Risk Assessment and Management Strategies for Supply Chain Disruptions in the Digital Intelligence

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Abstract. Global supply chains face increasing disruption risks due to pandemics, geopolitical tensions, and extreme weather events. This study examines whether digitalization mitigates supply chain disruption risk, using panel data of Chinese A-share manufacturing firms from 2010 to 2023. A fixed-effects regression framework is applied, with disruption risk as the dependent variable, a text-based digitalization index as the core explanatory variable, and supply chain concentration and visibility as moderators. The study adopts a fixed-effects regression model to construct an analytical framework, with supply chain disruption risk set as the dependent variable and the results show that digitalization significantly reduces disruption risk, supporting its role as a dynamic capability. Moreover, high supply chain concentration weakens this effect, while greater visibility strengthens it. These findings remain robust under alternative specifications, lagged models, and instrumental variable estimation. The study contributes to theory by integrating dynamic capability, resource-based, and network perspectives, and provides practical implications for enhancing supply chain resilience through digital investment, structural diversification, and transparency.

Keywords: Digitalization, Supply Chain Disruption Risk, Concentration, Visibility.

1 Introduction

The global production and distribution network is confronted with an increasing number of disruptive factors, such as public health crises, geopolitical tensions and severe climate events, all of which threaten the stability and continuity of operations. In particular, the Coronavirus Disease 2019 (COVID-19) pandemic has exposed the vulnerability of global supply chains and emphasized the urgent need to enhance the capacity to withstand system-wide hazards. In this environment, digital technologies - including big data analysis, artificial intelligence, blockchain systems and the Internet of Things - have been identified as important tools for strengthening supply chain risk management and building adaptability [1,2]. Therefore, understanding how digital adoption can mitigate the risk of disruption is both theoretically relevant and of practical value, providing guidance for organizations seeking to remain competitive in an uncertain environment.

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For a long time, academic discussions have emphasized the far-reaching impact of supply chain disruptions and their cascading consequences in multi-layer networks [3,4]. Early research examined how network architecture and governance mechanisms shape the outcomes of such events [5]. Recent surveys suggest that digital tools have enhanced early warning, continuous monitoring and recovery processes, thereby improving resilience [6]. Empirical research shows that analysis and artificial intelligence have enhanced the accuracy of predictions, while distributed ledger technology and digital platforms have increased transparency and mutual trust among partners [7]. Other analyses indicate that the high concentration of suppliers or customers exacerbates the vulnerability of the system, although digital capabilities can partially offset these weaknesses [8]. These findings jointly promote the integration of dynamic capabilities and complex network perspectives into interrupt management research.

With the acceleration of digital transformation in various industries, scholars are increasingly studying how these technologies are reshaping risk governance in supply chains. Evidence from case studies and investigations indicates that blockchain-supported traceability, cloud-based coordination tools, and other digital applications enhance visibility and information sharing across multiple levels [9]. Text mining methods applied to corporate disclosure have been used to develop digital-oriented quantitative metrics that link operational results and innovation performance [10]. However, the research also emphasizes that over-concentration remains a persistent weakness, especially in manufacturing. Achieving transparency through disclosure and traceability is crucial for enhancing robustness [11,12]. Despite this progress, the evidence on how digitalization can curb the risk of disruption, especially in systems combined with structural and information characteristics, remains limited.

Building on these insights, this study develops an analytical framework to examine how digitalization influences supply chain disruption risks in Chinese A-share manufacturing firms from 2010 to 2023. To reflect recent global developments, the analysis incorporates post-2020 supply chain shocks such as pandemic disruptions, geopolitical tensions, and climate-related events, highlighting the urgency of the topic. Drawing on dynamic capability theory, the resource-based view, and complex network theory, the study assumes that digitalization lowers disruption risk, while supply chain concentration weakens and visibility enhances this relationship. The methodology integrates fixed-effects estimation, robustness tests, and moderation analysis with detailed data collection procedures to reduce potential sample bias. Finally, the study broadens the discussion by outlining practical implications across industries and offering future research directions on digital resilience strategies.

2 Theoretical Framework and Research Hypotheses

The resilience of supply chains under conditions of uncertainty has become an important issue in both academic and managerial research. Existing theories provide multiple perspectives to understand how digitalization affects the evaluation and mitigation of disruption risks. In this study, three theoretical lenses are employed to construct the analytical framework: dynamic capability theory, the resource-based view (RBV), and

complex network theory. The block diagrams of the three theories are shown in Figure 1. Together, these perspectives explain why digitalization enables firms to better sense and respond to risks, how digital capability functions as a strategic resource, and how supply chain structures condition the effectiveness of such capabilities.

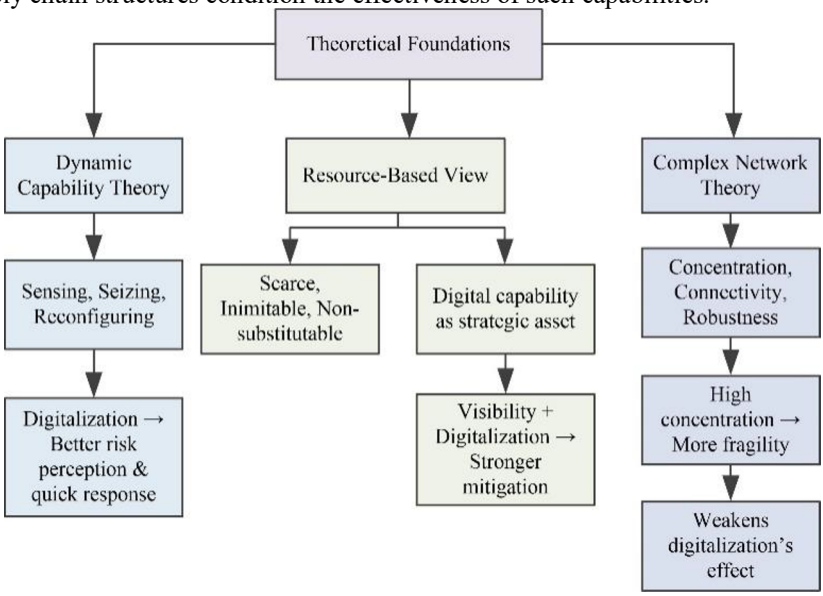

Fig. 1. The block diagrams of the three theories(Picture credit: Original)

Dynamic capability theory emphasizes that firms must continuously adapt by sensing, seizing and reconfiguring resources in response to shocks. Emerging tools such as big data, Artificial Intelligence (AI) and blockchain improve risk detection, forecasting and recovery capacity. From a resource-based perspective, digital capability is a valuable and hard-to-imitate asset, and its effect is amplified when combined with visibility practices like traceability platforms. Complex network theory highlights that supply chain resilience depends on structural features; high concentration raises vulnerability to node failures and reduces the payoff from digitalization. Together, these perspectives suggest that digitalization lowers disruption risk, but its impact is shaped by both network design and information transparency.

2.1 Analysis and Hypotheses

The spread of digital technologies is reshaping supply chain risk management. Tools such as big data, AI, blockchain and Internet of Things (IoT) improve information use, enabling firms to detect threats, react quickly and recover more effectively. Yet disruption risk also depends on network features. High concentration can magnify vulnerability, while greater visibility may reinforce the role of digital solutions. Guided by these insights, this study proposes three hypotheses.

H1. Digitalization reduces disruption risk by enhancing firms' ability to sense and respond.

H2. Concentrated supply chains weaken this effect, as dependence on few partners heightens fragility.

H3. Visibility strengthens the impact of digitalization, since transparency and traceability improve coordination and resilience.

3 Research Design

3.1 Data Sources and Sample Description

This study utilized the panel data of China's A-share manufacturing enterprises from 2010 to 2023. These data are from China Stock Market & Accounting Research Database (CSMAR) (Suppliers, Customers, Finance and Events), China Information (CNINFO) (Annual Report on Digitalization and Visibility), MacroData (Keyword Frequency) and Wind (Disruption Events). After excluding Special Treatment (ST)/*ST companies and those with missing data, the final sample covered approximately 1,800 companies, with nearly 25,000 companies having annual observation results.

3.2 Model Design and Variable Definition

To empirically examine the impact of digitalization on supply chain disruption risk, this study constructs a firm-year panel regression model with fixed effects. The baseline specification is defined as:

$$\begin{aligned} Risk\_Disruption_{it} = {} & \alpha + \beta_1 Digital\_Index_{it} \\ & + \gamma Controls_{it} \\ & + \mu_i + \lambda_t + \varepsilon_{it} \end{aligned} \tag{1}$$

where Risk_Disruptionit represents the probability that firm i experiences a supply chain disruption in year t, Digital_Indexit captures the firm's digitalization level, Controlsit is a vector of control variables, μi denotes firm fixed effects, λt denotes year fixed effects, and ϵit is the error term. Firm fixed effects are employed to account for unobserved time-invariant heterogeneity, while year fixed effects control for macro shocks such as policy changes, pandemics, and global disruptions.

To further explore the mechanisms, this study incorporates interaction terms with supply chain concentration and visibility, yielding the extended model:

$$\begin{aligned} Risk\_Disruption_{it} = {} & \alpha + \beta_1 Digital\_Index_{it} \\ & + \beta_2 \left(Digital\_Index_{it} \times SC\_Network\_HHI_{it} \right) \\ & + \beta_3 \left(Digital\_Index_{it} \times SC\_Visibility_{it} \right) \\ & + \gamma Controls_{it} + \mu_i + \lambda_t + \varepsilon_{it} \end{aligned} \tag{2}$$

Here, β2 measures whether higher supply chain concentration weakens the mitigating effect of digitalization, while β3 captures whether greater visibility enhances the effectiveness of digitalization in reducing disruption risk.

Table 1 summarizes the variables. The dependent variable is the risk of supply chain disruption, defined as a binary outcome indicating whether the company reported disruptions in a specific year. The key explanatory variable is the digitalization index constructed based on the annual report of Juchao Information Network, which is based on the relative frequency of terms such as digitalization, artificial intelligence, blockchain and intelligent manufacturing. Two moderating factors have been introduced: supply chain concentration, which is measured by the Herfindal-Hirschman index of the top five suppliers and customers; Supply chain visibility is coded as 1 when a company discloses a traceability system or digital platform. Control variables include company size, profitability, leverage ratio and industry model. This design jointly provides a structured framework for assessing how digitalization affects interruption risk under different structural and information conditions.

Table 1. Variable definitions and data sources

Variable	Symbol	Definition	Source
Disruption risk	Risk_Disruption	Dummy =1 if supply chain disruption event occurs, 0 otherwise	CSMAR, Wind
Digitalization index	Digital_Index	Keyword frequency ratio of digital-related terms in annual reports	CNINFO, MacroData
Supply chain concentration	SC_Network_HHI	Herfindahl–Hirschman Index of top 5 suppliers/customers	CSMAR
Supply chain visibility	SC_Visibility	Dummy =1 if report discloses digital/traceability platforms	CNINFO
Firm size	Size	Log of total assets	CSMAR
Profitability	ROA	Net profit / total assets	CSMAR
Leverage	Leverage	Total debt / total assets	CSMAR

4 Empirical Analysis

4.1 Baseline Regression Results

The baseline regressions are estimated without interaction terms, and the results are reported in Table 2. Model 1 considers only the digitalization index, Model 2 adds firm-level controls, and Model 3 further introduces firm and year fixed effects. In all cases,

the coefficient of digitalization remains negative and significant, confirming that higher digital adoption reduces disruption risk. Control variables behave as expected: larger size and stronger profitability lower risk, while higher leverage raises it, consistent with financial fragility. These findings strongly support H1.

Table 2. Baseline regression results

Variables	(1)	(2)	(3)
Digital_Index	-0.158*** (0.042)	-0.141*** (0.039)	-0.137*** (0.037)
Size (log assets)		-0.026** (0.012)	-0.028** (0.012)
ROA		-0.064*** (0.019)	-0.062*** (0.018)
Leverage		0.049*** (0.014)	0.052*** (0.014)
Industry dummies	No	Yes	Yes
Firm FE	No	No	Yes
Year FE	No	No	Yes
Observations	25,320	25,320	25,320
R^2	0.071	0.123	0.156

Notes: Robust standard errors are reported in parentheses. ***, **, * denote significance at the 1%, 5%, and 10% levels, respectively.

4.2 Robustness Checks

Multiple robustness tests have confirmed the stability of the results. Alternative estimators such as fixed-effect logit and probit provide consistent negative coefficients for digitalization. Using the one-year lag of the index or constructing alternative indicators using TF-IDF and PCA (TF-IDF) and TF-IDF and PCA (PCA) will produce similar results. Trimming extreme values will not change the research results. The Instrumental Variable - Two-Stage Least Squares (IV-2SLS) strategy, which uses the industry's annual average as a tool, demonstrates strong identifiability and maintains a negative impact. Further examination of cluster errors, balanced panels, and matching methods all reinforce the conclusion that higher digitalization reduces the risk of supply chain disruptions as shown in Table 3.

It also verify the moderation mechanisms (H2–H3). Under both non-linear and lagged specifications, the interaction between digitalization and supply chain concentration remains positive (weaker mitigation when networks are more concentrated),

while the interaction with visibility remains negative (stronger mitigation when visibility is higher) as shown in Table 4.

Table 3. Baseline Regression Results under Alternative Specifications

Variables / Specs	FE-LPM (baseline)	FE-Logit (AME)	Probit (AME)	Lagged Digital_Index	Alt. Digital_Index (PCA)	2SLS-IV
Digital_Index	-0.137* (0.037)	-0.036* (0.010)	-0.021* (0.006)	-0.122* (0.040)	-0.115* (0.035)	-0.162 (0.074)
Controls, FE	Yes	Yes	Yes	Yes	Yes	Yes
Firm & Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Obs.	25,320	25,320	25,320	21,600	25,320	24,980

Notes: Robust SE in parentheses; AME(average marginal effect) (logit/probit). 2SLS uses leave-one-out industry-year digitalization as instrument. ***, **, * as above.

Table 4. Moderating Effects of Supply Chain Concentration and Visibility

Interaction terms	FE-Logit (AME)	FE-LPM with Lagged Digital_Index
Digital_Index × SC_Network_HHI	+0.008* (0.003)	+0.029 (0.013)
Digital_Index × SC_Visibility	-0.011* (0.004)	-0.041* (0.015)
Controls, FE	Yes	Yes
Obs.	25,320	21,600

Notes: AME reported for logit; lagged model uses Digital_Index_{t−1}. Robust SE in parentheses. ***, **, * as above.

Across all robustness assessments, the direction, size, and significance of the digitalization coefficient remain consistent, reinforcing Hypothesis 1. In addition, the positive interaction with supply-chain concentration and the negative interaction with visibility continue to emerge, offering solid evidence in favor of Hypotheses 2 and 3. Taken together, the results suggest that, digital technologies reliably lessen the probability of supply disruptions, dense or highly concentrated networks weaken these benefits, and transparency and traceability function as complementary resources that heighten the protective value of digital capabilities.

4.3 Moderating Effects Analysis

To clarify how digitalization affects disruption risk, this study regards supply chain concentration and visibility as moderating factors. This analysis reveals a significant positive interaction with concentration: although digital initiatives typically reduce the risk of disruption, their effectiveness decreases when companies rely heavily on a limited number of suppliers or customers. This dependence exacerbates the vulnerability of the system and limits the buffering capacity of digital tools. In contrast, the interaction with visibility is clearly negative, indicating that the enhanced transparency achieved through traceability systems and public disclosure strengthens the protective role of digitalization as shown in Table 5.

Including these two regulators in the model, the main mode remains unchanged. Digitalization continues to offer substantial protection against disruptions, but its influence is limited by high concentration and enhanced by greater visibility. These findings confirm theoretical expectations and emphasize that structural vulnerability and information openness jointly determine the advantages of digital technology. They also mean that companies seeking flexibility should combine digital investment with diversification strategies and enhance the transparency of their supply network.

Table 5. Moderating effects of concentration and visibility on digitalization

Variables	(1) Digitalization × Concentration	(2) Digitalization × Visibility	(3) Full Model
Digitalization (Digital_Index)	-0.129*** (0.038)	-0.134*** (0.037)	-0.128*** (0.036)
Supply chain concentration (HHI)	0.061** (0.025)		0.059** (0.024)
Supply chain visibility (Dummy)		-0.082*** (0.021)	-0.085*** (0.020)
Digitalization × HHI	0.033** (0.015)		0.031** (0.014)
Digitalization × Visibility		-0.047*** (0.017)	-0.045*** (0.016)
Controls	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Observations	25,320	25,320	25,320
R^2	0.148	0.153	0.161

Notes: Robust standard errors are reported in parentheses. ***, **, * as above.

4.4 Heterogeneity Analysis

Heterogeneity analysis indicates that the ability of digitalization to mitigate the risk of supply chain disruptions varies depending on the attributes of enterprises and networks. Small businesses benefit the most because digital tools make up for the shortage of resources and coordination skills. Private enterprises have also experienced greater improvement because, unlike state-owned enterprises, they lack institutional buffers and rely more on enhanced information processing. Companies engaged in export markets have gained a greater advantage because they have been repeatedly hit by external shocks. High-tech manufacturers have demonstrated stronger performance, reflecting their richer data assets and IT readiness, while in more traditional industries, visibility mechanisms play an important supplementary role. Given the greater demands of downstream participants for orchestration and demand perception, they have reaped greater benefits than upstream suppliers.

These cross-sectional comparisons remained stable in the robustness test. Statistical evidence confirmed significant coefficient differences between groups, and the moderating pattern held true: in each sub-sample, the concentration of digitalization decreased, while visibility increased, reducing the risk. Overall, digitalization continues to reduce the possibility of supply chain disruptions, but the intensity of its impact depends on enterprise resources, global uncertainties, technology absorption capacity, and the company's position in the supply chain.

Table 6. Heterogeneity of the Digitalization Effect

Subsample	β (Digital_Index)	SE	N
Small firms (below median Size)	−0.176*	0.045	12,780
Large firms (above median Size)	−0.102*	0.040	12,540
Non-SOE	−0.154*	0.038	17,210
SOE	−0.089	0.044	8,110
High export intensity (top terc.)	−0.191*	0.051	8,350
Low export intensity (bottom terc.)	−0.094	0.048	8,420
High-tech manufacturing	−0.160*	0.043	9,870
Traditional manufacturing	−0.121*	0.036	15,450
Downstream (assemblers/brands)	−0.168*	0.046	10,230
Upstream (component suppliers)	−0.110*	0.039	14,910

Notes: Each row reports the coefficient on Digital_Index from a separate subsample regression including the full set of controls (Size, ROA, Leverage, industry dummies), supply-side moderators (HHI, Visibility and their interactions with Digital_Index), firm fixed effects, and year fixed effects. Robust standard errors shown. ***, **, * as above.

The stratified evidence indicates that digitalization is most valuable where (1) organizational slack is limited, (2) institutional buffers are weaker, (3) exposure to global shocks is higher, (4) technological absorptive capacity is stronger (high-tech sectors), and (5) orchestration needs are greater. From a managerial perspective, these results

imply that digital investment should be paired with supply-chain design choices—reducing over-concentration and institutionalizing visibility—while tailoring deployment to firm size, ownership, sectoral capability, and network position to maximize disruption risk reduction as shown in Table 6.

5 Conclusion

This study investigates how digitalization influences supply chain disruption risk in an environment shaped by pandemics, geopolitical tensions, and climate shocks. Drawing on dynamic capability theory, the resource-based view, and complex network theory, it uses panel data from Chinese A-share manufacturing firms between 2010 and 2023. A fixed-effects model, supported by robustness and interaction analyses, evaluates both the direct and conditional effects of digitalization across different supply chain structures.

The results confirm that digitalization significantly reduces disruption risk, yet its effectiveness varies across contexts. Highly concentrated networks weaken the mitigating effect of digital tools, while stronger visibility through traceability and disclosure amplifies it. Moreover, the findings reveal industry heterogeneity: high-tech and export-oriented sectors gain more from digital transformation, whereas traditional industries rely more on visibility mechanisms to enhance resilience. These insights deepen the theoretical link between digital capability, structure, and information flow, and offer managerial implications for aligning technology investment with diversification and transparency strategies. Future research could extend this framework to cross-industry and international comparisons, or incorporate new indicators such as patent data and platform adoption to strengthen generalizability.

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