally, we use the case of Huawei to validate the findings.


**Keywords**: Firm resilience, Relational embeddedness, Social network analysis, Digitalization; Semi-conductor industry

**Managerial relevance statement**: This study offers the following recommendations

for SCM, digital transformation, and policy coordination: Enterprises should establish long-term strategic collaborations with core suppliers, promote joint research and development (R&D), and pursue customized production. Adopting multi-source procurement and leveraging blockchain technology can enhance transparency and mitigate supply chain risks. Additionally, maintaining a balanced customer structure and employing dynamic contracts and digital demand forecasting will help avoid reduced bargaining power. Companies should prioritize the development of real-time monitoring and emergency response systems in upstream supply chains. Utilizing big data analytics for capacity planning and building flexible digital infrastructures can prevent the risks of technology lock-in caused by reliance on a single platform. Multinational enterprises can deploy regionally distributed supply chains and establish blockchain nodes in sensitive areas to enhance resilience. Governments can facilitate this process by offering tax incentives for digital infrastructure investments, encouraging industry associations to build collaborative digital ecosystems, and promoting supply chain coordination. In key sectors, fostering strategic alliances and using digital twin technology for risk simulation and rapid recovery will further strengthen resilience.

## 1. Introduction

Affected by Sino-US trade tensions, the COVID-19 pandemic, and geopolitical conflicts, the global chip shortage from 2020 to 2022 resulted in losses exceeding $500 billion in the automotive industry, highlighting the fragility of the semiconductor supply chain. In this context, enhancing the resilience of the semiconductor industry has become an urgent priority. Firm resilience is defined as a firm’s ability to maintain operational continuity and restore stability through rapid response, resource reconfiguration, and strategic adaptation in the face of external shocks [1]. Recent studies suggest that resilience is not only contingent on internal resource redundancy and flexibility—such as inventory buffers and multi-sourcing strategies—but also closely linked to the dynamic coordination capabilities of the supply chain network [2]. However, much of the existing literature predominantly focuses on internal resilience-building strategies, including crisis management processes and investments in information technology, while the role of supply chain network structures in shaping firm resilience remains underexplored [3]. In particular, relationship embeddedness within the supply chain network—representing the depth and quality of interactions between firms and their upstream and downstream partners—has yet to be fully examined.

Relational embeddedness literature, rooted in Social Network Analysis (SNA), highlights a firm's ability to access resources and information through long-term, close partnerships [4]. Within supply chains, relational embeddedness is typically reflected in supplier and customer concentration, which denote a firm’s reliance on a limited number of key suppliers or customers [5]. Existing research suggests that highly concentrated supplier relationships can enhance efficiency by reducing coordination costs and fostering trust [6]; however, they may also heighten risk due to excessive dependence [7]. This “double-edged sword” effect becomes particularly intricate when examined through the lens of resilience. That is, while strong supplier relationships can enhance supply chain resilience by facilitating information sharing and rapid response, excessive concentration may create systemic vulnerabilities due to single points of failure.

Despite these theoretical insights, empirical research on this paradox, particularly within network-based frameworks, remains scarce [3]. Similarly, the impact of customer concentration on firm resilience remains a subject of debate. Some scholars argue that heavy reliance on a few large customers weakens a firm's bargaining power, increasing its susceptibility to demand fluctuations during crises [8]. Conversely, others suggest that strategic coordination with core customers can provide firms with stable demand forecasts and resource support, ultimately enhancing resilience [9]. These contrasting perspectives highlight the complexity of the nonlinear relationship between relational embeddedness and firm resilience, underscoring the need for systematic empirical investigation.

Furthermore, digitalization, as a key driver of the ongoing transformation of supply chains, may reshape the relationship between relational embeddedness and firm resilience. Digital technologies—such as blockchain, the Internet of Things (IoT), and big data analytics—are redefining interfirm interactions by enhancing supply chain visibility, enabling real-time monitoring, and facilitating collaborative decision-making [10]. For example, smart contracts can automate supplier agreements, minimizing delays caused by human intervention, while IoT sensors can track logistics in real time, providing early warnings of potential disruptions. Theoretically, digitalization has the potential to reinforce the positive effects of relational embeddedness by reducing information asymmetry and strengthening trust between supply chain partners [11]. However, digitalization may also intensify the "lock-in effect," restricting firms' flexibility by increasing their dependence on technology [12]. Despite its growing significance, empirical research on this moderating effect remains limited, constraining managers' ability to balance digital investments with resilience enhancement.

The limitations of existing research can be summarized in three aspects. First, most studies examine the drivers of resilience from the perspective of individual firms, overlooking the interconnected and dynamic nature of supply chain networks. While social network theory offers a valuable framework for analyzing network structures [13], its application to resilience studies remains limited. Second, the "double-edged sword" effect of relational embeddedness has not been thoroughly validated through empirical industry-based research. For instance, does supplier concentration enhance resilience by fostering synergy and efficiency, or does it heighten risk due to resource dependence? Similarly, what role does customer concentration play in mitigating or amplifying demand-side shocks? Addressing these questions requires a multi-level analytical approach that integrates both firm- and network-level data. Third, existing research on digitalization and supply chain resilience primarily focuses on technological applications without fully incorporating network embedding theory. The extent to which digital technologies reshape power dynamics, information flow, and risk-sharing mechanisms within supply chain networks remains an open question, necessitating further theoretical development and empirical validation.

Based on the gaps identified, we develop the research questions as follows:

*RQ1: What is the effect of supplier or customer concentration on firm resilience?*

*RQ2: Under what conditions does digitalization enhance or diminish the aforementioned relationships?*

To address these research questions, this study collect data from the CSMAR database and Wind disclosure reports to construct a unique dataset of 477 core firms in the semiconductor industry and their extended supply chains. Empirical analysis is conducted using panel regression and a moderating effect model. Finally, we use the case Huawei to validate the findings of the secondary data analysis.

Compared with existing research, this study advances the understanding of supply chain resilience through three key innovations. First, at the theoretical level, it applies SNA for the first time, demonstrating that the "bidirectional embeddedness" of supplier and customer concentration in the semiconductor industry enhances firm resilience—moving beyond the traditional firm-centric perspective [3]. Second, at the technical mechanism level, this study deconstructs digital transformation in terms of degree (DT) and speed (DTV), identifies the heterogeneity of its moderating effects, and reveals the dynamic interplay between digitalization and network embeddedness [14]. Finally, at the methodological level, we employ a hybrid approach that integrates case studies with secondary data analysis, addressing endogeneity through instrumental variables and counterfactual analysis. This enables us to offer both academia and industry a management paradigm that balances theoretical rigor with practical applicability.

The remainder of the paper is structured as follows: Section 2 reviews the relevant literature and develops testable hypotheses; Section 3 outlines the research design, including variable definitions and sample selection; Section 4 presents the empirical analysis and results; Section 5 discusses the findings and their implications. The paper concludes with a summary of key contributions and suggestions for future research.

# 2. Literature review and hypothesis development

## 2.1 Firm resilience and relational embeddedness

Grounded in the resource-based view, scholars argue that resources and their allocation capabilities are central to resilience [15], with increasing attention being paid to intangible resources, including human, organizational, relational, and technical resources [16]. Research indicates that factors such as managerial overconfidence and greed [17], organizational learning and flexible integration [18], and network adaptability alongside structural vulnerabilities in strategic alliances [19], all influence resilience through the dimensions of human and organizational resources. On the other hand, corporate social responsibility enhances a firm's risk-resilience through relational resources, such as reputation capital and brand equity [20, 21]. Despite these contributions, while current research addresses the key types of intangible resources, the mechanisms underlying the synergy between technical resources and the supply chain network remain underexplored, particularly in terms of their impact on the structural characteristics of supply chains [3].

Social Network Theory offers a fresh perspective on this issue. Within the context of supply chains, relational embeddedness is manifested through the frequency of interactions, the level of trust, and the degree of resource dependence between firms and their key suppliers and customers [5]. Enhancing relational embeddedness can bolster firm resilience in areas such as risk management, resource coordination, and informal governance mechanisms. Firstly, strong supplier relationships facilitate real-time information exchange, allowing firms to proactively identify potential risks—such as raw material shortages and logistics delays—and develop contingency plans accordingly [22]. Secondly, firms that are highly dependent on core suppliers can leverage the lock-in effect to prioritize supply assurance and swiftly adjust order allocations during crises [23]. Furthermore, informal governance mechanisms established through long-term cooperative relationships—such as reciprocal commitments and reputation constraints—can mitigate opportunistic behavior among partners and enhance collaboration efficiency during crises [24].

Supplier concentration specifically reflects a firm's resource dependence on a limited number of core suppliers. Highly concentrated supplier relationships foster deep collaboration and trust, and such long-term partnerships can encourage specific investments, such as joint research and development (R&D) and customized production. This makes suppliers more inclined to prioritize the needs of key firms during crises [5]. Furthermore, the strong ties between firms and their core suppliers facilitate the unification of production processes and quality standards, thereby reducing coordination frictions in emergencies [6]. In terms of governance, suppliers with a high dependency on specific clients may be compelled to accept stricter social responsibility provisions, such as compliance with ESG standards. This can help mitigate the moral hazard associated with the supplier concentration [25]. Customer concentration refers to a firm's reliance on a limited number of large customers. While excessive dependence can weaken bargaining power [8], strategic coordination with key customers can provide stability during crises. Strong relationships with core customers foster collaborative mechanisms, such as joint inventory management and shared logistics resources, which can help alleviate sudden fluctuations in demand [9]. Furthermore, companies that depend on large customers may leverage their industry position to secure policy support or preferential resource allocation, such as government subsidies during the pandemic. Accordingly, H1 and H2 are proposed:

*H1: Supplier concentration has a positive impact on firm resilience.*

*H2: Customer concentration has a positive effect on firm resilience.*

## 2.2 The moderating effect of digital environment

The digital environment enhances the positive impact of relational embeddedness on firm resilience, as evidenced by improved supply chain transparency and overall network robustness. Digital technologies, such as blockchain, artificial intelligence, and the Internet of Things, reduce communication costs among supply chain members and facilitate high-frequency, high-quality information exchange [26]. For instance, blockchain technology enables comprehensive traceability, while smart contracts ensure data transparency, allowing suppliers and core firms to share ESG information in real time. This reduces information asymmetry and enhances supply chain transparency [27]. The digital platform offers a comprehensive information disclosure framework for supply chain participants, facilitating the integration of ESG data from suppliers via a cloud-based system. It promotes the establishment of shared sustainable practice standards for both upstream and downstream stakeholders. Technology-driven collaborative governance enhances suppliers' reliance on core firms [28], creating a lock-in effect that encourages suppliers to actively adhere to transparency requirements and develop a self-monitoring mechanism. Such as, core firms are intricately woven into the supplier network through digital tools, such as supply chain management (SCM) systems and Enterprise Resource Planning (ERP) software, which enable real-time monitoring of supplier behavior and the rapid identification of potential risks, including labor issues and environmental violations. Accordingly, H3 is proposed:

*H3: The digital environment positively moderates the relationship between relational embeddedness and firm resilience.*

## 2.3 The moderating effect of digital transformation

Digital transformation reconstructs the operational logic of supply chain networks through technological empowerment. Digital technologies, such as the Internet of Things, blockchain, and artificial intelligence, not only enhance the visibility and responsiveness of supply chains [29], but also reshape the power dynamics and collaboration modes among firms [30]. According to dynamic capability theory [14], digital transformation can positively influence the impact of relational embeddedness on firm resilience. For instance, blockchain technology improves supply chain traceability and reduces coordination costs associated with information asymmetry through tamper-proof distributed ledgers [31]. Smart contracts and predictive maintenance systems can automate crisis response processes, thereby shortening the time frame from risk identification to action [32]. Additionally, digital ecosystems, such as industrial Internet platforms, facilitate cross-firm resource sharing and enable firms to dynamically adjust their supply chain structures to address uncertainty [12]. It is important to note that the impact of digital transformation on firm resilience may exhibit heterogeneous characteristics: Digitalization Depth refers to the extent and intensity of the current application of digital technology within firms. A high degree of digitalization can enhance the synergistic effects of relationship embedding by integrating multiple data flows [33]. Digitalization speed pertains to the rate, at which firms advance their digitalization efforts [34].

A high degree of digital transformation, exemplified by the comprehensive implementation of AI-driven demand forecasting systems, can enhance the positive effects of supplier concentration. For instance, IoT sensors monitor suppliers' production statuses in real time, enabling firms to swiftly identify disruption risks and initiate contingency plans [33]. Additionally, smart contracts supported by blockchain technology can automatically trigger emergency procurement agreements, thereby reducing negotiation delays [31]. Digital platforms also integrate secondary supplier data to improve the management of multi-tier supply chains [35]. Similarly, firms that are highly digitalized can leverage the stability of customer concentration more effectively. They utilize big data to analyze historical customer behavior, predict and mitigate demand fluctuations [11], and simulate customer demand scenarios using digital twin technology, allowing for rapid adjustments to product configurations [32]. Consequently, H4 is proposed:

*H4: The degree of digital transformation positively moderates the relationship* *between relational embeddedness and firm resilience.*

Firms that swiftly embrace digital transformation are more likely to capitalize on opportunities through technological iteration. For suppliers, the rapid deployment of cloud and edge computing capabilities facilitates the dynamic reconfiguration of supply chain networks [29]. Firms that lead in establishing digital ecosystems can attract a greater number of high-quality suppliers, thereby creating technical barriers to entry [12]. For customers, accelerated digitalization enables firms to respond more quickly to shifts in customer demand and utilize virtual reality to collaboratively optimize product solutions, thereby shortening delivery cycles [36]. Additionally, real-time adjustments to pricing strategies based on machine learning can help balance large customer orders with market fluctuations [37]. Consequently, H5 is proposed:

*H5: The speed of digital transformation positively moderates the relationship between relational embeddedness and firm resilience.*

Based on the assumptions above, we have developed a theoretical framework that integrates "relationship embeddedness, digital transformation, and firm resilience" (see Figure 1). This model highlights the concentration of suppliers and customers as the central dimension of relationship embeddedness, which directly enhances resilience through resource integration and risk-sharing mechanisms. The degree and speed of digital transformation reinforce this relationship at two levels: static capacity accumulation and dynamic adaptive capacity.

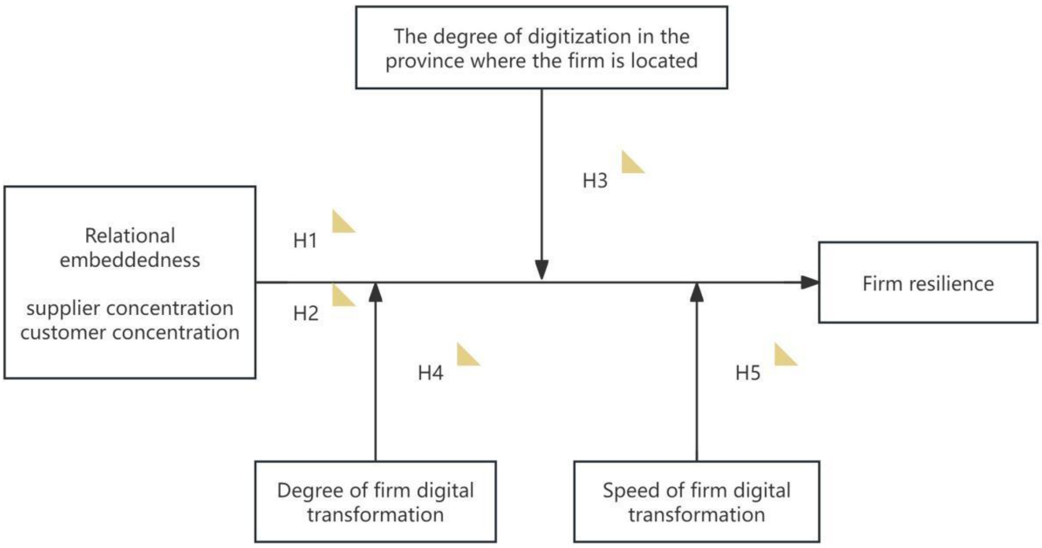


**FIGURE 1** The Conceptual Model

## 3. Methodology

### 3.1 Data and sample

We adopt a mixed method approach. First, we conduct secondary data analysis and then used the case of Huawei to validate our findings. We collected relevant sample data from two major databases: the China Stock Market and Accounting Research (CSMAR) and the Wind China Financial Database, to analyze the impact of supplier concentration relationship embeddedness on firm resilience, as well as the multi-dimensional moderating effect of digital transformation. The data used in this study encompasses listed companies in the semiconductor manufacturing industry from 2017 to 2023, following the issuance of the List in March 2016, which imposed sanctions on China's semiconductor industry. Additionally, we utilized the company code and year as identifiers across different databases, integrating environmental and financial information while matching environmental regulatory pressure based on the company's location and year. After excluding firms designated for special treatment (ST), we ultimately obtained data on 477 listed firms, resulting in a total of 2,259 data points that form the foundation for our empirical analysis.

## 3.2 Variables

### 3.2.1 Firm resilience

Following Dormady, et al. [38], we utilize the production function to assess the resilience of firms. The production function illustrates how a firm operates, provides insights into input allocation and associated productivity levels, and explicitly demonstrates how the input-output relationship varies with scale. It encompasses intermediate inputs, labor inputs, and capital investment. In line with the approach outlined by Nagle [39], we employ the classic Cobb-Douglas production function to estimate total factor productivity (TFP), using the change in TFP as a measure of firm resilience. Specifically, we define resilience as the degree of change in TFP in the current period relative to the previous period [5, 40]. There are several methods available for calculating the total factor productivity of firms, with common approaches including the Ordinary Least Squares (OLS) method, the Olley-Pakes (OP) method [41], and the Levinsohn-Petrin (LP) method [42]. Given that this study employs panel data, we have opted to use the OLS method to calculate the total factor productivity of firms while controlling for fixed effects related to both year and firm.

$$\mathrm{Re}\,siliences_{it} = TFP_{it} - TFP_{it-1} \qquad (1)$$

### 3.2.2 Relational embeddedness

Following the study by Jiang, et al. [5], we measure supplier concentration by calculating the proportion of expenditure allocated to the top five suppliers relative to total expenditure, referred to as SC_Top5. Customer concentration is measured by the ratio of revenue generated by the top five customers relative to total revenue, denoted as CC_Top5. The calculations are as follows:

$$SC_{it} = \sum_{1}^{5} Purchases_{ist} \Big/ Purchases_{it} \quad (2)$$

$$CC_{it} = \sum_{1}^{5} Sales_{ist} \Big/ Sales_{it} \quad (3)$$

$SC_{it}$ represents the supplier concentration of the focal company $i$ in the year $t$, $Purchases_{ist}$ is the company's procurement expenditure on suppliers in the year $t$, $Purchases_{it}$ is the total procurement expenditure paid by the focal company $i$ in the year. $CC_{it}$ represents the customer concentration of the focus company $i$ in the year $t$, $Sales_{ist}$ denotes the sales revenue that the focus company $i$ obtains from customers $s$ in the year $t$, and $Sales_{it}$ denotes the total sales revenue that the focus company $i$ obtains in the year $t$. A higher value of $SC_{it}$ and $CC_{it}$ indicates a higher concentration of suppliers and customers.

**3.2.3 Control variables**

To ensure the accuracy of our estimates and to eliminate confounding factors, we include a range of control variables that may influence firm resilience. Specifically, we control for firm size (Size), leverage ratio (Lev), tangible assets ratio (Tang), return on assets (ROA), research and development investment (R&D), board size (Board), ownership concentration (OC), and board independence (Indep). Larger companies typically possess more financial and managerial resources than smaller firms, enabling them to better absorb shocks and adjust their production processes [43]. Consequently, we control for size (Size) by using the natural logarithm of total assets as the measurement standard[44]. The availability of financial resources can significantly impact cash flow and the resilience of firms during crises [45]. Therefore, we include leverage (Lev) as a control variable, defined as the ratio of total debt to total assets[46]. Some firms possess a greater proportion of intangible assets, which may provide them with increased flexibility in responding to shocks. We control for tangibility (Tang) by calculating the ratio of tangible assets to total assets [47]. Firms with strong profitability are generally more likely to demonstrate sustainable development performance [48], and we include return on assets (ROA) as a control variable. High-tech companies often exhibit superior innovation capabilities, allowing them to adapt to uncertain environments by innovating their processes and products [49]. Therefore, we control for R&D input (R&D), measured as the ratio of R&D expenditure to income [50]. Board size (Board) may enhance firm resilience by providing additional resources and information; however, if it becomes excessively large, it may lead to inefficient decision-making, thereby negatively impacting firm resilience. We measure board size by the number of directors [51]. Ownership concentration (OC) is assessed by the shareholding ratio of the largest shareholder [52], which can influence decision-making dynamics and strategic choices within a company. The independence of the board of directors (Indep) positively affects firm performance, and research indicates that board independence may enhance the resilience of firms in the face of disruptive events [53]. We measure board independence by the proportion of independent directors on the board [54].

### 3.2.4 Mechanism variables

The digital environment (DE) may amplify the positive impact of relational embeddedness on firm resilience through technological empowerment and network reconstruction. We measure the digital environment using the digitalization index of the province in which the firm is located, with data sourced from the China Digital Economy Development Index Report.

Digital Transformation Degree (DT): We analyzed the frequency of 99 digital-related terms across four dimensions: digital technology application, internet business models, intelligent manufacturing, and modern information systems. Through keyword text analysis, we constructed an index to measure the degree of firm digital transformation. Companies pursue digital transformation to leverage technology for creating new products and services, streamlining operations, enhancing efficiency, and achieving a competitive advantage in the market [55].

Digital Transformation Velocity (DTV): Based on the annual report of the firm, we assess the degree of digital transformation for the current year and compare it to the previous year. Using this information, we construct a measurement index for digital transformation velocity $DTV = \left(DT_{it} - DT_{it-1}\right)/DT_{it-1}$ . Specifically, digital transformation velocity is defined as the ratio of the current year's degree of digital transformation to that of the previous year. A higher value $DTV$ indicates a faster rate of digital transformation for the firm. (All variables describe see Appendix 1.)

## 4. Empirical tests

### 4.1 Descriptive statistics and model setting

Appendix 2 presents the descriptive statistical results for each variable. Appendix 3 displays the Pearson correlation coefficients among the variables. Appendix 4 provides the results of the multicollinearity test to prevent redundancy among the variables. The findings indicate that the variance inflation factor (VIF) is less than 3, significantly below the threshold of 10, suggesting that multicollinearity among the variables does not impact the subsequent empirical analysis.

As shown in Appendix 5, the results of the Hausman test are statistically significant, indicating that the fixed effects model is more appropriate for this study than the random effects model. Furthermore, given the panel data utilized in this research, we believe it is suitable to apply the two-way fixed effects model. The regression model is specified as follows:

$$RES_{i,t} = \alpha_0 + \alpha_1 SC_{i,t} + \alpha_2 X_{i,t} + \mu_i + \eta_t + \varepsilon_{it} \quad (4)$$

$$RES_{i,t} = \beta_0 + \beta_1 CC_{i,t} + \beta_2 X_{i,t} + \mu_i + \eta_t + \varepsilon_{it} \quad (5)$$

In the constructed model, Res represents firm resilience, SC represents the firm's supplier concentration, CC represents the firm's customer concentration, and X contains control variables. i and t refer to the firm and year, respectively. The model includes both individual and time fixed effects, while the random disturbance term is denoted as $\varepsilon_{it}$ . The coefficient $\alpha_1$ , $\beta_1$ quantifies the impact of supplier concentration and customer concentration on firm resilience respectively, while the coefficient $\alpha_2$, $\beta_2$ evaluates the impact of control variables on firm resilience. Finally, the constant term is expressed as $\alpha_0$ , $\beta_0$ .

## 4.2 Regression Results

As shown in Table 1, Models (1) and (2) present the estimation results of the benchmark regression models for Supplier Concentration (SC) and Customer Concentration (CC) with two-way fixed effects. The estimated coefficient for SC is 0.002, which is statistically significant at the 10% level. This finding indicates that a significant increase in a company's supplier concentration contributes to the enhancement of its resilience level. In contrast, the estimated coefficient for CC is also 0.002, achieving significance at the 5% level, indicating a positive relationship between a firm's customer concentration and its level of resilience, thereby confirming hypotheses H1 and H2. For the control variables, the estimated coefficients for Size are 0.094 and 0.096, respectively, both significant at the 1% level. This finding indicates that an increase in firm size positively impacts its resilience. The estimated coefficients for Lev are 0.223 and 0.225, respectively, also significant at the 1% level. This suggests that an increase in leverage enhances resilience. The estimated coefficients for ROA are 0.981 and 1.000, respectively, both significant at the 1% level. This indicates that an increase in a firm's earnings positively affects its resilience. Conversely, the estimated coefficients for R&D are consistently −0.016 and significant at the 1% level. This finding suggests that an increase in a firm's R&D expenditure may have a dampening effect on its resilience.

**TABLE 1** Results of fixed effect regression analysis

| | (1) | (2) |
| --- | --- | --- |
| Variables | RES | RES |
| SC | 0.002* | |
| | (1.80) | |
| CC | | 0.002** |
| | | (2.21) |

| | | |
|---|---|---|
| Size | 0.094*** | 0.096*** |
| | (2.84) | (2.90) |
| Lev | 0.223*** | 0.225*** |
| | (5.40) | (5.45) |
| Tang | 0.272 | 0.252 |
| | (0.48) | (0.44) |
| Indep | 0.003 | 0.003 |
| | (0.07) | (0.07) |
| ROA | 0.981*** | 1.000*** |
| | (8.78) | (9.02) |
| OC | 0.001 | 0.001 |
| | (0.45) | (0.52) |
| Board | 0.007 | 0.008 |
| | (0.46) | (0.53) |
| R&D | -0.016*** | -0.016*** |
| | (-7.29) | (-7.16) |
| Constant | -2.163*** | -2.260*** |
| | (-2.90) | (-3.02) |
| ID FE | YES | YES |
| YEAR FE | YES | YES |
| Observations | 1,324 | 1,324 |
| R-squared | 0.500 | 0.501 |

Note: *, **, and *** stand for significant at the level of 10%, 5%, and 1%, respectively.

## 4.3 Robustness Test

Since extreme values in the regression samples can lead to deviations in the estimation results, this paper trims the explanatory variables in the benchmark regression at the 5% and 95% quantiles. Based on this adjustment, it modifies the Total Factor Productivity (TFP) measurement methods (OP method & LP method) to conduct a robustness test. The specific regression results are presented in Appendix 6. It can be observed that after eliminating the extreme values and altering the TFP measurement methods, the conclusions remain largely unchanged.

## 4.4 Endogeneity Test

By controlling for the one-period lag of explanatory variables, this paper addresses the issue of two-way causality and considers a wide range of factors that influence firm resilience. However, due to data limitations, it is inevitable that some variables may be omitted, leading to endogeneity issues in the regression analysis. To effectively mitigate the endogeneity problem, this paper follows the methodology outlined by Fisman and Svensson [56], and employs the median ratio of the purchase amount from the largest supplier to the total purchase amount of other firms in the same year as the instrumental variable for SC. Additionally, the median customer concentration of other firms in the same year serves as the instrumental variable for customer concentration (CC). These variables meet the exogeneity and correlation assumptions required for instrumental variables. The regression results, presented in Appendix 7, indicate that endogeneity issues do not compromise the conclusion that relational embeddedness enhances firm resilience.

## 4.5 Test of mechanism

To examine the moderating impact of digital transformation on the relationship between relational embeddedness and firm resilience, we employ a moderating effect model to assess the presence of a moderating effect by analyzing the significance of the coefficient associated with the interaction term. To mitigate the risk of spurious regression resulting from multicollinearity, the moderator variables are centered prior to the inclusion of the interaction terms. The results of the regression analysis are presented in the table. The configuration of the moderating effect model is as follows:

$$RES_{i,t} = \chi_0 + \chi_1 SC_{i,t} + \chi_2 M_{i,t} + \chi_3 M_{i,t} \times SC_{i,t} + \chi_4 X_{i,t} + \mu_i + \eta_t + \varepsilon_{i,t} \quad (6)$$

$$RES_{i,t} = \delta_0 + \delta_1 CC_{i,t} + \delta_2 M_{i,t} + \delta_3 M_{i,t} \times CC_{i,t} + \delta_4 X_{i,t} + \mu_i + \eta_t + \varepsilon_{i,t} \quad (7)$$

The test results for the moderating effect of Digital Environment (DE) are presented in Model (1) and Model (2) in Table 2. The interaction coefficients of DE with SC and CC are not significant, indicating that the digital environment does not play a moderating role in the relationship between relational embeddedness and firm resilience; therefore, Hypothesis H3 is not supported. The test results for the moderating effect of Digital Transformation (DT) are presented in Model (3) and Model (4). The interaction coefficient between digital engagement and SC is found to be positive and significant at the 10% level, indicating statistical significance. In contrast, the interaction coefficient between DT and CC is not significant, suggesting that DT has an enhanced moderating effect on the relationship between SC and firm resilience. However, the moderating effect of DT on the relationship between CC and firm resilience is not significant, which partially supports Hypothesis H4.

**TABLE 2** Results of mechanistic testing

| | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| VARIABLES | RES | RES | RES | RES | RES | RES |
| SC | 0.002* | | 0.002 | | 0.002* | |
| | (1.71) | | (1.56) | | (1.89) | |
| CC | | 0.002** | | 0.002** | | 0.002** |
| | | (2.16) | | (2.15) | | (2.19) |
| DE | 0.001 | 0.001 | | | | |
| | (0.98) | (0.90) | | | | |
| DE*SC | -0.000 | | | | | |
| | (-1.10) | | | | | |
| DE*CC | | 0.000 | | | | |
| | | (0.48) | | | | |
| DT | | | 0.010 | 0.011 | | |
| | | | (0.48) | (0.49) | | |
| DT*SC | | | 0.002* | | | |
| | | | (1.70) | | | |
| DT*CC | | | | 0.001 | | |
| | | | | (0.40) | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| DTV | | | | | 0.124** | 0.081* |
| | | | | | (2.42) | (1.75) |
| DTV*SC | | | | | 0.005* | |
| | | | | | (1.70) | |
| DTV*CC | | | | | | -0.001 |
| | | | | | | (-0.07) |
| CONTROL | YES | YES | YES | YES | YES | YES |
| Constant | -2.723*** | -2.771*** | -2.217*** | -2.246*** | -2.106*** | -2.214*** |
| | (-2.94) | (-2.98) | (-2.96) | (-2.99) | (-2.83) | (-2.95) |
| ID FE | YES | YES | YES | YES | YES | YES |
| YEAR FE | YES | YES | YES | YES | YES | YES |
| Observations | 1,322 | 1,322 | 1,322 | 1,322 | 1,321 | 1,321 |
| R-squared | 0.501 | 0.501 | 0.501 | 0.501 | 0.503 | 0.502 |

Note: *, **, and *** stand for significant at the level of 10%, 5%, and 1%, respectively.

## 5. Case study of Huawei

In this section, we adopt the secondary qualitative data gathered from the news report and corporate document and report to validate the empirical results of this study. As the world's leading manufacturer of communication technology and intelligent terminals, Huawei occupies an important position in the global telecommunications industry. Its business covers 5G infrastructure construction, cloud computing, intelligent terminals, AI, and enterprise solutions. Over the past few decades, Huawei has consistently strengthened its SCM, customer relationships, and digital transformation initiatives, resulting in a highly concentrated supplier network and customer base, while making significant investments in digital technologies.

However, since 2019, Huawei has faced a succession of external shocks, US sanction severely restricted Huawei’s access to advanced semiconductor chips, leading to serious shortages in high performance chips and therefore affecting its 5G infrastructure and smart terminal products [68]. To overcome this challenge, Huawei has increased investment in its own chips, such as the Kirin series, and is looking for alternative suppliers [68]. In addition, Huawei has effectively enhanced its resilience by adjusting its supply chain strategy, deepening customer cooperation, and accelerating its digital transformation, which provides a good verification scenario for the empirical conclusions of this study.

First, in terms of supplier concentration, Huawei has long relied on core suppliers around the world to support its technology research and development and production. In the past, Huawei's chips were mainly contracted by TSMC, and other core suppliers also included global semiconductor companies such as Broadcom to provide communications chips and key components [66]. However, since the US imposed sanctions on Huawei in 2020, suppliers such as TSMC were forced to stop supplying Huawei, which made it face unprecedented supply chain challenges [65]. To cope with this crisis, Huawei has had to significantly change its supply chain structure and strengthen cooperation with local suppliers, especially strengthening its relationship with Semiconductor Manufacturing International Corporation (SMIC) to ensure the stability of core chips [56; 67]. At the same time, Huawei still maintains cooperation with international manufacturers in the supply of low or medium level chips and strives to find a balance point in the context of the limited global supply chain.

In terms of customer relationships, Huawei shows a highly concentrated feature, especially in the domestic market, where it maintains long-term and stable cooperative relationships with China's three major telecom operators (China Mobile, China Telecom, China Unicom) [56]. These three operators are the core customers of Huawei's communication equipment business. Their stable orders and clear demand forecast provide a strong guarantee for Huawei in terms of capacity planning, SCM and market layout, help it effectively reduce the uncertainty caused by the market demand wave, and improve the firm resilience [61]. In the international market, although Huawei's business cooperation in some European and American markets has surged in recent years due to the policy restrictions of some countries, its customer concentration advantage in emerging markets is still significant. Especially in Africa, the Middle East, Southeast Asia and other regions, Huawei has established long-term cooperative relationships with major local telecom operators and government-led infrastructure projects and participated in the construction of communication networks in many countries [63]. The stability of these market partnerships not only provides Huawei with continuous order demand, but also helps it obtain policy support and resource tilt from local governments, further enhancing the resilience of firms in the uncertain global environment.

In terms of digital transformation, Huawei has greatly invested technology development. First, Huawei operates in a superior digital environment with sound infrastructures [56]. While the superior digital environment has played an important role in increasing information sharing and improving network governance, it has not significantly changed the structure of Huawei's relationships with suppliers and customers. This is because, while the digital environment provides a solid technical foundation that helps improve the transparency of information flow and the efficiency of decision-making, it mainly supports and optimizes the management of supply chains but fails to fundamentally change the core structure of supply chain relationships. For example, Huawei's relationship with suppliers is still based on long-term strategic cooperation and trust, while customer concentration is still affected by market demand fluctuations and policy changes [62]. The digital environment improves operational efficiency by increasing the flexibility and visibility of the supply chain but does not significantly change key factors such as the mode of cooperation, dependence or depth of cooperation between suppliers and customers.

Second, the case of Huawei demonstrates that the degree of digital transformation enhances supplier concentration and has a significant impact on resilience, while its stability effect on customer concentration is relatively limited. Specifically, Huawei deploys intelligent manufacturing in its supply chain, using robotics and AI for production optimization. Its big data platforms gather and analyze vast amounts of supply chain-related data daily. Additionally, the cloud collaboration system enables seamless global communication among supply chain members for efficient SCM [56]. For example, Huawei and SMIC realize real-time sharing of production data and flexible adjustment of orders through digital platforms, which improves the collaborative efficiency of both parties and reduces the friction cost of the supply chain [67; 69]. In terms of customer concentration, although Huawei's digital capability is also leading, changes in customer demand are more affected by market and policy factors.

Finally, after encountering external sanctions, Huawei quickly promoted the construction of intelligent manufacturing systems, using AI, big data and other technologies to improve the flexibility of production scheduling and shorten the response time of the supply chain [56]. For example, Huawei Smart Factory can adjust production plans in real time according to supply chain dynamics and cope with uncertain events such as global chip shortage [67]. By rapidly promoting digital transformation, Huawei has enhanced its synergy with core suppliers, thus maintaining stable operations despite supply chain constraints.

Overall, Huawei's strategic response to external shocks illustrates how supplier concentration, customer concentration, and digital transformation interact to strengthen firm resilience. By deepening long-term partnerships with core suppliers like SMIC, Huawei mitigated supply chain disruptions, exemplifying the positive effect of supplier concentration on resilience. Similarly, its stable relationships with key domestic telecom operators and major clients in emerging markets ensured predictable demand, validating the resilience-enhancing role of customer concentration. Furthermore, Huawei's extensive application of digital technologies and accelerated digital transformation not only improved supply chain visibility and supplier coordination but also amplified the positive impacts of relational embeddedness on resilience. Therefore, Huawei's case provides robust practical evidence supporting the empirical findings of this study.

# 6.Discussion

## 6.1 Theoretical implications

Based on the research focus and theoretical innovations, the contributions of this study can be summarized as follows:

First, this study extends the network-based perspective in resilience research. It examines enterprise resilience through the lens of SNA, proposing that relationship embeddedness—measured by supplier and customer concentration—plays a critical role in shaping firm resilience. Existing studies on firm resilience are largely grounded in the Resource-Based View (RBV), emphasizing internal redundant resources (such as inventory buffers and multi-sourcing) or flexible capabilities [2, 3]. However, insufficient attention has been given to the dynamic role of supply chain network structures. Although SNA has been applied to supply chain research [13], its integration with resilience mechanisms remains limited. This study highlights the positive impact of the semiconductor industry's unique bidirectional supply chain concentration on firm resilience, offering a novel paradigm for understanding resilience formation in networked environments. Responding to Dubey, et al. [3]'s call for research on network dynamics, our empirical findings demonstrate that SC and CC enhance resilience through deep collaboration, rather than relying solely on redundant resources.

Second, this study empirically examines the heterogeneous moderating effect of digital transformation. Existing research primarily focuses on the technological applications of digitization—such as blockchain and the Internet of Things [11, 30]—but lacks a comparative analysis of firm-level digital transformation. To address this gap, we deconstruct digital transformation into two key dimensions: degree (DT) and speed (DTV). Aligning with the conclusions of Zhou and Li [33], our findings reveal that DT enhances the positive effect of supply chain on resilience,. Moreover, our discovery of significant heterogeneity in the moderating effect of relational embeddedness challenges the prevailing technology-centric perspective in digital research. This study advances the literature by uncovering the complex interplay between technological dynamics and network embeddedness, extending the theoretical insights of [14].

Third, this study innovatively integrates empirical analysis with case study, employing cross-validation of multi-source data to enhance the robustness and practical relevance of its findings. Existing research on firm resilience often relies on single-firm data or case studies, making it difficult to address endogeneity concerns, such as reverse causality [56]. To overcome these limitations, we employ a panel dataset of 477 listed companies and apply the instrumental variable (IV) method to mitigate issues of omitted variable bias and bidirectional causality, thereby isolating the net effect of relationship embeddedness on resilience. For instance, we use the industry-median SC/CC as an IV, aligning with Jiang, et al. [5]'s industry mean exogeneity' hypothesis. Additionally, by integrating the enterprise-province digitalization index (DE) with annual report text analysis (DT), we establish a macro-micro data linkage, addressing the shortcomings of single-level analyses [45].

## 6.2 Practical implications

This study offers several practical implications for SCM, digital transformation strategies, and policy coordination.

First, firms should prioritize long-term strategic partnerships with core suppliers, such as foundries and key equipment manufacturers, to enhance supply chain resilience. This includes promoting joint research and development, customized production, and mitigating over-reliance risks through multi-sourcing and well-designed contractual agreements (e.g., priority supply agreements). For instance, leveraging IBM's blockchain technology for full-process traceability enables real-time production data sharing, improving transparency and risk management. While relying on major customers provides demand stability, firms must balance their customer portfolio to minimize risk exposure. Strategies such as dynamic contracts, customer diversification, and digital demand forecasting can help prevent weakened bargaining power and technological path dependency.

Second, digital investment should be prioritized in upstream operations to enable real-time monitoring of suppliers' production status, automate emergency response processes, and enhance supplier network coordination. Big data analytics should be utilized to predict demand fluctuations and optimize capacity planning. However, firms must avoid technological lock-in caused by excessive reliance on a single digital platform, such as a customized CRM system. A flexible and adaptive digital infrastructure is crucial for long-term resilience.

Third, multinational corporations are adopting regionally distributed supply chains and deploying blockchain nodes in technologically sensitive areas, while maintaining moderately decentralized networks in stable markets to enhance flexibility. Governments can support digital infrastructure investments through tax incentives and foster industry associations that establish digital ecosystem platforms. This would encourage collaboration between core enterprises and upstream/downstream partners, strengthening the resilience of the entire industrial chain. In critical supply chain segments, such as photoresist supply, firms should form deep collaborative alliances and leverage digital twin technology to conduct risk simulations and enhance rapid recovery capabilities.

## 7. Conclusion

This study examines the influence of relational embeddedness within the semiconductor industry on firm resilience, along with the multifaceted moderating effects of digitalization factors. To accomplish this objective, the research utilizes an analysis of secondary data from 477 publicly listed manufacturing companies in the Chinese semiconductor sector, spanning the period from 2017 to 2023.

The regression analysis indicates a positive relationship between relational embeddedness and firm resilience. Furthermore, the study identifies the multidimensional moderating effects of digital factors, specifically the digital environment (DE), the degree of firm digital transformation (DT), and the speed of firm digital transformation (DTV). Notably, DT positively moderates the impact of supplier concentration on firm resilience, while DTV also demonstrates a positive moderating effect on this relationship. Conversely, customer concentration may result from the weak bargaining power of core firms, and the moderating effects of digital factors in this context are not significant. Firms should regard digitalization as a strategic tool, integrating it with network embedded features to enhance supply chains resilience. These findings significantly advance the understanding of buyer-supplier relationships and offer valuable insights for scholars and practitioners in the field of operations and SCM.

This study is not free from limitations. First, the use of different measurement methods for firm resilience may influence the research outcomes [52, 57, 58]. We anticipate future studies employing alternative measures to validate the robustness of our findings. Second, while China is a major developing country, focusing on a single nation limits the generalizability of the findings to other emerging economies. Future research could explore these results in the context of various ownership structures beyond China. Lastly, the validity of the findings may need to be evaluated in an international context. Future studies could benefit from expanding the sample size to enhance the model through comprehensive data collection techniques.

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**Appendix 1** Variable description

| Variables | Operationalization | Data Source | Reference |
|---|---|---|---|
| Res | The change in total factor productivity in the current period relative to the previous period | CSMAR | Jiang et al., (2023); Ambulkar et al., (2015) |
| SC | The proportion of expenditure of the top five suppliers relative to total expenditure | CSMAR | Jiang et al., (2023) |
| CC | The proportion of revenue generated by the top five customers relative to total revenue | CSMAR | Jiang et al., (2023) |
| DE | The digitization index of the province where the enterprise is located | China Digital Economy Development Index report | |
| DT | The frequency of digital related words was counted and the keyword text was analyzed | CSMAR | Zhai et al., 2022 |
| DTV | The relative speed of a firm's digital transformation | CSMAR | |
| Size | The natural logarithm of a firm's assets as a proxy for firm size | CSMAR | Tafti et al., (2013) |
| Lev | The ratio of current liabilities to assets | CSMAR | Wiengarten et al., (2017) |
| Tang | The ratio of tangible assets to total assets | CSMAR | Lo et al., (2014) |
| ROA | Return on assets | CSMAR | Lu et al., (2022) |
| R&D | The ratio of R&D expenditure to total sales for the year | CSMAR | Yiu et al., (2020) |
| Board | Number of directors | CSMAR | Ambulkar et al., (2023) |
| OC | The shareholding ratio of the largest shareholder | CSMAR | Xu et al., (2024) |
| Indep | The ratio of independent directors to the total number of directors on the board | CSMAR | Lefort, (2008) |

**Appendix 2** Descriptive statistics

| Variables | Obs | Mean | Std. dev. | Min | Max |
|---|---|---|---|---|---|
| Res | 1,985 | 0.059 | 0.321 | -2.896 | 2.555 |

| | | | | | |
|---|---|---|---|---|---|
| SC | 1,806 | 35.390 | 17.956 | 6.570 | 100.000 |
| CC | 1,806 | 42.731 | 21.719 | 2.430 | 99.640 |
| DE | 1,807 | 412.511 | 40.009 | 304.100 | 467.172 |
| DT | 1,804 | 3.843 | 0.995 | 0.000 | 6.860 |
| DTV | 1,803 | 0.035 | 0.177 | -1.000 | 3.000 |
| Size | 2,259 | 22.205 | 1.216 | 17.545 | 26.832 |
| Lev | 2,259 | 0.401 | 0.313 | 0.026 | 8.009 |
| Tang | 2,259 | 0.033 | 0.029 | 0.000 | 0.243 |
| ROA | 2,259 | 0.025 | 0.113 | -1.751 | 0.664 |
| R&D | 1,805 | 8.686 | 7.697 | 0.260 | 110.900 |
| Board | 1,874 | 7.935 | 1.623 | 0.000 | 17.000 |
| OC | 2,259 | 29.048 | 13.881 | 1.840 | 77.380 |
| Indep | 2,259 | 3.029 | 0.532 | 0.000 | 7.000 |

**Appendix 3** Correlations

| Variables | Res | SC | CC | DE | DT | DTV | Size | Lev | Tang | Indep | ROA | OC | Board | R&D |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Res | 1.000 | | | | | | | | | | | | | |
| SC | -0.018 | 1.000 | | | | | | | | | | | | |
| CC | 0.009 | 0.272*** | 1.000 | | | | | | | | | | | |
| DE | -0.100*** | 0.054** | 0.065*** | 1.000 | | | | | | | | | | |
| DT | -0.118*** | -0.096*** | -0.122*** | 0.109*** | 1.000 | | | | | | | | | |
| DTV | 0.104*** | -0.009 | 0.030 | -0.067*** | 0.047** | 1.000 | | | | | | | | |
| Size | 0.123*** | -0.207* | -0.101* | -0.013 | 0.127*** | -0.026 | 1.000 | | | | | | | |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | ** | ** | | | | | | | | | | | |
| Lev | -0.206*** | -0.061** | -0.029 | -0.023 | 0.087*** | -0.027 | 0.187*** | 1.000 | | | | | | |
| Tang | 0.001 | -0.016 | 0.009 | -0.025 | 0.059** | 0.013 | 0.044** | 0.071*** | 1.000 | | | | | |
| Indep | -0.009 | -0.013 | 0.004 | -0.038 | 0.021 | -0.006 | 0.216*** | 0.021 | -0.041* | 1.000 | | | | |
| ROA | 0.459*** | 0.007 | -0.048** | 0.009 | -0.083*** | 0.074*** | 0.132*** | -0.619*** | -0.135*** | 0.019 | 1.000 | | | |
| OC | 0.033 | -0.040* | 0.036 | -0.064*** | -0.025 | 0.048** | -0.007 | -0.030 | -0.095*** | -0.042** | 0.115*** | 1.000 | | |
| Board | 0.039 | -0.024 | -0.037 | -0.033 | -0.017 | -0.019 | 0.247*** | -0.006 | -0.049** | 0.713*** | 0.059** | -0.065*** | 1.000 | |
| R&D | -0.223*** | 0.063*** | 0.016 | 0.116*** | 0.211*** | -0.052** | -0.120*** | 0.074*** | 0.183*** | 0.031 | -0.270*** | -0.111*** | -0.039 | 1.000 |

Note: *, **, and *** stand for significant at the level of 10%, 5%, and 1%, respectively.

Appendix **4** The multicollinearity test

| Variables | VIF | SQRT-VIF | TOLERANCE | R2 |
|---|---|---|---|---|
| Res | 1.38 | 1.17 | 0.7260 | 0.2740 |
| SC | 1.14 | 1.07 | 0.8799 | 0.1201 |
| CC | 1.12 | 1.06 | 0.8934 | 0.1066 |
| DE | 1.05 | 1.02 | 0.9563 | 0.0437 |
| DT | 1.13 | 1.06 | 0.8827 | 0.1173 |
| DTV | 1.03 | 1.01 | 0.9721 | 0.0279 |
| Size | 1.33 | 1.15 | 0.7545 | 0.2455 |
| Lev | 2.01 | 1.42 | 0.4979 | 0.5021 |
| Tang | 1.08 | 1.04 | 0.9233 | 0.0767 |
| Indep | 2.10 | 1.45 | 0.4752 | 0.5248 |
| ROA | 2.57 | 1.60 | 0.3895 | 0.6105 |
| OC | 1.03 | 1.02 | 0.9695 | 0.0305 |
| Board | 2.11 | 1.45 | 0.4731 | 0.5269 |
| R&D | 1.26 | 1.12 | 0.7921 | 0.2079 |

| MEAN-VIF | 1.45 |
|---|---|

**Appendix 5** Haussmann test

| hausman | (b-B)'[(V_b-V_B)^(-1)](b-B) | p |
|---|---|---|
| Chi2(SC) | 81.50 | 0.000 |
| Chi2(CC) | 81.85 | 0.000 |

**Appendix 6** Results of robustness checks

| Variables | (1) Res_winsor | (2) Res_OP | (3) Res_LP | (4) Res_winsor | (5) Res_OP | (6) Res_LP |
|---|---|---|---|---|---|---|
| SC | 0.002* | 0.002* | 0.002* | | | |
| | (1.79) | (1.70) | (1.87) | | | |
| CC | | | | 0.003** | 0.003** | 0.002* |
| | | | | (2.51) | (2.47) | (1.94) |
| Size | 0.093*** | -0.009 | 0.008 | 0.095*** | -0.007 | 0.009 |
| | (2.83) | (-0.28) | (0.22) | (2.90) | (-0.21) | (0.26) |
| Lev | 0.222*** | 0.153*** | 0.200*** | 0.224*** | 0.156*** | 0.201*** |
| | (5.38) | (3.76) | (4.54) | (5.44) | (3.82) | (4.58) |
| Tang | 0.273 | -0.128 | -0.158 | 0.254 | -0.146 | -0.183 |
| | (0.48) | (-0.23) | (-0.26) | (0.45) | (-0.26) | (-0.30) |
| Indep | 0.003 | 0.007 | -0.006 | 0.003 | 0.007 | -0.006 |
| | (0.08) | (0.20) | (-0.17) | (0.07) | (0.19) | (-0.15) |
| ROA | 0.982*** | 0.844*** | 0.908*** | 0.998*** | 0.858*** | 0.927*** |
| | (8.81) | (7.65) | (7.63) | (9.01) | (7.84) | (7.83) |
| OC | 0.001 | 0.000 | 0.000 | 0.001 | 0.000 | 0.001 |
| | (0.43) | (0.08) | (0.19) | (0.54) | (0.19) | (0.26) |
| Board | 0.007 | 0.004 | 0.007 | 0.008 | 0.005 | 0.008 |
| | (0.45) | (0.26) | (0.44) | (0.54) | (0.36) | (0.49) |
| R&D | -0.016*** | -0.013*** | -0.015*** | -0.016*** | -0.012*** | -0.014*** |
| | (-7.29) | (-5.68) | (-6.09) | (-7.16) | (-5.56) | (-5.96) |
| Constant | -2.160*** | 0.163 | -0.225 | -2.272*** | 0.051 | -0.292 |
| | (-2.90) | (0.22) | (-0.28) | (-3.04) | (0.07) | (-0.37) |
| ID FE | YES | YES | YES | YES | YES | YES |
| YEAR FE | YES | YES | YES | YES | YES | YES |
| Observation | 1,324 | 1,324 | 1,324 | 1,324 | 1,324 | 1,324 |

| s | | | | | | |
|---|---|---|---|---|---|---|
| R-squared | 0.500 | 0.378 | 0.421 | 0.501 | 0.380 | 0.422 |

Note: *, **, and *** stand for significant at the level of 10%, 5%, and 1%, respectively.

**Appendix 7** Results of the Endogeneity test

| Variables | FIRST SC | 2SLS Res | FIRST CC | 2SLS Res |
|---|---|---|---|---|
| IV-sc | 10.639*** | | | |
| | (0.746) | | | |
| SC | | 0.004* | | |
| | | (0.002) | | |
| IV-cc | | | 12.011*** | |
| | | | (0.770) | |
| CC | | | | 0.004* |
| | | | | (0.002) |
| Size | -0.122 | 0.102*** | -0.798 | 0.098*** |
| | (0.992) | (0.034) | (0.867) | (0.033) |
| Lev | -3.531** | 0.460*** | -1.483 | 0.228*** |
| | (1.633) | (0.055) | (1.083) | (0.041) |
| Tang | -19.678 | 0.451 | 2.880 | 0.256 |
| | (16.568) | (0.564) | (14.927) | (0.568) |
| Indep | 1.604 | 0.026 | 1.658* | 0.000 |
| | (1.040) | (0.036) | (0.955) | (0.036) |
| ROA | 15.011*** | 1.283*** | 3.224 | 0.996*** |
| | (3.727) | (0.132) | (2.914) | (0.111) |
| OC | -0.054 | -0.001 | -0.107* | 0.001 |
| | (0.069) | (0.002) | (0.057) | (0.002) |
| Board | -0.878** | -0.016 | -1.252*** | 0.010 |
| | (0.432) | (0.015) | (0.382) | (0.015) |
| R&D | 0.226*** | -0.013*** | 0.004 | -0.016*** |
| | (0.065) | (0.002) | (0.059) | (0.002) |
| Obs | 1077 | 1077 | 1324 | 1324 |
| R2 | | 0.233 | | 0.188 |
| F | 203.213 | 28.842 | 243.330 | 26.848 |
| CD Wald F | 203.213 | | 243.330 | |
| SW S stat. | 3.586 | | 3.925 | |

Note: *, **, and *** stand for significant at the level of 10%, 5%, and 1%, respectively.