Supply Chain Digitalization and Risk Mitigation: The Roles of Supply Chain Concentration and Liquidity Management

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Abstract. Based on the data from Chinese A-share listed manufacturing firms spanning 2020 to 2024, this study empirically examines the impact of supply chain digitalization on supply chain risk and identifies an important transmission channel. Using panel regressions with year fixed effects and the Bootstrap tests, the results show that supply chain digitalization significantly mitigates firms' supply chain risk, and that reduced supply chain concentration constitutes an important transmission channel. Further analysis shows that supply chain liquidity management moderates digitalization's mitigating impact on supply chain risk: the greater the accounts receivable pressure and the higher the days payable outstanding (DPO), the weaker the risk-mitigating effect of supply chain digitalization. Heterogeneity analysis further reveals that the risk-mitigating effect of digitalization is more pronounced in state-owned enterprises and non-high-tech firms, reflecting the moderating role of firm resources and technological foundations. This study provides empirical evidence for understanding how digitalization enhances supply chain risk management and offers practical implications for firms seeking to optimize supply chain liquidity management.

Keywords: supply chain digitalization; supply chain risk; supply chain concentration; accounts receivable pressure; days payable outstanding

1 Introduction

In recent years, global supply chains have repeatedly exhibited vulnerabilities. Existing studies show that digital supply chain policies help improve firm resilience [1]. Digital transformation can enhance supply chain resilience by strengthening information sharing and improving the speed of demand response, while also improving supply chain efficiency by reducing transaction costs and alleviating customer concentration [2-5]. At the same time, growing attention has been paid to the effect of digitalization on upstream and downstream relationship structures, particularly whether it helps firms reduce dependence on a small number of key customers and suppliers [6].

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Prior research shows that supply chain digitalization enhances financial stability, reduces firms' risk exposure, and alleviates supply chain vulnerability [2,7-8]. However, investment in digitalization may increase financial risk[9], excessively high customer or supplier concentration may worsen financing conditions and increase corporate risk-taking [10-11], while the underlying mechanisms remain insufficiently examined. In addition, liquidity management within the supply chain may shape effectiveness of digitalization, as trade credit supports production networks stability whereas accounts receivable pressure and supplier payment arrangements affect cash flow, cooperative relationships and network stability [12-13].

Therefore, using Chinese A-share listed manufacturing firms, this study systematically analyzes the direct effect of supply chain digitalization on supply chain risk, the transmission channel and the moderating roles of accounts receivable pressure and days payable outstanding (DPO).

2 Theoretical Analysis and Research Hypotheses

2.1 Supply Chain Digitalization and Supply Chain Risk

Supply chain digitalization refers to the integration of digital technologies into planning, procurement, production, sales, and logistics. It enhances real-time monitoring, information sharing, and supply chain visibility, enabling firms to detect disruptions more promptly and improve response efficiency [2,4]. It also reduces transaction costs, broadens firms' partner base, and improves supply-demand matching, thereby alleviating concentration risk arising from over-dependence on a few trading partners [6]. In addition, digitalization improves firms' information environment and operational stability, enhancing external credit support and coordination efficiency across the chain [8,13].

H1: Supply chain digitalization can significantly reduce firms' supply chain risk.

2.2 Supply Chain Concentration as an Important Transmission Channel

Beyond the direct role of technology, supply chain digitalization may reduce risk indirectly by reshaping firms'supply chain structure. Existing studies show that firm digitalization lowers customer concentration by reducing information asymmetry and improving matching efficiency, enhances information transparency and acquisition capabilities, and improves performance by reducing supply chain dependence [4,6,14].

Meanwhile, high supply chain concentration increases risk by intensifying upstream firms' financing constraints and corporate risk-taking [10-11]. From the perspective of resource dependence, when firms rely excessively on a few core trading partners, they become more passive in negotiating prices, arranging credit and responding to external shocks, thereby amplifying operational uncertainty.

H2: Supply chain concentration plays an important role in the relationship between supply chain digitalization and supply chain risk

2.3 Moderating Role of Supply Chain Liquidity Management

Supply chain risk is shaped not only by physical and information flows but also by credit and cash-flow arrangements. Existing studies show that digitalization of business processes can improve the efficiency of working capital management by enhancing data accuracy, and supply chain finance enhances resilience by reinforcing liquidity management [15-16]. However, When firms face high accounts receivable pressure or delayed payments, the risk-mitigating effect of digitalization may be weakened as trade credit is to maintain the stability of production networks [12]. On the customer side, high accounts receivable tie up capital and slow cash recovery, high customer concentration exacerbates upstream firms' financing constraints [10]. On the supplier side, a longer payment cycle generally implies greater reliance on supplier financing, and payment arrangements affect the sustainability of supplier relationships [17].

H3a: Higher accounts receivable pressure weakens the risk-mitigating effect of supply chain digitalization.

H3b: Higher DPO weakens the risk-mitigating effect of supply chain digitalization.

3 Research Design

3.1 Data Sources and Sample Selection

The data used in this study were obtained from the CSMAR and FactSet databases, covering Chinese A-share-listed firms from 2020 to 2024. CSMAR provided financial statement data, while FactSet provided supply chain relationship data.

The sample screening and cleaning procedures were as follows: This study focused on manufacturing firms because manufacturing firms have clearer upstream and downstream transaction chains and are more vulnerable to shocks. Financial firms were excluded. ST, *ST, and PT firms were excluded. Observations with severe missing values for key variables were excluded. All continuous variables were winsorized at the 1% level at both tails. After screening, the final sample contained 3,738 firms and 15,868 firm-year observations, but the effective sample size varied with data availability for the variables.

3.2 Variable Definitions

Dependent Variable. Supply chain risk reflects the extent to which supply-side volatility differs from demand-side volatility. Following Liu et al., supply chain risk is measured as the deviation between fluctuations in firm production and demand [18]. Firm production is proxied by the sum of quarterly cost of sales and net inventory, and demand by quarterly sales revenue. A larger value indicates higher supply chain risk.

Independent Variable. Supply chain digitalization reflects the extent to which digital technologies are integrated into supply chain business operations. Following Jia et al., this study measures it through textual analysis of annual reports based on supply chain digitalization keywords covering planning, procurement, production, sales, and logistics, examples include intelligent prediction, digital planning, e-procurement, supplier management, smart manufacturing, industrial internet, digital marketing, e-commerce, smart logistics, and warehouse management systems. The indicator is calculated as the frequency of supply-chain-digitalization-related keywords divided by the total number of words in the MD&A section and multiplied by 100 [4]. A larger value indicates a higher level of supply chain digitalization.

Transmission-Channel Variable. Supply chain concentration characterizes the extent to which a firm depends on a limited number of core upstream and downstream trading partners. A higher value indicates greater concentration and potentially higher exposure to supply chain risk.

Control Variables. Firm size (Size): natural logarithm of total assets. Leverage (Lev): total liabilities divided by total assets. Profitability (ROA): net income divided by total assets. Growth: year-over-year revenue growth rate. Cash flow (CFO): operating cash flow divided by total assets. State-owned Enterprise (SOE): 1 for state-owned enterprises, 0 otherwise.

Moderating Variables. Accounts receivable pressure is measured as the logarithm of accounts receivable divided by operating revenue, reflecting the extent to which cash recovery is hindered after sales are realized. It is calculated as follows:

$$\text{ARRatio}=\ln\left(\frac{\text{Accounts Receivable}}{\text{Operating Revenue}}\right) \tag{1}$$

DPO is used to capture firms' payment arrangements with upstream suppliers. It reflects the time between the recognition of accounts payable arising from procurement and the actual payment. It is calculated as follows:

$$\text{Paycycle}=\frac{\text{Accounts Payable}}{\text{Operating Cost}}\times 365 \tag{2}$$

3.3 Model Specification

To test the direct impact of supply chain digitalization on supply chain risk, this study constructed the following baseline regression model:

$$\text{Risk}_{it}=\alpha_0+\alpha_1\text{SCDigital}_{it}+\alpha_2\text{Controls}_{it}+\gamma_t+\varepsilon_{it} \tag{3}$$

In Equation (3), $Risk_{it}$ denotes the level of supply chain risk faced by firm i in period t, $SCDigital_{it}$ denotes the degree of supply chain digitalization, $Controls_{it}$ denote the control variables, γ_t denotes year fixed effects, and ε_{it} is the random disturbance term. Given the short sample period from 2020 to 2024, supply chain digitalization exhibits limited within-firm variation. The within-firm standard deviation of SCDigital accounts for only 30.54% of its overall standard deviation, and the coefficient of SCDigital becomes insignificant after firm fixed effects are included. Therefore, the baseline specification retains year fixed effects, and the results are interpreted as associations rather than strict causal estimates.

To test whether supply chain concentration serves as an important transmission channel, this study first examined whether supply chain digitalization significantly affects supply chain concentration by estimating the following model:

$$SupplyChainConcentration_{it}=\beta_0+\beta_1 SCDigital_{it}+\beta_2 Controls_{it}+\gamma_t+\mu_{it} \quad (4)$$

On this basis, supply chain concentration was further introduced into the risk equation to test whether it serves as a transmission channel:

$$Risk_{it}=\theta_0+\theta_1 SCDigital_{it}+\theta_2 SupplyChainConcentration_{it}+\theta_3 Controls_{it}+\gamma_t+\nu_{it} \quad (5)$$

To test the moderating role of liquidity management within the supply chain, this study further introduced the interaction term between accounts receivable pressure and supply chain digitalization. The relevant variables are mean-centered before constructing the interaction term. This model was then used to test H3a:

$$Risk_{it}=\delta_0+\delta_1 SCDigital^c_{it}+\delta_2 ARRatio^c_{it}+\delta_3 (SCDigital^c_{it} \times ARRatio^c_{it})+\delta_4 Controls_{it}+\gamma_t+\xi_{it} \quad (6)$$

$SCDigital^c_{it}$ denotes the centered level of supply chain digitalization, $ARRatio^c_{it}$ denotes centered accounts receivable pressure, and their interaction term captures the moderating effect of accounts receivable pressure on the relationship between supply chain digitalization and supply chain risk.

This study further introduces the interaction term between the supplier payment cycle and supply chain digitalization to test H3b:

$$Risk_{it}=\phi_0+\phi_1 SCDigital^c_{it}+\phi_2 DPO^c_{it}+\phi_3 (SCDigital^c_{it} \times DPO^c_{it})+\phi_4 Controls_{it}+\gamma_t+\omega_{it} \quad (7)$$

Additionally, multicollinearity is not a serious concern, as all variance inflation factors (VIF) within an acceptable range (max = 1.9153).

4 Empirical Results

Table 1 reports that supply chain digitalization significantly reduces supply chain risk (-0.0261, $p < 0.01$), supporting H1. It also significantly lowers supply chain concentration (-22.1225, $p < 0.01$), while supply chain concentration increases supply chain risk (0.0019, $p < 0.001$), supporting H2 together with the Sobel test ($z = -14.7133$, p

< 0.001). After SupplyChainConcentration is included, the coefficient of SCDigital becomes insignificant, indicating that the direct association between digitalization and supply chain risk is no longer evident once the concentration channel is controlled for. Therefore, this study interprets supply chain concentration as a dominant transmission channel, while avoiding a strong claim of definitive full mediation. In addition, the interaction terms SCDigital × ARRatio (0.0766, p< 0.001) and SCDigital × DPO (0.0008, p < 0.05) are significantly positive, indicating that higher accounts receivable pressure and longer payment cycles weaken the effect of digitalization, supporting H3a and H3b.

Table 1. Results of baseline regressions, transmission-channel analysis, and moderation tests.

Variable	Baseline regression	Channel path a	Channel path b	ARRatio moderation	DPO moderation
Supply chain digitalization (SCDigital)	-0.0261** (0.0107)	-22.1225*** (1.0325)	0.0153 (0.0105)		
Supply chain concentration (SupplyChainConcentration)			0.0019*** (0.0001)		
Accounts receivable pressure (ARRatio)				-0.0250*** (0.0018)	
Supply chain digitalization × ARRatio				0.0766*** (0.0192)	
DPO					-0.0006*** (0.0000)
Supply chain digitalization × DPO					0.0008** (0.0003)
Control variables	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes
Observations	14171	14171	14171	7868	7880
R^2	0.2495	0.1221	0.2717	0.2802	0.3239

Note: *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.

5 Further Analysis: Robustness and Heterogeneity

5.1 Robustness Tests

Robustness tests further exclude the 2020 sample and use the one-period-lagged digitalization indicator. In both cases, the baseline coefficient on digitalization remains

significantly negative (-0.0315, p = 0.0053; -0.0284, p = 0.0126), while the interaction terms SCDigital × ARRatio (0.0783, p = 0.0001; 0.0850, p < 0.0001) and SCDigital × DPO (0.0007, p = 0.0278; 0.0007, p = 0.05) remain significantly positive.The Bootstrap test shows that the mean indirect effect is -0.0416, with a 95% confidence interval of [-0.0471, -0.0361], which does not include zero (p< 0.001). This indicates that reduced supply chain concentration constitutes an important transmission channel through which supply chain digitalization is associated with lower supply chain risk. To further address reverse causality concerns, this study constructs a leave-one-out industry-year instrumental variable based on the average SCDigital of other firms in the same industry-year group. The first-stage coefficient is 0.9145, and the first-stage F-statistic is 316.82. In the second stage, SCDigital remains negative (-0.1334) and marginally significant (p = 0.0750). A lagged industry-year IV produces a similar negative coefficient (-0.1078), although it is not statistically significant. Overall, the IV results provide suggestive evidence consistent with the baseline findings, but they should be interpreted with caution.

5.2 Heterogeneity

Table 2. Results of heterogeneity analysis

Group	High group / Group 1	Low group / Group 2	Between-group difference
SOE	State-owned enterprises: -0.0707*** (0.0238)	Non-state-owned enterprises: -0.0160 (0.0119)	-0.0768*** (0.0271)
HighTech	High-tech enterprises: 0.0004 (0.0118)	Non-high-tech enterprises: -0.2147*** (0.0249)	0.2173*** (0.0279)
Industry competition	High-competition industries: 0.0458*** (0.0173)	Low-competition industries: -0.1224*** (0.0135)	0.1727*** (0.0218)
Industry concentration	High-HHI industries: -0.1713*** (0.0160)	Low-HHI industries: 0.0769*** (0.0147)	-0.2738*** (0.0216)
Firm age	Mature firms: -0.0210 (0.0144)	Young firms: -0.0341** (0.0159)	-0.0091 (0.0214)

Note: *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.

As reported in Table 2, the risk-mitigating effect of supply chain digitalization on supply chain risk exhibited clear heterogeneity. From the ownership perspective, the risk-mitigating effect of supply chain digitalization was mainly observed among state-owned enterprises(-0.0707, p <0.01) . From the perspective of firms' techno-

logical attributes, the risk-mitigating effect was much stronger and statistically significant among non-high-tech enterprises(-0.2147, p <0.01). In high-competition industries, the coefficient is significantly positive (0.0458, p < 0.01), while in low-competition industries it is significantly negative (-0.1224, p < 0.01). Similarly, the coefficient is significantly negative in high-HHI industries (-0.1713, p < 0.01), but significantly positive in low-HHI industries (0.0769, p< 0.01). The coefficient is negative but insignificant in mature firms (-0.0210, p = 0.1456), while it is significantly negative in young firms (-0.0341, p = 0.0315). These results suggest that digitalization reduces supply chain risk mainly in less competitive and more concentrated industries. Although the coefficient is significantly negative among younger firms, the between-group difference is insignificant, indicating limited evidence of age-based heterogeneity.

6 Discussion

6.1 Findings

This study identifies and verifies reduced supply chain concentration as an important transmission channel linking supply chain digitalization to lower supply chain risk. At the same time, its risk-mitigating effect is constrained by liquidity arrangements in the supply chain. Both accounts receivable pressure and DPO significantly weaken the effectiveness of digitalization, suggesting that its effectiveness remains contingent on liquidity arrangements across the supply chain.

The heterogeneity results show that this effect is stronger in state-owned and non-high-tech firms. State-owned enterprises typically possess stronger resource integration capabilities and digital infrastructure, while non-high-tech firms often have greater room for improvement. By contrast, high-tech firms face risks more related to technological change and market uncertainty. Therefore, firms should promote digitalization together with optimizing trading-partner structures, improving collection and payment arrangements, and formulating differentiated strategies. In less competitive industries, firms are more likely to convert digital investments into effective risk-management gains because market pressure is relatively moderate and operational relationships are comparatively stable. In highly competitive industries, however, intense rivalry may amplify uncertainty and weaken the risk-mitigating effect of digitalization. Likewise, in highly concentrated industries, firms often maintain more stable and coordinated trading relationships, which makes it easier for digital tools to improve monitoring, information sharing, and supply chain control. By contrast, in less concentrated industries, the fragmented market structure may limit the effectiveness of digitalization in reducing supply chain risk. Additionally, firm-age heterogeneity suggests a stronger risk-mitigating effect among younger firms, likely due to greater flexibility. However, the between-group difference is insignificant, so this pattern should be interpreted cautiously.

6.2 Limitations and Future Research

This study has several limitations. Supply chain digitalization is measured mainly through textual disclosure, which may not fully capture the actual implementation. In addition, the findings are based only on Chinese A-share listed manufacturing firms, so their generalizability to other firms and contexts requires further testing. This study focuses on one transmission channel from the perspectives of supply chain concentration and liquidity management, while factors such as the intensity of external shocks and other potential transmission channels are not fully examined. Future studies may further investigate other potential channels through which digitalization affects supply chain risk and supply chain financial risk. Moreover, while supply chain digitalization may improve efficiency, it may also generate problems such as resource redundancy, which also deserve further study.

7 Conclusion

This study shows that supply chain digitalization can significantly mitigate firms' supply chain risk. Its effect operates not merely in technological investment itself; rather, it is also realized through the structural channel of reducing supply chain concentration. However, weak liquidity management, reflected in high accounts receivable pressure and delayed supplier payments, constrains the realization of these benefits. Furthermore, the risk-mitigating effect of digitalization is more pronounced among state-owned enterprises, non-high-tech enterprises, and firms in less competitive or more concentrated industries, underscoring the moderating role of firms' resource endowments and technological foundations in shaping the effectiveness of digitalization in managing supply chain risk.

However, the external applicability of the findings should be further examined in specific institutional contexts and across different types of firms, as the measurement of supply chain digitalization still relies primarily on textual data and the sample is limited to Chinese A-share listed manufacturing firms.

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