

Article

Digital Empowerment and Supply Chain Resilience Reconstruction

Wei Lv, Qianwen Yang * and Yanhua Li 

School of Economics and Management, North University of China, Taiyuan 030051, China; lvwei@nuc.edu.cn (W.L.)

* Correspondence: sz202409076@st.nuc.edu.cn; Tel.: +1-55-3780-6620

Abstract

Improving regional supply chain resilience is crucial for achieving high-quality growth, especially in light of complicated international dynamics and national security strategies. This study focuses on a sample of A-share listed enterprises from six central provinces between 2013 and 2023, primarily employing a fixed-effects model to investigate the mechanisms through which corporate digital transformation influences supply chain resilience and its differentiated performance across regional heterogeneity. Findings reveal that digital transformation improves corporate supply chain resilience, both directly and indirectly by reducing supply chain concentration. Heterogeneity analysis indicates that this effect is more pronounced in non-state-owned enterprises, non-digital economy industries, larger-scale enterprises, and firms located in the Yangtze River Midstream Urban Agglomeration. Comparative analysis shows that digitalization's impact on supply chain resilience in the central region is still in its early stages, compared to the eastern coastline provinces. The paper identifies two methods by which digital transformation affects supply chain resilience, offering theoretical foundations and practical recommendations for developing diversified regional industrial policies and driving supply chain modernization in the central area.

Keywords: digital transformation; supply chain resilience; supply chain concentration; sustainable development; regional differences

1. Introduction

In the face of increased unpredictability and accumulating hazards in global supply chains, developing more robust supply chain systems has emerged as a critical problem for corporate survival and national economic security. From a national strategic perspective, enhancing supply chain resilience is not only an urgent necessity to counter external challenges like “deglobalization” but also an intrinsic requirement for promoting high-quality economic development and safeguarding industrial chain security. This provides an important practical starting point and policy context for investigating how digital transformation might systematically improve supply chain resilience. Beyond the impetus of national supply chain security strategies, there is also the practical demand driven by the Central Region Rise strategy. Shanxi, Henan, Hubei, Hunan, Anhui, and Jiangxi are the six central provinces that connect south and north, as well as east and west. As major national industrial centers and logistics hubs, they have a strong basis in traditional industries as well as great potential for new digital economies, making them an ideal regional case study for studying the interplay between transformation and resilience. The region's internal characteristics of uneven development, coupled with its “rise” mission within the national



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strategy for coordinated regional development, make exploring the differentiated outcomes of enterprise digital transformation not only valuable for specific policy references but also provide a crucial empirical window for understanding how regional heterogeneity modulates the effects of technological empowerment.

Corporate practice prioritizes supply chain resilience, yet standard reactive tactics fall short in dynamic and complex situations. Information delays and insufficient coordination create “data silos,” severely constraining the overall responsiveness and recovery capacity of supply chains. Digital transformation, through the deep integration of technologies like the Internet of Things, artificial intelligence, and cloud computing, is opening new possibilities for enterprises to achieve end-to-end data connectivity, intelligent decision-making, and cross-organizational resource coordination. This paves a critical path for overcoming existing bottlenecks and systematically enhancing supply chain resilience in a scientific manner [1].

In theoretical research, China’s academic community has progressively established a relatively comprehensive theoretical and empirical framework exploring how digital transformation enhances supply chain resilience. Related studies predominantly focus on influencing pathways, operational mechanisms, and heterogeneous manifestations across different scenarios. At the micro level, Ge Xinting et al. [2] and others utilized data from listed companies and suppliers to discover that digitalization can strengthen enterprises’ risk-coping capabilities through two pathways: diversifying supplier structures and enhancing inventory buffers. Song Donglin et al. [3] and colleagues developed a resilience evaluation framework encompassing prevention, adaptation, and recovery capabilities.

They proved that digitalization not only lowers transaction costs but also enhances supplier collaboration quality, adding a social network dimension to our understanding of its mechanics. Wang Ying et al. [4] and colleagues propose from a new-quality productivity perspective that digitalization enhances firms’ bargaining power and coordination efficiency within supply chains, thereby improving resilience performance. They note this effect is more pronounced among technology-intensive enterprises in eastern China. At the meso level, Xu Yiliang and Gou Jianhua [5] established a resilience analysis framework encompassing resistance, recovery, and transformation dimensions. They proposed that digitalization enhances overall resilience by reshaping subject relationships and structural configurations within supply chains, emphasizing the need for joint advancement through enterprise practices, industrial collaboration, and government governance. International academia has similarly focused on this topic. Dolgui and Ivanov [6] employ bibliometric analysis to argue that the COVID-19 pandemic marked a pivotal shift in supply chain resilience research, propelling the field from traditional “predict-prevent” paradigms toward new “adapt-recover” approaches. This transition has spurred emerging research directions such as digital twins and cyber-physical systems. Belhadi et al. [7] and colleagues conducted empirical research grounded in organizational information processing theory, introducing supply chain dynamism as a moderating variable. They found that the resilience-enhancing effects of artificial intelligence technologies vary with environmental uncertainty, providing new evidence for understanding the applicability boundaries of digital technologies. Dolgui et al. [6] and others focused on 5G technology applications, noting that its end-to-end real-time connectivity not only enhances manufacturing and operational efficiency but also fundamentally reshapes supply network structures. This reflects digital technology’s evolution from tactical tools to strategic enablers.

A review of existing research reveals two interrelated, deep-seated limitations despite its substantial achievements. First, in terms of mechanism explanation, most studies emphasize how digitalization enhances operational capabilities such as information processing efficiency and agile responsiveness, while relatively neglecting its core pathway as a

strategic restructuring tool—systematically building resilience by altering the fundamental structure of supply chain networks. This structural pathway is theoretically crucial yet lacks sufficient empirical testing and contextual analysis. Second, in terms of contextual consideration, existing research either draws general conclusions based on national samples, obscuring regional heterogeneity, or focuses on developed regions, whose findings may not apply to other areas at different stages of transformation. This propensity to segregate processes from context restricts our overall grasp of how digital empowerment might be adjusted to local circumstances. This study intends to overcome the gap by focusing on supply chain restructuring and testing it in China's central area. It seeks to reveal the conditional pathways through which digital transformation empowers supply chain resilience.

The research focuses on the six central provinces as a transitory zone for observing China's industrial chain digital transformation and resilience restoration. On one hand, the central region possesses both traditional industrial foundations and emerging digital elements. Its internal uneven development provides a valuable natural experiment scenario for examining how the effectiveness of digital transformation is constrained by regional conditions such as industrial structure, infrastructure, and policy coordination. In contrast to the digitally advanced eastern region, the central region is still in the process of catching up with transformation; compared to the western region with vastly different resource or location characteristics, its industrial system is more complete. This unique intermediate situation enables research on central region firms to better uncover the foundational effects and conditional bounds of digital transformation in enhancing supply chain resilience. This provides empirical evidence with theoretical depth and practical relevance for understanding the different penetration pathways and efficacy constraints of digital technologies across regions with varying developmental stages and resource endowments. Consequently, studying the central region helps move beyond universal conclusions about the effectiveness of digitalization, addressing the more theoretically profound question: "Under what regional conditions and through what structural mechanisms is digitalization most effective?" This provides micro-level evidence for understanding the interaction between technology diffusion and regional heterogeneity.

This analysis uses data from A-share-listed firms in six central provinces from 2013 to 2023. This study uses data and models to analyze how corporate digital transformation affects supply chain resilience and the underlying mechanisms. Based on these findings, it identifies deficiencies in the central region and proposes corresponding measures. The subsequent structure of this paper is as follows: First, research hypotheses are proposed based on theoretical analysis. Second, the research design is outlined, covering sample selection, variable definition, and model construction. Next, baseline regression results are reported, accompanied by endogeneity tests and robustness analysis. Subsequently, the mediating mechanism of supply chain diversification is further examined, along with an analysis of differences between eastern and central China and internal heterogeneity within the central region. Finally, research findings are summarized, and corresponding policy implications are proposed.

2. Theoretical Analysis and Research Hypotheses

2.1. Theoretical Analysis

To systematically elucidate how enterprise digital transformation ultimately enhances supply chain resilience, this paper constructs an integrated analytical framework centered on capability-driven structural optimization and resilience generation. Under conditions of external uncertainty, an enterprise's digital capabilities serve as the fundamental driving force for optimizing internal operations and external network structures. Structural opti-

mization, in turn, acts as the core transmission mechanism and implementation pathway for converting these capabilities into ultimate resilience—the ability to withstand, adapt to, and recover from disruptions. This framework comprises three progressive logical stages. The first stage is the capability foundation—the core competencies of an enterprise’s digital transformation. An organization’s ability to navigate uncertainty and pursue growth fundamentally hinges on possessing core competencies aligned with the era [8]. Digital transformation represents a new, integrated capability where enterprises deeply integrate data, algorithms, and intelligent technologies throughout their decision-making, operations, and collaboration processes. This capability manifests not merely as the adoption of technological tools but fundamentally reshapes the underlying logic of how enterprises perceive environmental information, process complex decisions, and coordinate across organizational boundaries. It provides the feasibility foundation and technological prerequisite for any subsequent structural optimization. Without this capability, restructuring complex systems like supply chains would incur exorbitant costs and uncontrollable risks. The second link is structural transmission, referring to the carrier function of supply chain configuration. Capability itself does not directly equate to performance; it must act upon specific “structures” within the enterprise to unlock value. In supply chain management, supply chain configuration is the most fundamental structural representation of an organization’s strategic arrangement of external resource networks.

This structure determines dependency relationships, risk distribution, and coordination models between the enterprise and its upstream/downstream partners. Enhanced capability ultimately guides enterprises to reassess and optimize this structure [9]. Specifically, digital capabilities enable the management of more dispersed and diverse supply chain networks by reducing information search costs, enhancing collaborative efficiency, and improving remote control precision—all while keeping costs manageable. The most direct influence of digital capabilities on corporate operations is through supply chain configuration changes, such as shifting from centralization to diversification. The third level is increasing efficacy. Capability building and structural optimization aim to improve an enterprise’s long-term survival and development in unstable situations. Supply chain resilience embodies this efficacy at the supply chain level, encompassing the system’s comprehensive performance in maintaining stability, dynamically adjusting, and rapidly recovering under shocks. An optimized supply chain structure, with its inherent risk dispersion, path redundancy, and resource flexibility, directly forms the material and relational foundation for resilience generation. When external shocks occur, this optimized structure can more effectively buffer, decompose, and respond to impacts, thereby transforming prior capability investments and structural transformations into tangible survival safeguards and competitive performance [10]. Our paradigm suggests that digital transformation is enabled by better information processing and network connectivity. These capabilities directly address the core obstacles to supply chain diversification—information asymmetry and coordination complexity. As a result, the key mechanism by which digital transformation increases resilience is not just general efficiency benefits, but also the intentional restructuring of supply chain networks toward lower concentration. This leads to our subsequent research hypotheses.

2.2. Research Hypothesis

Hypothesis H1. *Corporate digital transformation enhances supply chain resilience by fundamentally optimizing supply network configuration.*

The enabling effect of digital transformation on supply chain resilience is not a generic technological dividend. Instead, this empowerment stems from two core capabilities digital technologies confer upon enterprises: cross-border real-time information processing and

networked coordination capabilities [11]. These capabilities directly undermine the static equilibrium upon which traditional centralized, linear supply chain structures rely. In uncertain environments, highly centralized supply chains become exceptionally vulnerable due to their singular critical nodes. Digital capabilities significantly reduce the information search costs and coordination complexity for enterprises to identify, evaluate, and collaborate with diversified suppliers [12]. Creating and managing a resilient, multi-source supply network is both strategic and economically effective. We believe that digital transformation improves resilience by strategically reconfiguring supply chain networks, shifting from high-risk single-source dependency structures to more robust and distributed architectures.

Hypothesis H2. *Digital transformation positively impacts supply chain resilience by reducing supply chain concentration.*

An empirical investigation of the “structural optimization” mechanism requires a specific and quantified structural variable. Supply chain concentration is the most direct and important indication for determining the singularity and dependency of the supply chain network structure. High concentration implies risk aggregation, while low concentration (i.e., diversification) represents risk dispersion and redundancy [13]. The obvious expression of digital capabilities that enable structural optimization is that businesses can and do reduce their supply chain concentration. Digital platforms and technologies help organizations find and manage suitable suppliers; real-time data sharing and predictive analysis reduce the reliance on deep relationship-specific investments in a single supplier. Thus, the fall in supply chain concentration is the crucial mediating state and direct result of the digital-driven supply chain structure reconfiguration. If the “structural optimization” path as described in H1 holds true, then digital transformation should significantly reduce supply chain concentration, and this structural change should become an important transmission channel for resilience enhancement. Based on this, we propose H2, a more operationally grounded hypothesis regarding the intermediary mechanism.

3. Data and Methodology

3.1. Sample Selection and Data Sources

This study analyzed A-share listed firms in six central provinces from 2013 to 2023, using data from the Guotai An database (CSMAR). To enhance the study’s credibility, the sample underwent the following processing: (1) Exclusion of “special treatment” enterprises (“ST” companies); (2) Financial firms were excluded; (3) All missing and outlier observations in the regression data were removed; (4) Continuous variables underwent 1% two-tailed trimming. Following these steps, the final dataset comprises 4893 non-balanced panel observations.

3.2. Definition of Main Variables

3.2.1. Explained Variable

Supply Chain Resilience (SCR). Supply chain resilience refers to the capability of a supply chain system to maintain stable operations and prevent disruptions when facing external shocks, to self-adjust promptly after enduring crises to restore pre-impact operational performance, and even to leverage adversity for positive transformation and upgrade. To analyze and understand supply chain resilience more comprehensively, it can be divided into three core dimensions: supply chain resistance, supply chain adaptability, and supply chain recovery capability [14].

The dimension of supply chain resistance refers to the supply chain’s ability to maintain basic operations and effectively withstand risks when encountering external shocks, reflecting the system’s stability and interference resistance [15]. Its core lies in sustaining

ample and timely liquidity to address sudden payment demands and operational disruptions. This paper employs the current ratio and quick ratio as core financial metrics for measuring supply chain resilience. This assessment tool immediately draws on and incorporates the cutting-edge approach from organizational resilience research, which sees financial robustness as the foundation for enduring shocks. Specifically, the essence of supply chain resilience lies in the ability to prevent critical operations from collapsing during disruptions, which is highly dependent on the financial resources a company can mobilize in the short term. The current ratio reflects a company's overall buffering capacity to cover short-term liabilities using all current assets. The quick ratio further excludes inventory—which may rapidly depreciate due to supply chain disruptions—accurately capturing a company's immediate liquidity to meet sudden payment obligations. This method to evaluating resilience using the strength of a “financial cushion” builds on and utilizes research that sees liquidity management as a critical risk reduction strategy for businesses. The measures are objective and comparable, providing insight into a company's financial reserves for supply chain interruptions. This effectively captures the critical dimension of maintaining operational continuity within the resilience framework.

Supply chain adaptability refers to a supply chain's ability to shift operating strategies and resource allocation in reaction to external changes, highlighting its flexibility and potential for dynamic optimization. This article uses total asset turnover as a proxy variable for supply chain flexibility, which is based on resource orchestration and dynamic capability theory. Resilience underscores a company's ability to flexibly adjust resource allocation and operational processes in response to environmental shifts. Total asset turnover—the ratio of sales revenue to average total assets—serves as a core metric measuring how efficiently a company converts its overall assets into revenue. Digital transformation enhances data-driven decision-making, enabling businesses to adjust inventory levels more agilely, optimize production planning, and respond swiftly to market demand fluctuations. These actions ultimately manifest as an overall improvement in asset utilization efficiency, reflected in higher asset turnover rates. While this metric does not directly measure any specific supply chain link, it holistically reflects a company's comprehensive capability to adapt to external changes through internal resource optimization and restructuring within a dynamic environment. It serves as an aggregated, outcome-based manifestation of adaptability in financial performance. This indicator highlights how digitalization has transformed manufacturing-dominated, capital-intensive firms in China's six central provinces, resulting in operational streamlining and efficiency improvements.

Supply chain recovery capability refers to the ability of a supply chain to swiftly resume normal operations and mitigate performance losses after experiencing disruptions [16], fundamentally rooted in the system's self-repair capabilities. The speed of recovery following a supply chain disruption hinges critically on whether enterprises can rapidly rebuild healthy cash flow cycles [17]. Accounts receivable turnover directly monitors the speed and efficiency of converting sales into cash receipts, serving as an important indicator of cash generation potential. Following a shock, robust resilience signifies not only the restart of physical production but, more critically, the swift restoration of cash flow to fund recovery procurement, wages, and operational expenses. Digital tools significantly accelerate collection processes and shorten cash conversion cycles. A corporation that maintains or quickly returns a high accounts receivable turnover rate after a shock exhibits strong credit management and customer relationship networks. It can extract funds more quickly from the sales end, providing the critical lifeblood for repairing and restarting the entire supply chain. This measurement perspective anchors resilience—previously an abstract concept of speed—to observable, comparable cash cycle efficiency. In China's central regions, where small and medium-sized firms predominate, accounts receivable

turnover efficiency is very important. It serves as a key indicator for assessing whether digitalization alleviates traditional payment cycle bottlenecks.

Admittedly, financial metrics serve only as indirect measures, yet they hold significant reference value for publicly listed companies. A robust supply chain system must eventually demonstrate a company's ability to preserve financial health and operational continuity under pressure. The selected indicators directly reflect three core capabilities: withstanding shocks, reallocating resources, and restoring cash flow—which are precisely the three key manifestations of a resilient supply chain. While these metrics may not capture all qualitative factors, they provide objective, comparable, and financially substantive measures closely tied to a company's survival and growth capabilities during supply chain disruptions.

After clarifying the essence and rationale behind the three dimensions and their respective metrics, the entropy weighting method is applied to calculate supply chain resistance, adaptability, and resilience. This process generates a composite indicator capable of measuring the overarching concept of supply chain resilience. Table 1 clearly displays the content of each dimension of the indicators.

Table 1. Supply Chain Resilience Measurement Indicators.

First-Level Dimension	Second-Level Dimension	Third-Level Dimension
Supply chain resistance	Capital flow	Current ratio
	Debt-paying ability	Quick ratio
Supply chain adaptability	Resource utilization	Total asset turnover ratio
Supply chain resilience	Capital recovery	Accounts receivable turnover ratio

3.2.2. Explanatory Variables

Enterprise Digital Transformation (digit). This study employs the Digital Transformation Index from the Guotai An database as the explanatory variable [18]. This index is calculated by weighting six primary indicators: strategic leadership, technological enablement, organizational empowerment, environmental support, digital outcomes, and digital application (weighted at 34.72%, 16.20%, 9.69%, 3.42%, 27.13%, 8.84%), and standardized data processing methods were applied for weighted calculation. This index goes beyond mere technical term frequency or IT investment measures, providing a more comprehensive and profound picture of the overall progress and true depth of business digital transformation. The corporate digital transformation database was constructed based on relevant content disclosed in annual reports, fundraising announcements, qualification certifications, and other public disclosures of listed companies. Authoritative and dependable data sources provide a comprehensive and objective depiction of company digital transformation. This index was chosen as the primary explanatory variable in this study because of its systematic and authoritative measuring methodology, scientific and objective construction approach, and comprehensive nature and availability. Consequently, it has been widely adopted in authoritative academic research exploring the economic consequences of digital transformation. These studies confirm the index's significant explanatory power across multiple outcome variables, including corporate performance, innovation, and supply chain relationships, with its validity supported by existing literature. To mitigate the impact of extreme values on regression results, this paper applies the index after taking its logarithm.

3.2.3. Control Variables

The study selected the following five control variables: firm size (size), firm age (firmage), revenue growth rate (growth), return on assets (roa), and tangible asset ratio

(tar). Detailed variables are shown in Table 2. This paper also controlled for firm and year fixed effects.

Table 2. Variable Definitions and Explanations.

Variable Type	Variable Name	Variable Symbol	Variable Definition
The explained variable	Supply chain resilience	SCR	The specific calculation process is as described above
Explanatory variable	Enterprise digital transformation	digit	Take the logarithm of the digital transformation index
	Enterprise scale	size	The natural logarithm of annual total assets
Control variable	Enterprise age	firmage	Ln (Year of the current year – Year of company establishment + 1)
	Growth rate of operating income	growth	(Current period's operating income – previous period's operating income)/previous period's operating income
	Net profit margin on total assets	roa	Net profit/total assets
	Proportion of tangible assets	tar	(Total assets – Net intangible assets – net Goodwill)/Total assets

3.3. Model Setting

This study uses a panel data regression model to analyze how corporate digital transformation affects supply chain resilience, while controlling for company and year fixed effects. The model specification is as follows:

$$Y_{it} = \alpha + \beta_1 d_{it} + \sum Controls_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (1)$$

Among them, the explained variable Y_{it} represents supply chain resilience; d_{it} is the core explanatory variable, the degree of enterprise digital transformation; β_1 is the core coefficient that the research needs to focus on. If hypothesis H1 holds true, then the β_1 coefficient should be significantly positive. $Controls_{it}$ are a series of control variables; μ_i is the enterprise fixed effect, which controls the heterogeneity of enterprises that does not change over time. λ_t is the annual fixed effect, which controls the time trend and macro shock. ε_{it} is a random disturbance term, and in the regression equation, clustering to the robust standard error at the enterprise level is adopted.

4. Results

4.1. Descriptive Statistics

Table 3 presents the descriptive statistics for key variables. Among all 4893 observations, the mean value for supply chain resilience was 0.149, indicating that the overall resilience level of the sampled enterprises remains relatively low with significant room for improvement. The standard deviation of 0.085 reflects some variation among enterprises, though the degree of dispersion is limited. The mean for digital transformation was 3.512, indicating a moderately high level, suggesting that the sampled enterprises have established a certain digital foundation. The standard deviation of 0.259 indicates that the pace of digital transformation varies significantly among enterprises, with some having invested heavily and being relatively advanced, while others lag behind.

Table 3. Descriptive statistical results of the main variables.

Variable Name	Variable Symbol	Observations	Mean Value	Standard Deviation	Minimum Value	Maximum Value
Supply chain resilience	SCR	4893	0.149	0.085	0.001	0.673
Digital transformation	digit	4893	3.512	0.259	3.069	4.123
Enterprise scale	size	4893	22.331	1.265	19.478	26.282
Enterprise age	firmage	4893	2.986	0.290	1.792	3.689
Growth rate of operating income	growth	4893	0.308	0.892	−0.926	12.455
Net return on total assets	roa	4893	0.034	0.067	−0.578	0.220
Proportion of tangible assets	tar	4893	0.919	0.091	0.445	1

4.2. Results of Regression Analysis

This study used a dual fixed-effects model for both firms and years to conduct regression tests on the association between digital transformation and supply chain resilience. Table 4 reports the benchmark regression results for the impact of corporate digital transformation on supply chain resilience. To test model robustness and progressively control for potential confounding factors, a stepwise regression approach was adopted, sequentially introducing control variables such as firm size and firm age.

Table 4. Benchmark Regression Table.

Variables	(1) SCR	(2) SCR	(3) SCR	(4) SCR	(5) SCR	(6) SCR
digit	0.003 (0.007)	0.013 * (0.007)	0.014 * (0.007)	0.014 * (0.007)	0.017 ** (0.007)	0.017 ** (0.007)
size		−0.018 *** (0.002)	−0.019 *** (0.002)	−0.019 *** (0.002)	−0.015 *** (0.002)	−0.014 *** (0.002)
roa			0.118 *** (0.014)	0.119 *** (0.014)	0.119 *** (0.014)	0.115 *** (0.014)
growth				0 (0.001)	0 (0.001)	0 (0.001)
tar					0.131 *** (0.017)	0.132 *** (0.016)
firmage						−0.085 *** (0.02)
Constant	0.139 *** (0.026)	0.515 *** (0.052)	0.526 *** (0.051)	0.526 *** (0.051)	0.292 *** (0.053)	0.519 *** (0.074)
term						
Observed value	4893	4893	4893	4893	4893	4893
R ²	0.776	0.781	0.786	0.786	0.791	0.793
Individual effect	YES	YES	YES	YES	YES	YES
Time effect	YES	YES	YES	YES	YES	YES

Note: ***, **, and * represent significant levels of 1%, 5%, and 10%, respectively; The figures in parentheses are robust standard errors.

The coefficient for the core explanatory variable, digital transformation, remained positive across all models. Its magnitude and significance level progressively increased with the addition of control variables. In Column (1), which controlled only for individual and time effects, the coefficient for digit was 0.003 and failed to pass the significance test. After incorporating firm size (Column 2), the coefficient rose to 0.013 and became significant at the 10% level. By Column 6, which included all control variables, the coefficient further increased to 0.017 and achieved significance at the 5% level. After controlling for other

company characteristics, a one-unit increase in digital transformation results in an average improvement of 0.017 units in supply chain resilience, indicating strong effects. Regarding control variables, the coefficient for firm size remained significantly negative at the 1% level, implying that larger firms may have worse supply chain resilience due to structural complexity and slower response times. Profitable enterprises with higher physical asset proportions have stronger capacity and resources to create robust supply chain systems, as demonstrated by considerable beneficial effects on both return on net assets and tangible asset ratio. Revenue growth rate has minimal impact on supply chain resilience. The firm age coefficient is significantly negative, implying that older firms may have weakened supply chain responsiveness due to path dependence or organizational rigidity.

These findings indicate that while digital transformation enhances supply chain resilience for enterprises in the six central provinces, its promotional effect remains relatively limited. This may be closely related to the region's industrial structure, digital infrastructure, and policy environment. As a hub for traditional manufacturing and agriculture, the six central provinces exhibit relatively lagging digitalization among enterprises.

Most firms are still in the early stages of digital transformation, with digital technology applications focused on manufacturing automation or basic informatization. Applications in areas like supply chains remain insufficient, preventing the full realization of resilience gains from digitalization.

In summary, the regression results support Hypothesis H1, indicating that enterprise digital transformation can enhance supply chain resilience (achieved through optimizing supply network configuration). They also reveal the specific roles of other variables in influencing resilience.

4.3. Endogeneity Test

To address potential reverse causality interference in the model, drawing upon the research of Zhang Shushan et al. [19], two instrumental variables were selected and tested using the two-stage least squares instrumental variable method (2SLS). The first instrumental variable is terrain undulation, which is based on long-term, unchanging natural geographic features. Terrain limits impact the cost of digital infrastructure installation, which explains its association with digital transformation. This imposes inherent constraints on places with historically adverse terrain during subsequent digitalization processes, implying a negative association between terrain undulation and corporate digital transformation. Its exclusivity constraint is satisfied because, as a purely natural factor, topographic ruggedness—after controlling for regional fixed effects to absorb all non-temporal geoeconomic variations—can influence contemporary supply chain resilience only indirectly, through its unique channel of constraining or facilitating corporate digital transformation. However, terrain ruggedness is a natural geographic feature that does not change over the short term. Directly using it as an instrumental variable may limit our ability to capture temporal variations. The study adds an interaction term between terrain roughness and year to improve the exogeneity of the instrumental variable and maximize temporal information. The second instrumental variable is the average digital transformation level of other enterprises in the same industry during the same year [20]. Its relevance stems from the pervasive peer group effect in corporate digital transformation decisions, where firms are influenced by competitors' digitalization levels through competition, learning, or imitation. After adjusting for year and industry fixed effects and accounting for common industry trends and macroeconomic shocks, this instrumental variable predominantly reflects the exogenous social process of peer influence, thus satisfying the exclusion condition. This "peer influence" component should theoretically not directly affect a firm's unique supply chain resilience, as resilience heavily depends on the firm's own resources,

customer relationships, and internal management—aspects not captured by the average digitalization level of peers. The most plausible pathway for peer influence to impact a firm's resilience is by first driving or compelling the firm's own digital transformation.

Of course, the exogeneity of instrumental variables is a strong assumption that cannot be statistically tested. However, this study aims to optimize compliance with this criteria by employing the aforementioned theoretical arguments and a multidimensional fixed-effects model, hence increasing the causal explanatory power of the key conclusions. The integration of both instrumental factors in the same model results in a unique coefficient for digital transformation in the second-stage regression, indicating the causal effect of the combined instrumental variables.

The 2SLS regression results in Table 5 indicate that digital transformation exerts a significant positive impact on the dependent variable of supply chain resilience (coefficient = 0.072, $p < 0.01$). This finding demonstrates that the conclusion supporting Hypothesis H1 is still true after accounting for the endogeneity issue of reverse causality. The validity of the instrumental variables was verified through the first-stage F-statistic (585.36) and the overidentification test ($p = 0.617$). This study's instrumental variables are based on external data sources that may not accurately represent the initial sample. Furthermore, the instrumental variable approach places greater emphasis on data completeness, which means that any dimension of data missingness results in the elimination of observations. Sample loss is random, primarily stemming from data availability rather than systematic selection based on firm characteristics. Consequently, the retained sample exhibits good representativeness.

Table 5. Regression Results of Instrumental Variables.

Variables	Instrumental Variable 1		Instrumental Variable 2	
	(1) Digit	(2) SCR	(1) Digit	(2) SCR
digit		0.072 *** (0.009)		0.072 *** (0.009)
Terrain undulation	−0.014 *** (0.003)			
The average value of digital transformation of other enterprises			1.070 *** (0.020)	
Control variable	YES	YES	YES	YES
Enterprise/year fixed	YES	YES	YES	YES
Observed value	1894	1894	1894	1894
Wald F statistic		585.36		
Wald test p value		0.000		

Note: *** represent significant levels of 1%; The figures in parentheses are robust standard errors.

4.4. Robustness Test

4.4.1. Changing the Measurement Method of Variables

The study enhances the robustness of its findings by replacing the measurement methods of core explanatory and dependent variables. First, replacing the core explanatory variable: In the benchmark regression experiments, the Digital Transformation Index was selected to measure the degree of corporate digital transformation. Here, the core explanatory variable is replaced with the Digital Outcomes Score. Both metrics assess corporate digital transformation, but the former emphasizes overall capability and process, while the latter focuses on specific corporate outcomes and benefits. This substitution tests whether the research conclusions are sensitive to different measurement approaches for digital transformation, thereby enhancing the reliability of this paper's findings. Second,

in the benchmark regression, the coefficient of variation method was used to generate a composite indicator for the four tertiary aspects of supply chain resilience. Columns (1) and (2) of Table 6 show that after replacing the measurement method of the explanatory variable and the calculation method of the dependent variable, respectively, corporate digital transformation remains positive at the 1% level, with regression results consistent with the preceding analysis.

Table 6. Regression Results with Variable Measurement methods Changed.

Variables	Replacement of Explanatory Variables	Replacement of Explained Variable
	(1) SCR	(2) SCR
Digital transformation	0.018 *** (0.005)	0.091 *** (0.034)
Control variable	YES	YES
Enterprise/year fixed	YES	YES
Observed value	4893	4893
R ²	0.199	0.459

Note: *** represent significant levels of 1%; The figures in parentheses are robust standard errors.

4.4.2. Narrowing the Sample Time Range

To examine whether the research findings are sensitive to the choice of time span, thereby further validating the robustness and applicability of the conclusions, the data range was shortened from the original 2013–2023 to a sample covering the past five years. As shown in Table 7, while maintaining the same control variables and fixed effects, digital transformation still exhibits a significant positive effect on supply chain resilience, with a coefficient of 0.031 that is statistically significant at the 1% level ($t = 2.689$). This indicates that a 1% increase in a firm’s digitalization level leads to an average rise of 0.031 units in its supply chain resilience score. Digitalization has had a greater impact than the full-sample estimate in the last five years. Changes in the coefficients of the year dummy variables suggest a trend of gradually growing supply chain resilience from 2021 to 2023 ($\beta = 0.011$, $p < 0.10$ in 2021; $\beta = 0.018$, $p < 0.05$ in 2022; $\beta = 0.023$, $p < 0.05$ in 2023). This trend is most likely associated with a post-pandemic increased corporate attention on supply chain risk management, government deployment of chain-stabilizing regulations such as the “chain chief system,” and increased digitalization adoption in central China.

Table 7. Regression results of sample data from 2019 to 2023.

	(1) SCR
digit	0.031 *** (2.689)
2019.year	0.009 (0.006)
2020.year	0.002 (0.605)
2021.year	0.011 * (1.931)
2022.year	0.018 ** (2.376)
2023.year	0.023 ** (2.327)
Control Variable	YES
Enterprise/year fixed	YES
Observed value	2699
R ²	0.102

Note: ***, **, and * represent significant levels of 1%, 5%, and 10%, respectively; The figures in parentheses are robust standard errors.

5. Further Analysis

5.1. Mediating Effect Test

This study explores how varied supply chain configurations play a vital role in enhancing supply chain resilience through enterprise digital transformation processes. The focus on “diversified supply chain configurations” as a specific mechanism stems primarily from considerations of research design and theoretical contribution: First, the study’s objective is not to exhaustively list or compare all possible transmission pathways, but rather to conduct in-depth causal identification and validation of a structural mechanism that is central to theory yet remains under-explored in practice. Supply chain concentration directly reflects a company’s strategic decision on external network design, acting as the most direct and strategically significant structural relationship between digital technologies and resilience outcomes. Compared to process-oriented information visualization or technology-driven IT integration, structural optimization better reflects the strategic-level impact of digital transformation. Second, at the methodological level, focusing on a single, clearly defined theoretical core and mediating variable makes causal identification easier and more reliable inference. Simultaneously testing multiple mediating variables with potential collinearity increases model complexity and interpretive ambiguity. This study prioritizes depth over breadth to give strong evidence for the essential mechanism of structural remodeling. This does not rule out the presence of other parallel or interactive mechanisms, but it does provide a more solid platform for future research into various, even nonlinear, transmission networks.

The core logical chain in this study is: Corporate digital transformation (X) enhances supply chain resilience (Y) by reducing supply chain concentration, i.e., promoting supply chain configuration diversification (M). Here, supply chain concentration (scc) serves as the inverse key indicator for supply chain diversification. Lower concentration signifies greater diversification and a more dispersed supply chain structure, thereby better dispersing risks and enhancing resilience [13]. It directly represents the structural aspects of business resource dependency and risk distribution, demonstrating a reliance on a small number of suppliers. This makes it the most fundamental and direct link connecting digital technology with resilience building. A lower concentration indicates a more dispersed supplier structure and diversified collaborative ties, therefore limiting undue reliance on single suppliers and boosting resilience against external disturbances. For instance, when a key supplier faces production issues or delivery delays, a diversified supply system enables faster order diversion to alternative partners, maintaining operational continuity.

Based on this, the study selects supply chain concentration as a quantitative indicator for supply chain diversification. It is derived by averaging the procurement share of the top five suppliers and the sales share of the top five customers. For empirical strategy, this paper adopts a two-step verification method to validate the aforementioned mechanism, drawing on Jiang Ting’s [21] mediation effect analysis framework based on causal inference. Unlike traditional “three-step” or stepwise regression methods, the two-step approach shifts focus from pursuing statistical significance to ensuring the reliability of causal identification at each step within the mechanism pathway. This is especially appropriate for research situations with complex endogenous interactions, such as digital transformation and supply chain decision-making. The specific operations and logic of this study are as follows:

Step 1:

$$Y_{it} = \beta_0 + \beta_1 X_{it} + \beta_2 Controls_{it} + \beta_3 Year_t + \varepsilon_{it} \quad (2)$$

In the first step, the overall impact of the independent variable X on the dependent variable Y is examined. The purpose of this phase is to confirm a meaningful and interpretable relationship between digital transformation and supply chain resilience, which

is necessary for mechanism analysis. Y_{it} represents the supply chain resilience of the i -th enterprise in the t -th year, X_{it} represents the degree of digital transformation of the i -th enterprise in the t -th year, *Controls* is the set of control variables, representing other enterprise characteristics or industry factors that may affect supply chain resilience, *Year* is the year dummy variable, used to control for the time trend; β_0 is the intercept term, representing the baseline supply chain resilience level when all independent variables are 0, $\beta_{1,2,3}$ are the influence coefficients, and ε is the error term.

Step 2:

$$M_{it} = \gamma_0 + \gamma_1 X_{it} + \gamma_2 Controls_{it} + \gamma_3 Year_t + v_{it} \quad (3)$$

In the second step, the causal effect of the independent variable X on the mediating variable M is specifically examined. This is the core of the two-step method, and its logic lies in that if M is the true mechanism by which X affects Y , then X must be able to significantly and reliably cause changes in M . In this study, this suggests that it is required to confirm that digital transformation can successfully minimize supplier concentration and improve supply chain diversification. M_{it} is the mediating variable, used to measure the supplier concentration (scc) of the supply chain diversification configuration. γ_0 is the intercept term, $\gamma_{1,2,3}$ are the influence coefficients, and the other symbols have the same meanings as before.

Table 8 presents the regression results for the impact of digital transformation on supply chain resilience and supplier concentration. Due to the lack of supplier concentration data for some organizations, the number of observations in this experimental findings section is lower than in the baseline regression. In the first regression step, digital transformation exerts a significant positive effect on supply chain resilience (coefficient = 0.022, $p < 0.05$), indicating that digital transformation directly enhances supply chain resilience. In the second regression step, digital transformation exhibits a significant negative effect on supplier concentration (coefficient = -0.230 , $p < 0.01$). This indicates that digital transformation significantly reduces supplier concentration, thereby promoting a shift toward diversified supply chain configurations.

Table 8. Regression Results of mediating Effect test.

	(1)	(2)
	SCR	scc
digit	0.022 ** (0.010)	-0.230 *** (0.077)
Control variable	YES	YES
Enterprise/year fixed	YES	YES
Observed value	1912	1898
R ²	0.155	0.043

Note: *** and ** represent significant levels of 1% and 5%, respectively; The figures in parentheses are robust standard errors.

After completing the above two verification steps, the article has established an empirical evidence chain from “ $X \rightarrow M$.” Combined with existing robust theoretical literature, the chain from “ $M \rightarrow Y$ ” can be logically and rigorously closed. Extensive research indicates that excessive supplier concentration (i.e., insufficient diversification) exacerbates supply chain vulnerability, making it more susceptible to disruptions at single nodes and weakening firms’ bargaining power and capacity for emergency adjustments. Supply chain diversification is a key method for improving resilience by distributing risk sources, offering alternatives, and increasing network elasticity. Research by Zeng Yan et al. [22] confirms from a resource integration perspective that supply chain concentration significantly impacts corporate sustainability performance. This provides compelling theoretical

corroboration from another dimension for the paper’s central argument: supply chain configuration (as represented by concentration) is a critical mechanism influencing corporate resilience. Therefore, digital transformation theoretically enhances supply chain resilience by promoting supply chain configuration diversification through reduced concentration.

In summary, through two-step empirical verification—“digital transformation significantly enhances supply chain resilience ($X \rightarrow Y$)” and “digital transformation significantly reduces supply chain concentration ($X \rightarrow M$)”—combined with the established theory that “supply chain diversification enhances resilience ($M \rightarrow Y$),” this study establishes a logically coherent mechanism: corporate digital transformation empowers enterprises to reduce reliance on a few suppliers and build more dispersed and diversified supply networks, thereby effectively enhancing the supply chain’s resistance, adaptability, and recovery capabilities—i.e., improving supply chain resilience. This finding validates Hypothesis H2.

Furthermore, to ensure robustness, Sobel and Bootstrap tests were conducted. Table 9 shows that the Sobel-Goodman test confirms a significant mediating effect of supplier concentration between digital transformation and supply chain resilience (indirect effect coefficient: -0.003195 , $p < 0.001$). Specifically, digital transformation significantly reduces supplier concentration (a coefficient = -0.279537 , $p < 0.0001$), while lower supplier concentration significantly enhances supply chain resilience (b coefficient = 0.011429 , $p = 1.8 \times 10^{-6}$). At constant levels of digital transformation, increased supplier concentration leads to higher supply chain resilience scores, as indicated by the positive b coefficient in the model. This apparent contradiction reveals a trade-off in real-world supply chain management. Theoretically, diversification enhances long-term resilience through risk dispersion. Conversely, in static or short-term contexts, centralization may boost operational efficiency and stability via economies of scale, deep synergies, and relationship-specific investments—factors also reflected in resilience metrics. Thus, a positive b coefficient precisely reflects the trade-off between “efficiency-based resilience from centralization” and “risk-diversification-based resilience from diversification” after controlling for digital capabilities. The value of digital transformation stems from its potential to minimize the costs and complexity of diversification management (shown by a negative coefficient). This enables enterprises to adopt diversification strategies more readily to capture risk dispersion benefits without sacrificing efficiency, ultimately achieving a net increase in overall resilience. Furthermore, corporate digital transformation exerts a clear direct positive impact on supply chain resilience (direct effect coefficient = 0.061525 , $p \approx 0$), with a total effect coefficient of 0.05833 ($p \approx 0$). This suggests that digital transformation improves supply chain resilience through both direct and indirect effects caused by reduced supplier concentration. In Table 10, the direct effect is significant (coefficient = 0.0615252 , $p < 0.001$), indicating that digital transformation directly enhances supply chain resilience. The indirect effect is also significant (coefficient = -0.0031949 , $p < 0.001$) and negative, suggesting that digital transformation indirectly strengthens supply chain resilience by reducing supply chain concentration.

Table 9. Sobel Test Results.

	Coefficient	Standard Error	Z Value	p Value
Sobel test	−0.0032	0.0009	−3.421	0.0006
Goodman-1	−0.0032	0.0009	−3.385	0.0007
Goodman-2	−0.0032	0.0009	−3.458	0.0005
Coefficient a	−0.2795	0.0570	−4.9020	9.5×10^{-7}
Coefficient b	0.0114	0.0024	4.7768	1.8×10^{-6}
Indirect effect	−0.0032	0.0009	−3.4211	0.0006
Direct effect	0.0615	0.0060	10.3042	0
Total effect	0.0583	0.0060	9.7748	0

Table 10. Bootstrap Test Results.

Variables	Coefficient	Standard Deviation	Z	$p > Z $	95% Confidence Interval	
					Lower Limit	Upper Limit
_bs_1: Indirect effect	−0.0032	0.0010	−3.51	0.000	−0.0050	−0.0014
_bs_2: Direct effect	0.0615	0.0061	10.02	0.000	0.0495	0.0736

5.2. Comparison with the More Economically Developed Regions Along the Eastern Coast of China

As the forefront of China's digital economy development, eastern coastal provinces lead the nation in corporate digital transformation and supply chain resilience. Analysis of documents reveals that economically advanced eastern coastal regions possess multiple developmental advantages. First, their digital infrastructure is relatively advanced, with high coverage of new infrastructure like 5G networks and industrial internet. This provides enterprises with a high-speed, stable data connectivity foundation, effectively ensuring real-time coordination across all supply chain segments. Second, digital collaboration mechanisms within industrial clusters are more mature, forming digital ecosystem networks centered around large enterprises with broad participation from small and medium-sized businesses. By sharing orders, production capacity, and logistics resources, enterprises significantly enhance the entire supply chain's resilience against disruptions. Third, policy and financial support is more substantial. For example, in 2023, Guangdong Province set aside more than 5 billion yuan in dedicated fiscal funds for the digital economy, but Hubei Province invested less than 2 billion yuan. Additionally, the eastern region hosts a concentration of high-level institutions, boasting a rich reserve of digital talent, whereas the central region continues to face pressure from talent outflow. Finally, from an enterprise structure perspective, non-state-owned enterprises account for over 70% of businesses in eastern regions (compared to approximately 50% in central regions). Such enterprises typically feature more flexible decision-making mechanisms, enabling faster adoption of digital technologies for supply chain optimization. In contrast, central regions still exhibit certain shortcomings in digital infrastructure coverage and data circulation efficiency, limiting the effectiveness of digitalization in enhancing supply chain resilience. Additionally, the region has a high proportion of small and medium-sized enterprises. Limited financial and technology capabilities confine digital transformation to certain parts, impeding full-chain coordination and limiting overall resilience enhancement.

Based on these disparities, this study used A-share-listed businesses from six eastern provinces and municipalities—Jiangsu, Shanghai, Zhejiang, Fujian, Guangdong, and Hainan—as comparison samples. Using the same variable definitions, data processing, and model settings as the central region study, regression models were validated. The regression results are shown in Table 11. The regression coefficient for the impact of digital transformation on supply chain resilience among enterprises in eastern coastal provinces is 0.000, which is statistically significant at the 5% level ($p < 0.05$). This finding indicates that the marginal contribution of enhanced digital capabilities to supply chain resilience among enterprises in China's eastern region has approached zero. This likely reflects relatively mature digital application among enterprises in this region, where supply chain efficiency is gradually approaching the optimal level achievable under current technological conditions, and the marginal benefits of digitalization are diminishing. During the early stages of digital transformation, enterprises can achieve significant marginal improvements in supply chain stability with relatively low investment by introducing digital technologies to address foundational issues such as information silos and process visibility. This is reflected in a high positive marginal effect coefficient, as observed in the central region in this study. High digital penetration leads to stronger infrastructure and limited potential for efficiency

increases at a single location. Further enhancements in supply chain resilience then rely more heavily on advanced systemic capabilities such as data-driven cross-organizational intelligent decision-making and industrial chain ecosystem collaboration. At this stage, pure digital investment struggles to yield substantial marginal resilience gains, with effects potentially flattening or becoming statistically insignificant—marking the onset of diminishing marginal returns, as observed in the eastern region of this study. The coefficient mismatch indicates that the center region is still utilizing digitalization for empowerment rewards, while the eastern region is moving towards resilience breakthroughs through systemic collaboration.

Table 11. Comparison of the regression results of the six eastern provinces and the six central provinces.

Variables	Six Central Provinces	Six Eastern Provinces
	(1) SCR	(2) SCR
digit	0.017 * (0.010)	0.000 ** (0.000)
Control variable	YES	YES
Enterprise/year fixed	YES	YES
Observed value	4893	18,925
R ²	0.105	0.166

Note: **, and * represent significant levels of 5%, and 10%, respectively; The figures in parentheses are robust standard errors.

The coefficient approaching zero in the eastern region precisely reflects its leading position in digitalization. Achieving this state relies on several conditions that remain relatively weak in the central region. First, the gap in infrastructure and data connectivity. The eastern region significantly leads in metrics such as 5G base station density, industrial internet platform penetration, and enterprise cloud adoption rates, providing the physical foundation for real-time data exchange across the entire supply chain—a prerequisite for achieving synergy. Central regions face notable shortcomings in infrastructure coverage, limiting the flow and enabling radius of data elements. Second, disparities exist in industrial cluster maturity and ecosystem development. Eastern regions have fostered numerous mature, digitally driven industrial clusters, where leading enterprises and supporting suppliers achieve deep coordination in orders, production capacity, and logistics through digital platforms, forming a networked resilience against risks. In contrast, the industrial digital ecosystem in central regions remains relatively loose, with insufficient breadth and depth in digital collaboration among enterprises. Finally, disparities exist in factor support and innovation environments. The eastern region holds absolute advantages in digital talent reserves, capital market support for digital innovation, and the richness of digital solution offerings, enabling the development and application of more complex, cutting-edge resilience solutions. The central region faces constraints such as talent outflow and relatively insufficient professional service supply.

The divergent empirical results across regions highlight the phased nature of digital transformation effects. Central China remains in the early stages of transformation, where digitalization yields modest resilience gains through basic information integration. Eastern China has advanced to the later stages, where resilience increasingly relies on systemic synergies between digitalization and other advanced factors—such as innovation ecosystems and global supply chain integration. This finding also provides regional-level empirical support for the theory of diminishing marginal returns in digital applications. Moreover, the near-zero marginal effects observed in the eastern region carry significant economic

implications. These provinces have successfully addressed basic inefficiencies through digitalization, resulting in high resilience returns. Under current technologies and business models, their supply chains may have approached the frontier of digital productivity. Achieving more substantial resilience gains requires not only increased digital investment but also driving architectural innovations that reshape supply chain coordination models. This highlights a critical policy insight: regional digital strategies must be tailored to local conditions. Central regions gain from fundamental digital empowerment, but eastern regions should prioritize deep, ecosystem-wide digital integration and innovation.

5.3. Internal Heterogeneity Analysis of the Six Provinces in Central China

The preceding section's comparison of eastern and central areas demonstrates that the six central provinces continue to lag significantly behind coastal developed provinces in terms of using digital transformation to improve supply chain resilience. The difference may be due to structural reasons like poor digitization and inadequate industrial coordination systems. To systematically identify the specific bottlenecks faced by the central region in this process, a further heterogeneity analysis is conducted across four dimensions. This approach seeks to provide empirical insights for formulating more targeted regional policies by examining internal variations.

5.3.1. Heterogeneity Under Property Rights Classification

Ownership structure often directly influences corporate governance models and resource allocation methods. State-owned (SOE) and non-state-owned enterprises exhibit distinct differences in institutional mechanisms, market responsiveness, and innovation capabilities. Regression results (see Table 12, Columns 1–2) indicate that digital transformation in non-state-owned enterprises significantly enhances supply chain resilience ($p < 0.05$), whereas this effect fails to pass the significance test in state-owned enterprises. Non-state-owned firms may be more flexible and adaptable, allowing for faster integration of digital technologies into supply chain management procedures. However, state-owned firms may be hampered by internal procedural limits and insufficient incentives, resulting in their digital transformation efforts not fully translating into actual resilience benefits.

Table 12. Heterogeneity analysis.

Variables	(1) State-Owned Enterprises SCR	(2) Non-State-Owned Enterprises SCR	(3) The Middle Reaches of the Yangtze River SCR	(4) Non-Middle Reaches of the Yangtze River SCR	(5) Digital Economy Industry SCR	(6) Non-Digital Economy Sectors SCR	(7) Large Scale Enterprises SCR	(8) Small and Medium-Sized Enterprises SCR
digit	0.005 (0.007)	0.021 ** (0.009)	0.020 ** (0.009)	0.011 (0.008)	−0.010 (0.009)	0.031 *** (0.009)	0.022 *** (0.005)	−0.000 (0.014)
Control variable	YES	YES	YES	YES	YES	YES	YES	YES
Enterprise/year fixed	YES	YES	YES	YES	YES	YES	YES	YES
<i>p</i> value		0.038		0.096		0.017		0.026
Sample size	1934	2944	2485	2390	2514	2361	2926	1940
R ²	0.117	0.252	0.248	0.155	0.242	0.179	0.173	0.225

Note: *** and ** represent significant levels of 1% and 5%, respectively; The figures in parentheses are robust standard errors.

5.3.2. Heterogeneity Under Regional Classification

Even within the central region, significant disparities exist in development conditions and policy environments among different provinces. For instance, The Yangtze River Middle Reaches Urban Agglomeration includes Hubei, Hunan, and Jiangxi, which have a higher proportion of advanced manufacturing and high-tech businesses. Digital transformation and supply chain management are inextricably linked in industries with complicated manufacturing processes and extensive supply chain coordination. Consequently, digital transformation can more directly enhance the supply chain resilience of such enterprises. In contrast, the industrial structures of Henan, Shanxi, and Anhui provinces feature higher proportions of traditional resource-based industries, bulk commodity manufacturing, and agriculture-related industrial chains. Digital transformation in these sectors may focus more on production safety monitoring, resource efficiency improvements, or primary product traceability. The linkages between these efforts and building resilience in complex supply chain networks are relatively longer and more indirect, potentially making the enabling effects of digitalization on overall supply chain resilience statistically harder to capture. Additionally, disparities exist in geographic positioning and logistics hub functionality. The middle Yangtze River region serves as the core area of China's "golden waterway" and integrated transportation hub, boasting a denser and more sophisticated multimodal logistics network. The informational advantages gained through digital transformation can generate stronger synergies with efficient physical distribution networks, thereby translating more directly and significantly into supply chain adaptability and resilience. Non-Middle Yangtze regions may have lagging logistics network structures and efficiency, limiting the usefulness of digital information flows in optimizing logistics and boosting resilience. Differences may also exist in regional innovation ecosystems and factor aggregation. As a relatively mature national-level urban cluster, the Middle Yangtze River cities may hold advantages in the regional flow and sharing of innovation factors like talent, technology, and data. This provides a more favorable external environment for enterprises, especially leading companies, to build digital supply chain collaboration ecosystems centered around themselves, thereby amplifying the network effects of digital transformation. In contrast, the other three provinces may continue to develop in terms of integrated allocation of innovation drivers across administrative regions. Enterprise digital transformation is more often manifested as individual corporate actions, limiting its enabling effects. The regression results in columns 3–4 of Table 12 further validate this analysis. While Henan, Shanxi, and Anhui each harbor outstanding enterprises that have successfully undergone digital supply chain transformation, their average effects across the full sample studied here are less pronounced. Structural variables including regional industrial foundations, geo-economic conditions, and innovation ecosystems significantly impact digital transformation efficacy.

5.3.3. Heterogeneity Under Industry Attribute Classification

Enterprises based on whether they belong to the digital economy sector, the results in Table 12 (5) to (6) indicate that digital transformation within the digital economy sector does not significantly enhance supply chain resilience, whereas it does so significantly in non-digital economy sectors. This indicates that digital economy industries already possess a high level of digitalization. As a result, the incremental gains from chasing perfection through digital transformation materialize as a continuous stream of benefits, making it difficult to achieve significant effect. Conversely, enterprises in non-digital economy industries can more readily achieve transformative breakthroughs by introducing emerging technologies and advanced management models during their digital transformation. This

enables them to break old patterns and establish new ones, achieving a qualitative leap and significantly enhancing their supply chain resilience.

5.3.4. Heterogeneity Under Enterprise Size Classification

Enterprise scale is commonly regarded as a key indicator reflecting a company's developmental stage and overall capabilities. It is widely assumed that larger firms have more robust institutional structures and more profitability, perhaps giving them an advantage in progressing digital transformation. The sample was divided into large and small enterprises based on scale for separate regression analysis. Results from columns (7) to (8) in Table 12 indicate that digital transformation initiatives enhance supply chain resilience more significantly for large enterprises, while the impact on small enterprises fails to pass the significance test. This may stem from large enterprises' greater financial resources and technological accumulation, enabling more effective integration of digital technologies into supply chain management systems. In contrast, small and medium-sized enterprises face resource and capability constraints, with their digital practices still in the exploratory phase, limiting the full manifestation of their contribution to overall resilience.

6. Conclusions and Policy Implications

Against the backdrop of deepening global economic integration and intensifying market competition, the stability and resilience of supply chains have become critical safeguards for sustainable corporate development. The rapid advancement of digital technologies presents both new opportunities and challenges, propelling digital transformation into a vital pathway for enterprises to adapt to complex environments and enhance core competitiveness. As a vital strategic economic zone for the nation, the six central provinces possess multiple advantages, including geographical location, labor resources, and industrial diversity. Promoting supply chain resilience through digitalization among enterprises in this region holds significant practical and strategic importance. While the link between digital transformation and supply chain resilience has received significant academic attention, further study is needed to better understand the underlying transmission mechanisms and boundary conditions. This study's contribution lies not merely in verifying their general correlation but in focusing the research question on "how digital capabilities influence resilience through the specific strategic pathway of reshaping structural supply chain configurations." It is the first systematic examination of this mechanism within China's central region. By constructing an integrated "capability–structure–resilience" framework and employing rigorous causal inference methods to identify the mediating role of diversified supply chain configurations, this study not only provides more granular micro-level evidence for understanding digital empowerment but also reveals that this enabling effect is profoundly contingent on contextual factors such as firm ownership, scale, and regional endowments. Thus, this paper aims to transcend the verification of universal relationships, focusing instead on revealing the specific pathways and heterogeneous contexts through which digital transformation impacts supply chain resilience. Theoretically, this enriches our understanding of how digital technologies can be adapted to local conditions to enhance organizational resilience. Practically, it provides more targeted evidence for formulating regionally differentiated policies.

Despite rigorous efforts, this study has limitations. The sample size of A-share listed companies limits its applicability to small and medium-sized enterprises that are not publicly traded. Second, both supply chain resilience and digital transformation are complex concepts. While the composite indicators and text analysis methods employed are mainstream, they remain proxy variables that cannot fully capture all dimensions and substantive depth of these concepts. Future research could expand to broader micro-

enterprise samples, develop more business-scenario-specific digitalization and resilience measurement methods, and further explore how digital technologies shape resilience and their ecological effects from the perspective of supply chain network collaboration.

This study uses data from A-share listed companies in six central provinces from 2013 to 2023 to empirically investigate the influence of digital transformation on supply chain resilience and its underlying mechanisms. Key findings include: (1) Digital transformation generally enhances corporate supply chain resilience, a conclusion that remains robust across a series of tests—including distinguishing resilience dimensions, addressing endogeneity issues, altering variable measurement methods, and adjusting sample timeframes; (2) Mechanism analysis indicates that digital transformation indirectly strengthens supply chain resilience by promoting diversified supply chain configurations—particularly by reducing supplier concentration; (3) Heterogeneity research suggests that, compared to developed coastal regions in eastern China, the digital empowerment effect in central China is still in its early stages. Within the region, the resilience-enhancing effect of digital transformation is more pronounced for non-state-owned enterprises, traditional industries, larger firms, and enterprises located in the Yangtze River Midstream Urban Agglomeration.

Based on the aforesaid findings, the study identifies three important issues that firms in the six central provinces confront during their digital transformation initiatives to improve supply chain resilience: (1) The overall digital empowerment effect remains minimal, with applications still in their early stages. Benchmark regression results (Table 4) and comparisons with eastern coastal regions (Table 11) indicate that the marginal improvement in resilience from digitalization has plateaued. This suggests that digital applications in central China may still be confined to foundational levels—such as information visualization and process digitization—rather than advanced stages involving predictive analytics, collaboration, and restructuring through data intelligence. Consequently, both the absolute efficacy and marginal benefits of digital “empowerment” hold significant room for improvement. (2) Empowerment effects exhibit significant structural disparities across enterprises. Heterogeneity analysis (Table 12) clearly demonstrates that the resilience-enhancing effects of digital transformation are not universally beneficial. It has a major influence on non-state-owned and large-scale organizations, but has little or no effect on state-owned and small-to-medium-sized businesses. This internal divergence directly confirms that the “digital divide” persists within the region. State-owned firms may suffer institutional and incentive constraints, whilst small and medium-sized enterprises may face resource and competence shortages, preventing investments in digital transformation from effectively translating into supply chain resilience outcomes; (3) Digitalization has relatively limited effects on optimizing supply chain structures. While mediation effects validate the pathway of “promoting diversified supply chain allocation” (Tables 8–10), current digital transformation among central enterprises may enhance resilience primarily through internal operational improvements rather than fundamental optimization and coordination of external supply chain networks. The potential of digitalization to drive diversified supply chain allocation and build resilient ecosystems remains largely untapped. (4) Regional external conditions profoundly constrain the realization of digitalization’s efficacy. Comparisons with eastern regions (Table 11) and intra-regional heterogeneity analysis (Table 12, where the “Middle Yangtze River Region” exhibits superior effects) jointly point to a conclusion: digital empowerment does not occur in a vacuum. Regional endowments—including infrastructure, industrial cluster maturity, talent, and capital—serve as critical moderating variables. The relative deficiencies in these external enabling conditions across central China impose a macro-level ceiling on the overall effectiveness of corporate digital transformation, constituting a key external factor behind its gap with the eastern regions. To address these issues, the following differentiated measures are proposed:

First, addressing the previously identified issue of “overall weak digital empowerment effects and rudimentary application stages,” foundational capability building must be strengthened to drive deeper digital application penetration. On one hand, fiscal support should be provided by offering higher matching subsidies or tax credits for enterprises adopting advanced digital applications such as AI-driven demand forecasting, digital twin simulation, and blockchain traceability, incentivizing them to transcend the “basic informatization” threshold. Second, the government should lead cooperation between top firms and cloud service providers to create public data hubs and algorithm model libraries for key industries. This “platform-enabled” approach will reduce the cost and complexity for individual enterprises—especially small and medium-sized enterprises—to access and deploy intelligent analytics tools, thereby achieving inclusive provision of advanced capabilities. This program intends to systematically promote the depth and breadth of digital adoption among firms in central China, harnessing the advanced potential of digitalization to improve supply chain resilience.

Second, addressing the “significant structural disparities in empowerment outcomes across enterprises” requires differentiated support policies to break the transformation deadlock in state-owned enterprises and resolve the capability constraints of small and medium-sized enterprises. Deepen SOE digital reform pilots by incorporating key supply chain resilience metrics into SOE executive performance evaluations and strongly linking them to performance-based compensation. Allow SOEs more financial and procurement autonomy for digital transformation projects, while providing error-tolerant methods to boost intrinsic motivation. Establish “platform- small and medium-sized enterprises” digital empowerment consortia, encouraging industry leaders or platform enterprises to open their digital management systems in modular, lightweight formats for use by upstream and downstream small and medium-sized enterprises. Governments should provide two-way incentives for such empowerment projects, rapidly elevating small and medium-sized enterprises’ digital starting points and collaborative capabilities through “big-to-small” mentorship. Simultaneously, regional coordination should be strengthened by implementing cross-provincial supply chain data-sharing agreements in Henan, Shanxi, and Anhui provinces, unifying data standards, and dismantling administrative barriers.

Third, addressing the findings that “digitalization has relatively limited effects on optimizing supply chain structures” and the challenges in intermediary mechanisms, policies should shift from encouraging “intra-enterprise transformation” to incentivizing “supply chain collaborative transformation,” thereby strengthening network structure optimization. Certify businesses who effectively create and retain qualified new suppliers using digital platforms, and provide corresponding credit incentives or logistics subsidies. This aims to explicitly redirect digital value from “internal cost reduction” toward “external network expansion and strengthening.” Fund the construction of industry-level supply chain collaboration platforms. In key manufacturing clusters, support industry associations or leading enterprises in developing and deploying shared platforms for capacity matching, collaborative production scheduling, and joint inventory management. Government funding will support initial development, with incentives for active enterprise alliances to promote industrial chain collaboration through digital means and reduce coordination costs associated with diversification.

Fourth, addressing the “significant constraints imposed by regional external conditions on digital effectiveness,” efforts must focus on addressing regional shortcomings and systematically optimizing the external ecosystem for digital empowerment. In core node cities outside the Yangtze River Delta, such as Taiyuan, Luoyang, and Fuyang, plan and construct regional-level edge computing centers directly connected to national backbone networks to ensure low-latency, high-reliability data flow. Include enterprise access fees

for such computing services in subsidy programs to level the playing field for digital transformation by equalizing infrastructure. Create rules to encourage top domestic internet solution providers and data service companies to build regional headquarters or delivery hubs in Central China. Simultaneously, collaborate with local universities and vocational colleges to launch specialized training programs and sign “reservation-to-employment” agreements with enterprises. This approach strengthens the “supply side” to address talent drain and technical service gaps, fostering a sustainable digital ecosystem.

7. Implications

7.1. Theoretical Implications

Unlike most existing studies that focus on how digitalization enhances internal operational capabilities such as information processing efficiency and agile responsiveness, this paper constructs and tests an integrated “capability–structure–resilience” framework. The study identifies how digital transformation improves supply chain resilience by reducing concentration and encouraging diversification at the network level. This finding advances the broad literature conclusion that “digitalization enhances risk resistance” to the level of empirical validation of specific structural mechanisms, offering a new theoretical perspective on how digitalization can be “tailored to local conditions” to translate into organizational resilience. Simultaneously, this study tests the mechanism within the unique regional context of Central China, revealing the conditional dependence of digital empowerment effects on regional industrial foundations and factor endowments. This study tackles the disregard of regional variability in existing research and offers micro-level data for multidisciplinary studies on technology diffusion and regional development theory.

7.2. Managerial Implications

For corporate managers, the findings of this study offer the following specific insights: First, digital transformation should be positioned as a strategic tool for “supply chain restructuring,” rather than merely a means to enhance internal efficiency. Managers should grasp that the primary advantage of digital capabilities is to reduce the management and coordination costs of supply chain diversification, allowing businesses to transition from high-risk single-source dependency structures to more resilient diversified networks. Second, enterprises should develop differentiated digital strategies based on their unique endowments. Non-state-owned and larger companies should use their flexibility and resources to diversify supply chains, while state-owned and small and medium-sized enterprises must rely on external enabling mechanisms to compensate for their own transformation capabilities. Third, building supply chain resilience must evolve from “internal optimization” to “network collaboration.” Managers should proactively utilize digital platforms to expand external partnerships, establish multi-source supply systems, and actively participate in the development and utilization of industry-level collaborative platforms. This method lowers the costs of diverse collaboration while increasing resilience from individual firms to the entire supply chain network.

7.3. Practical Implications

The study’s conclusions provide strategic insights for the accurate development of regional industrial policies that go beyond particular actions. First, policymakers must deeply recognize the “phased” nature of digitalization in empowering supply chain resilience. The regional disparity effects revealed in this study indicate that no universally applicable digital policy template exists. Policy design must adhere to the fundamental principles of digital transformation and dynamically modify its focus according to the developmental stage of each region: in areas that are just beginning to undergo transfor-

mation, the focus should be on bolstering foundations and encouraging the adoption of new technologies; in regions at the later stage, the focus should shift toward encouraging ecosystem collaboration and architectural innovation. Second, policy implementation must confront the “structural inequality” in empowerment outcomes. The “digital divide” between state-owned and non-state-owned businesses, as well as between big corporations and small and medium-sized businesses, may unintentionally increase rather than close as a result of blanket digital incentive programs. This necessitates shifting from “one-size-fits-all” approaches to “targeted interventions,” designing differentiated support mechanisms tailored to the specific transformation barriers faced by enterprises of varying ownership structures and scales. Finally, regional coordination policies should focus on building “systemic ecosystems” rather than strengthening “isolated capabilities.” The core policy logic for enhancing regional supply chain resilience must shift from supporting individual enterprises (“point thinking”) to optimizing regional innovation ecosystems (“system thinking”). By addressing ecosystem weaknesses, this approach provides a more robust foundation and broader space for the digital transformation of all enterprises.

From a broader perspective, the six central provinces serve as vital national manufacturing bases and logistics hubs. Enhancing their supply chain resilience directly impacts the overall stability and risk-resistance capabilities of the national industrial chain. Research indicates that digitalization significantly strengthens enterprises’ ability to withstand external shocks by optimizing supply chain structures. This not only injects sustainable endogenous momentum into the central region’s rise strategy but also solidifies the microfoundations for building a unified national market. At this critical juncture for advancing high-quality development, this study provides empirical evidence for addressing regional development imbalances and fostering industrial synergy among eastern, central, and western regions. It holds significant practical value for building a more resilient national industrial system, safeguarding national economic security, and achieving sustainable development goals—by reshaping supply chain structures through digital transformation, shifting economic development from fragile single-point dependencies to resilient networked support, and laying a solid foundation for navigating complex and volatile international environments.

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Abbreviations

The following abbreviations are used in this manuscript:

ST	Special Treatment
SCR	Supply Chain Resilience
scc	Supplier concentration
SOE	State-Owned Enterprise

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