

Article

Does Digital Finance Build a Sustainable Buffer? Exploring Its Impacts on Manufacturing Supply Chain Resilience

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Abstract

Enhancing supply chain resilience has become crucial for sustainable manufacturing development as firms face repeated disruptions from pandemics, geopolitical shocks, logistics bottlenecks, and climate-related uncertainty. As digital finance alleviates corporate financing constraints and improves information transmission across supply chains, it may strengthen supply chain resilience, thereby supporting the sustainable development of manufacturing firms. Accordingly, this paper examines this effect using panel data consisting of 21,060 firm-year observations of Chinese A-share listed manufacturing firms spanning the period 2011–2023. It combines the proxy of digital finance, which is the city-level Baidu search index for digital finance, with the entropy-weighted and firm-level supply chain resilience index to assess its sustainability. Based on the fixed-effects model, digital finance positively affects the resilience of manufacturing companies' supply chains and, by extension, promotes the sustainable development of manufacturing supply chains. We also find that digital finance improves manufacturing supply chain resilience by enhancing information transparency, resolving maturity mismatches between investment and financing, and mitigating financial risks. This impact is larger in poorly developed traditional financial regions, firms with poor governance, and in growing companies. Policy recommendations center on advancing digital supply chain finance, strengthening data governance, and improving risk management systems to reinforce supply chain resilience and promote the long-term sustainable development of manufacturing firms.

Keywords: manufacturing firms; supply chain resilience; manufacturing sustainability; digital finance; China



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1. Introduction

Supply chains in manufacturing are becoming increasingly vulnerable to repeated interruptions caused by pandemics, geopolitical conflicts, logistic problems, fluctuations in energy prices, and climatic uncertainties. The outbreak of coronavirus disease and shipping disruptions in the Strait of Hormuz have shown that manufacturing sustainability cannot be assured only by the capacity to produce goods but also depends on the availability of liquidity, accurate information, and coordination between suppliers, customers, and financial institutions [1,2]. These conditions have brought about increased awareness of the significance of the resilience of supply chains for the sustainability of manufacturing systems and, more generally, industrial sustainability [3,4]. Within such a framework,

digital finance might provide innovative tools to increase the ability of organizations to survive and recover from any form of interruption [5,6]. Through the combination of big data analytics, cloud computing, artificial intelligence, mobile payments, and blockchain technology infrastructure, digital finance can help in enhancing credit analysis, risk assessment, receivables financing, verification of transactions, and communication of risk information through supply chains [7–11].

Early foundational studies on supply chain resilience define this construct as a system-level capability to anticipate, respond to, and recover from operational disruptions [12–15]. Further studies on resilient supply chains highlight the connection between resilience, collaboration, visibility, and dynamic capability [1,3,16–19]. In this paper, we emphasize the importance of finance for the analysis of resilience. If digital finance decreases information asymmetry and liquidity availability, it could increase firms' resilience and their ability to recover from shocks and adapt their supply chain strategy. Otherwise, if digital finance just increases short-term credit and brings new information and platform risks, then its influence on resilience would not be so strong. Therefore, the empirical prediction is not obvious and requires firm-level study.

The case of China is especially well suited to exploring the association between digital finance and manufacturing supply chain resilience. Firstly, there is an extensive manufacturing sector in China where firms are tightly integrated into export networks, industrial clusters in the region, and dense networks of suppliers [20,21]. Under such circumstances, disturbances are unlikely to impact just one individual firm due to trade credit, order fulfillment, and supplier management that ties firms together in the supply chain [22]. Secondly, despite the fast development of digital finance, the Chinese manufacturing sector still consists of firms with limited access to finance and higher-than-average interest rates on debt [23,24]. The situation is especially acute during shocks when firms need to access immediate financing for inventory, accounts receivable, emergency purchases, and supplier substitution. Thirdly, digital finance has the ability to transform transactions, trade credits, e-commerce activities, and industrial cluster data into credit information and improve financial conditions and inter-firm cooperation [25]. Thus, the Chinese example provides an opportunity to test whether digital finance may be used to increase the resilience of supply chains in an economy where production is vulnerable to export shocks, dependent on industrial clustering, and constrained in financing.

There are three scholarly contributions that can be attributed to the present study. The first extends the literature on supply chain resilience in that the concept of digital finance is taken into consideration not only as a source of funding but also as a complex platform. This study widens the scope of investigation for the microeconomic consequences of digital finance and factors behind manufacturing firms' supply chain resilience. Earlier literature found that resilience relies on cooperation, flexibility, information exchange, diversification of suppliers, and organizational capabilities. Based on theories of information asymmetry, dynamic capability, and the resource-based view, this research proposes digital finance as an enabler of supply chain resilience through the linked functions of liquidity, information exchange, diversification of risks, and supply chain coordination. This research enriches the existing academic literature by clarifying the correlation between digital finance and the key constituent elements of resilience.

Second, it develops a systematic mechanism approach. In addition to estimating the direct effect of digital finance, the study specifies three transmission mechanisms: improved information transparency, decreased maturity mismatch between investments and funding, and decreased financial risks. This helps us understand how these wider theoretical roles of digital finance materialize in supply chain resilience. Improved information transparency improves the information exchange and coordination between firms, banks, suppliers, and

customers. Decreased maturity gaps between investments and financing provide greater stability in terms of liquidity support for investments and supply chain adaptation. Lower financial risks minimize the likelihood of spreading of liquidity problems, payment failures, and disruption throughout the supply chain network.

Third, it shows heterogeneous boundary conditions. Digital finance positively affects firms that have an underdeveloped traditional financial sector, poor corporate governance, or are growing. The reason why heterogeneity appears is that digital finance is not technology neutral and is valuable only when it addresses shortcomings in information, collateral, and risk gathering. Matching a proxy for city-level digital finance with firm-year panel data from 2011 to 2023, this study sheds light on the microeconomic financial drivers of manufacturing supply chain resilience in the emerging market context.

The structural arrangement of this paper proceeds as outlined below. A review of the existing literature is provided in Section 2. Section 3 outlines the theory and formulates the four research hypotheses. The description of the sample, the definition of variables, and the specification of the econometric model follow in Section 4. Section 5 covers the benchmark results, robustness checks, endogeneity issues, channels, and heterogeneities. Section 6 summarizes the overall conclusions and proposes targeted suggestions.

2. Literature Review

Scholarly works closely related to the current research can be divided into three inter-related strands. The first stream concerns the development of the concept and measurement of supply chain resilience. Initially, resilience is defined as the capability of a supply chain to resist, cope with disruptions, recover from damage, and reestablish its original functionality after exposure to external disruptions [12–14]. Later, the understanding of the concept expanded with the consideration of factors such as adaptation, reconfiguration, learning, and constant renewal of inter-firm relations after disruptions [15,26,27]. More recent papers develop this idea by considering supply chain resilience as the capability of an enterprise to be resilient within its supplier networks, customer dependency, industrial positioning, and external resource accessibility [4,28–30]. For example, An et al. [4] define corporate supply chain resilience as resistance, recovery, and creativity. Ren and Ren [30] shift the focus toward capital, governance, ESG performance, and innovation, pointing out that resilience is possible not only in the case of redundant operational capabilities but also in terms of stable financial and organizational resources.

The second stream of literature explores the effect of digitalization on increasing the resilience of supply chains. Digitalization increases the level of visibility regarding orders, logistics, production schedules, supplier risks, and customers' demands; hence, it reduces the gap between disruptions and actions taken [2,8,31,32]. More recent empirical research focused on Chinese companies provides evidence on this issue. Dong et al. [29] prove that artificial intelligence may increase resilience in the face of geopolitical risks due to lower costs and efficiency. Li et al. [33] prove that digitalization increases supply chain resilience, and one of the channels is through the increase in supply chain power and transparency. Tian and Cui [34] reveal that digitalization improves the resilience of supply chains because of the enhancement in information processes, recovery capabilities, and efficiency of inventory turnover. Zhang et al. [35] demonstrate that supply chain collaboration acts as the mediating channel linking digital transformation to supply chain resilience, while social capital plays a moderating role in such a causal linkage. Li et al. [36] confirm that corporate digital transformation increases the resilience of manufacturing supply chains. Li and Wang [37] argue that both digital capabilities and financial support may impact the resilience of industrial networks.

Thirdly, digital finance, FinTech, and supply chain finance have been extensively studied in the literature. Supply chain disruptions frequently stem from firms' limited liquidity, difficulties in rolling over short-term liabilities, barriers to inventory financing, and pressures to settle supplier invoices. Digital finance can solve these issues by turning transactional information, logistics information, accounts receivable, payment behavior, tax information, platform data, etc. into credit signals [5,7,9]. In contrast with traditional finance, digital finance demonstrates higher effectiveness in providing services to businesses with no collateral but with repeated transactions. Li et al. [9] state that digital finance improves the resilience of supply chains. While financing constraints influence resilience adversely, technological innovation acts as an important mediation channel for the connection between digital finance and resilience. Chen and Yu [38] find the same results for Chinese listed manufacturing firms where digital finance contributes to supply chain resilience through value co-creation. Liu et al. [10] prove that FinTech improves the resilience of corporate supply chains by developing supply chain finance and reducing supply chain concentration. Zheng et al. [39] reveal that supply chain finance improves the resilience of firms due to a reduction in financial constraints and an improvement in total factor productivity. Liu and Pan [11] indicate that digital finance could enhance supply chain resilience through the reduction of financing constraints, facilitating the digitalization of firms and the improvement of innovation ability. Liu and Shang [40] find that supply chain finance could improve the resilience of corporate supply chains under external uncertainty. According to Ma et al. [19], digital finance bears significant correlations with green economic advancement and the resilience of industrial supply chains, where green credit allocation and green technological innovations are critical mechanisms. Qiao et al. [41] discover that digital finance improves the resilience of Chinese manufacturing firms' supply chains by lowering search costs of information, alleviating financing constraints, and improving innovation ability. Qin and Xue [42] conclude that digital supply chain finance can contribute to corporate digital maturity and manufacturing resilience, and digital collaboration plays crucial roles.

The main research streams and the position of this study are summarized in Table 1.

Table 1. Literature comparison.

Research Streams	Representative Studies and Main Findings	Research Gaps and Position of This Study
Conceptualization and measurement of supply chain resilience	Initial studies define supply chain resilience as the ability to withstand disturbances, maintain core operations, and bounce back from setbacks [12–14]. Subsequent studies expand this concept to include adaptation, learning, reconfiguration, and restoration of relationships between firms [15,26,27]. More recent studies further emphasize supplier networks, customer dependence, industrial positioning, external resource accessibility, governance, innovation, and ESG performance [4,28–30].	Existing studies provide a multidimensional understanding of resilience but pay relatively limited attention to its financial foundations. This study constructs a firm-level resilience index covering resistance, recovery, operational capability, supply–demand matching, and renewal capacity, and examines whether digital finance strengthens these capabilities.

Table 1. *Cont.*

Research Streams	Representative Studies and Main Findings	Research Gaps and Position of This Study
Digitalization and supply chain resilience	Digital technologies improve the visibility of orders, logistics, production schedules, supplier risks, and customer demand, thereby shortening the interval between disruption detection and organizational response [2,8,31,32]. Recent studies show that artificial intelligence and corporate digital transformation enhance resilience by reducing costs, improving information processing, strengthening transparency and collaboration, and increasing inventory and recovery efficiency [29,33–37].	This literature mainly focuses on firms' internal digital transformation and operational digital capabilities. This study shifts attention to external digital financial infrastructure and investigates how regional digital finance affects resilience through financing, information-processing, and risk-management functions.
Digital finance, FinTech, and supply chain finance	Digital finance converts transaction records, logistics information, receivables, payment behavior, tax information, and platform data into credit signals, thereby improving financial access for firms with limited collateral [5,7,9]. Existing studies find that digital finance, FinTech, and supply chain finance enhance resilience by alleviating financing constraints, promoting innovation and value co-creation, reducing supply chain concentration, improving total factor productivity, and strengthening digital collaboration and financial stability [10,19,38–42].	Previous studies often examine financing constraints, innovation, information sharing, or value co-creation separately. This study integrates information transparency, investment–financing maturity mismatch, and financial risk into a unified mechanism framework. It also examines heterogeneity across regional financial development, corporate governance quality, and firm growth stages and clarifies how stronger resilience supports sustainable manufacturing development.

In short, the present literature review has improved knowledge of the significance and evolutionary aspects of supply chain resilience and confirmed the vital importance of digitalization and supply chain finance in increasing supply chain resilience in terms of resistance and recovery. Even though previous studies have proven the advantages of both digitalization and financial optimization in enhancing supply chain resilience, the influence of digital finance on manufacturing supply chain resilience remains to be further explored. This paper addresses the aforementioned research deficiencies by empirically examining the causal relationship, internal mechanisms, and heterogeneous influences of digital finance on manufacturing supply chain resilience in China, thereby supplementing and enriching the relevant research.

3. Theoretical Analysis and Hypotheses

This study develops a theoretical framework to elaborate the nexus between digital finance and supply chain resilience, building on three canonical theories: information asymmetry theory, dynamic capability theory, and the resource-based view.

Firstly, information asymmetry theory helps explain why traditional finance is often unable to support the firms embedded in complex supply chain networks. Financial institutions usually have easy access to balance sheets and collateral information, but gathering timely information about orders, logistics situations, the performance and behavior of suppliers, and the payment habits of clients is more difficult. Information asymmetry may cause problems, such as adverse selection and moral hazard, leading to credit rationing even while the firm in question is still alive [43]. Digital finance helps solve this problem

with the help of transaction history, payment history, online firm information, logistics information, and platform credit history. In the supply chain, such information helps boost the credibility of receivables, inventory pledges, and order financing. As a result, firms can maintain their production and supplier relations despite disruptions.

Secondly, dynamic capability theory offers another theoretical perspective on digital finance. Teece et al. [44] conceptualize dynamic capabilities as firms' high-order organizational competencies to combine, develop, and restructure internal and external resources, enabling them to adapt to turbulent market environments. Resilience of the supply chain is associated with dynamic capability, since the former requires sensing of the disruptions, identification of opportunities to react to them, and reconfiguration of the firm's resources after the shock occurs. Digital finance contributes to such abilities in two ways. Firstly, real-time data and platform monitoring contribute to sensing, since a firm and the financial institution notice abnormal payment delays, inventory accumulation, supplier problems, and logistics disruption earlier than they could with periodic financial statements. Secondly, digital financial products help with reconfiguration as they allow firms to receive liquidity quickly, change suppliers, and adjust inventories and payment schedules.

The resource-based view provides the third theoretical lens for consideration. Barney [45] contends that enduring competitive superiority derives from firm resources characterized by value, rareness, imperfect imitability, and non-substitutability. In the sphere of digital finance, it is necessary to view data resources and the analytics that are performed on them as complementary resources [46]. In cases where a company shows that it can provide legitimate supply chain transactions, use digital means to prove their legitimacy, and receive financing by virtue of such data analysis, the company's resource position becomes stronger than that of a company that depends on collateral and personal networks alone. Such resources are especially valuable to manufacturing companies, since their supply chain resilience is based on two factors: capacity and liquidity. Hence, digital finance serves both as a financial service and a resource accumulation process.

It can thus be concluded from these three theoretical perspectives that digital finance improves supply chain resilience through integration of liquidity, information, and risk diversification in supply chain coordination. Provision of liquidity ensures that there is enough financial capability to coordinate production, purchasing, inventory management, and payment systems in times of disruption. Information helps to better understand risks and coordinates the management of risks amongst the various parties, involving firms, their suppliers, their customers, and the financiers. Risk diversification reduces dependence on just one means of financing and one party in the supply chain to increase the flexibility of coordination when disruptions occur. Through liquidity-backed, information-enabled, and risk-diversified coordination, digital finance increases firms' capability to conduct business, coordinate supply chains, and overcome disruptions. This results in the following hypothesis:

H1. *Digital finance significantly enhances the supply chain resilience of manufacturing firms.*

The first mechanism concerns information transparency. Supply chains become vulnerable because information is dispersed among suppliers, manufacturers, customers, and financiers. For example, a manufacturer cannot easily distinguish the reason why its customer delays payment, which can be due to logistical difficulties, poor demand, or financial problems. At the same time, a bank has trouble differentiating a good receivable from an unreliable one when considering a loan request. Digital finance helps solve these problems by creating a traceable platform and verifying information related to payments and logistics, as well as analyzing abnormal activity using data analysis tools. The effects go beyond financing, as information transparency can help with inventory management,

coordination with suppliers, demand forecasting, and early warning. If digital finance leads to more transparent reporting and fewer earnings manipulations, the firm becomes more understandable to its financiers and supply chain partners. It helps minimize distrust and coordinate actions in response to disruption more quickly. Therefore, the following hypothesis is formulated:

H2. *Digital finance increases the resilience of manufacturing firms' supply chains through increased information transparency.*

The second mechanism concerns the reduction of the investment–financing maturity mismatch. Manufacturing companies usually finance long-term investment projects, such as capital expenditures and supply chain restructuring, with short-term loans. This creates refinancing pressure. In times of disruption, short-term credit disappears at the moment when liquidity is needed to maintain the production process, pay suppliers, or replenish inventories. Digital finance can reduce the maturity mismatch problem due to more efficient credit matching. Online platforms can use order data, receivables, tax information, and other payment histories to estimate the need for long-term financing. Additionally, there are supply chain finance products that convert receivables and inventories into collateral for financing. By aligning the maturity of funding and the investment horizon, digital finance provides more stable financial support for supply chain adaptation. Hence, the following hypothesis is formulated:

H3. *Digital finance increases the resilience of manufacturing firms' supply chains by reducing the investment–financing maturity mismatch.*

The third mechanism concerns the reduction of financial risks. Financial fragility can cause a chain reaction of disruption throughout the supply network. For example, a company with poor solvency and liquidity risks may delay payments, cancel orders, neglect quality control efforts, or reduce the size of safety stocks. In this way, the financial risk spreads across the network upstream and downstream. Digital finance helps mitigate these risks due to more accurate credit assessments, pricing of financial risks, and continuous monitoring. More advanced risk models can detect changes in cash flows or payments of the company, and credit sharing via online platforms can provide better opportunities for mitigation. The higher the Altman-type Z-score, which indicates better financial stability of the company, the lower the risk of supply chain disruptions. Therefore, if digital finance increases financial stability, the ability of the firm to withstand and recover from a shock increases as well. This leads to the following hypothesis:

H4. *Digital finance increases the resilience of manufacturing firms' supply chains through reduced financial risks.*

4. Data and Methodology

4.1. Data Sources

The data analysis is based on Chinese A-share listed firms within the manufacturing industry during the years 2011–2023. The sample is constructed through aligning city-level digital finance development with firm-level accounting, governance, and regional measures. The sample period begins in 2011, since the city-level data on the Baidu Index used for calculating the index of digital finance only became available from that period. This study ends with data in 2023, the last year when all required sources provide data at the same time and can be consistently merged into one data set without introducing non-random missing data. Data on digital finance development are collected from the Baidu Index

website. Financial, patent, and governance data are collected from CSMAR, CNRDS, and annual reports of listed companies. The sampling process follows the standard practice used in research on Chinese listed companies. ST and *ST firms with unusual operating and listing conditions are excluded due to possible anomalies in the finance–resilience relationship. Firms with significant missing observations on relevant variables are also excluded. To alleviate the estimation bias caused by extreme outliers, all continuous variables are winsorized at the 1% and 99% levels. After this data processing procedure, the final sample comprises 21,060 firm-year observations.

4.2. Variable Definitions

The dependent variable is firm-level supply chain resilience, named Tough. Drawing on the theoretical conceptualization of prior research and existing frameworks on manufacturing resilience, this study constructs a multi-dimensional resilience index covering five core dimensions: risk resistance, recovery capacity, operational capability, supply–demand matching ability, and renewal potential. The risk resistance dimension captures a firm’s ability to maintain stable upstream and downstream relational governance amid environmental uncertainty. This dimension is measured by the ratio of accounts receivable to core operating revenue. A lower value of this indicator implies less capital occupation from supplier partners, thereby reflecting more stable supply chain linkages. The firm’s recovery capacity is quantified using the residual gap between its actual performance and the predicted baseline value. Operational capability refers to the firm’s ability to continue its regular operations when faced with supply chain stress and is proxied by payable turnover and receivable turnover. Supply–demand matching capability measures the pressures on the firm to make inventory adjustments and is proxied by the absolute value of the net inventory change relative to last period. The renewal capability is proxied by the logarithm of the number of invention patent grants plus one. Following the normalization of firm-year indicators, the entropy approach is applied to consolidate all dimensions into an overall resilience index, giving a higher weight to dimensions with higher informational variation. Since the level of dispersion changes from one year to another, entropy weights are calculated annually.

The core explanatory variable is the development of local digital finance, represented by the variable *difin*. *difin* is created at the prefecture-city level through the Baidu Search Index with the help of keywords on resource allocation, payment and settlement, technical infrastructure, risk management, and network channels. Since the search volume cannot provide information on the transaction volume directly, this paper regards the index as an indicator of the local diffusion, attention, and environment of digital financial services, rather than the supply of finance in general. However, the proxy indicator has several merits for our research: it provides yearly variations during the whole sample period, it gives us more prefecture-level data than many administrative indicators, and it can capture the local demand and diffusion of digital financial instruments. The keyword series are first normalized and weighted by entropy, and then aligned to the prefectures where the firms are registered. In order to rule out the possibility that search volume may deviate from digital financial development, we use the total Peking University Digital Financial Inclusion Index and its two subindexes, coverage breadth and usage depth, as a robustness check for *difin*.

The control variables are as follows: firm size controls for the differences in asset size and organizational capability, denoted as *Size*. Leverage reflects the capital structure and debt pressure, denoted as *Lev*. Board size, CEO chair duality, and ownership concentration control for governance characteristics that might affect disclosure, financing, and supply chain management, denoted as *Board*, *Dual*, and *Top5*, respectively. Revenue growth and

return on assets control operating performance and profitability, denoted as Growth and ROA, respectively. Firm age reflects operating experience, denoted as FirmAge. Regional GDP per capita and government intervention control for the economic and institutional environment of the city or province where the firm operates, denoted as GDP and Gov. Table 2 lists all variable definitions.

Table 2. Definition of variables.

Type	Symbol	Variable	Definition
Dependent variable	Tough	Supply chain resilience	Entropy-weighted index from five dimensions: resistance, recovery, operational capability, supply–demand matching, and renewal capability
Core explanatory variable	difin	Digital finance development	City-level digital finance index constructed from Baidu Search Index keywords
Control variables	Size	Firm size	Natural logarithm of total assets
	Lev	Leverage	Total liabilities divided by total assets
	Board	Board size	Natural logarithm of the number of directors plus one
	Dual	CEO–chair duality	1 if chairperson and general manager are the same person, 0 otherwise
	Top5	Ownership concentration	Shareholding ratio of the top five shareholders
	Growth	Revenue growth	Current operating revenue minus previous operating revenue divided by previous operating revenue
	ROA	Return on assets	Net profit divided by total assets
	FirmAge	Firm age	Natural logarithm of years since firm establishment
	GDP	Economic development	Natural logarithm of per capita regional GDP
	Gov	Government intervention	Education expenditure plus science and technology expenditure divided by fiscal expenditure

Table 3 presents the summary statistics of the main variables. For the variable Tough, the mean is 0.1715, and the standard deviation is 0.0418, while the minimum and the maximum values are 0.1072 and 0.2935, respectively. From this, it can be seen that there is a high level of diversity in the supply chain resilience of manufacturing listed firms. As for difin, its mean is 0.5710, and its standard deviation is 0.4637, with values ranging from 0.0433 to 2.0214.

Table 3. Descriptive statistics.

Variables	Obs.	Mean	Std. Dev.	Min	Median	Max
Tough	21,060	0.1715	0.0418	0.1072	0.1675	0.2935
difin	21,060	0.5710	0.4637	0.0433	0.4230	2.0214
Size	21,060	22.1169	1.1792	20.0133	21.9455	25.7419
Lev	21,060	0.3906	0.1912	0.0540	0.3820	0.8600
Top5	21,060	0.5268	0.1484	0.2003	0.5255	0.8600
Growth	21,060	0.1432	0.3160	−0.4755	0.0994	1.6981
Board	21,060	2.1040	0.1907	1.6094	2.1972	2.5649
Dual	21,060	0.3219	0.4672	0	0	1
ROA	21,060	0.0440	0.0639	−0.1930	0.0421	0.2271
FirmAge	21,060	2.9374	0.3188	1.9459	2.9957	3.5553
GDP	21,060	11.4897	0.5084	10.0769	11.5503	12.2234
Gov	21,060	0.2145	0.0416	0.1263	0.2124	0.3046

4.3. Benchmark Econometric Model

To investigate how digital finance affects the resilience of manufacturing supply chains, this study constructs the following baseline econometric specification:

$$\text{Tough}_{it} = \beta_0 + \beta_1 \text{difin}_{it} + \beta_i X_{it} + \lambda_t + \eta_i + \mu_{it} \quad (1)$$

where i denotes industry, t denotes year, X represents the vector of control variables, η_i and λ_t capture industry and year fixed effects, respectively, and μ_{it} is the random error term.

5. Empirical Results

5.1. Benchmark Regression Results

Baseline estimates are presented in Table 4. Column (1) presents the regression results controlled for year and industry fixed effects without additional covariates. The coefficient of digital finance is 0.0095, which is statistically significant at the 1% level. In column (2), we add firm-level controls and reduce the coefficient to 0.0073, maintaining its high statistical significance. In column (3), we further incorporate regional controls, and the corresponding coefficient drops to 0.0063, which remains significant at the 1% level. Therefore, the core finding verifies that digital finance effectively strengthens manufacturing firms' supply chain resilience and acts as an effective risk buffer for industrial supply chains, which confirms H1.

Table 4. Baseline regression results.

Variables	(1) Tough	(2) Tough	(3) Tough
difin	0.0095 *** (0.0007)	0.0073 *** (0.0005)	0.0063 *** (0.0007)
Size		0.0200 *** (0.0002)	0.0201 *** (0.0002)
Lev		−0.0117 *** (0.0015)	−0.0120 *** (0.0015)
Top5		−0.0081 *** (0.0016)	−0.0086 *** (0.0016)
Growth		−0.0019 ** (0.0008)	−0.0017 ** (0.0008)
Board		0.0068 *** (0.0012)	0.0072 *** (0.0012)
Dual		−0.0005 (0.0005)	−0.0008 * (0.0005)
ROA		0.0909 *** (0.0042)	0.0884 *** (0.0042)
FirmAge		0.0054 *** (0.0008)	0.0057 *** (0.0008)
GDP			0.0012 * (0.0006)
Gov			0.0644 *** (0.0057)
Constant	0.1661 *** (0.0005)	−0.2997 *** (0.0056)	−0.3298 *** (0.0091)
Observations	21,060	21,060	21,060
Adjusted R ²	0.1135	0.4142	0.4181
Year FE	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes

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

All control variables' estimated coefficients align with economic theories. Firm size exhibits a positive and statistically significant correlation with Tough, which implies that bigger manufacturers usually have larger resource stocks, a strong bargaining position, and stable supplier–customer relationships that help avoid supply chain shocks. There is a significant and negative relationship between Lev and Tough, which implies that highly leveraged firms face more pressure in servicing their debts and less financial flexibility in case of shocks. There is a significant and negative relationship between Top5 and Tough, which implies that concentrated control may lower the efficiency of internal controls and the ability to cope with uncertainties in the supply chain. Growth is negative, which may be caused by the fact that rapidly growing firms need more inventories, accounts receivable, and coordination with suppliers, which may temporarily decrease the resilience of such firms. Board has a positive sign, indicating that the larger board provides more managerial resources and more monitoring capabilities for managing supply chain risks. Dual has a negative sign, which means that the joint position of the chairman of the board and CEO reduces corporate governance and management of risks. ROA has a positive coefficient, which means that more profitable firms have better internal cash flow and financing ability for recovery, accommodating suppliers, and keeping their operations continuous. FirmAge is positive, which means that firms with more operating experience, stable suppliers, and better risk management practices are more resilient. Regionally, GDP is positive, which means that the firms in more developed regions may have better infrastructure, market environment, and local financial resources. Gov is also positively correlated with Tough, which indicates that the governmental support of education and science may create a better innovation and institutional environment for the firms.

5.2. Robustness Tests

To validate the reliability of the baseline regression outcomes, this study conducts a robustness test by redefining and remeasuring the core explanatory variable (difin) with alternative proxies. Based on the Peking University Digital Financial Inclusion Index system, the comprehensive aggregate index is selected as the first alternative indicator for regional digital finance development, denoted as difinrb1. Additionally, two secondary sub-indices are adopted for further validation: coverage breadth (difinrb2) and usage depth (difinrb3). The former depicts the accessibility of digital financial services for market participants, while the latter characterizes the practical application intensity of digital financial tools in business operations. The regression outcomes presented in Columns (1) through (3) of Table 5 consistently show positive and statistically significant coefficients. This set of evidence confirms that the documented positive impact of digital finance on supply chain resilience is not sensitive to the measurement approach of the core explanatory variable, further verifying the robustness of the baseline findings.

This study then adopts alternative estimation methods to address potential estimation bias. First, we use the bootstrap method with 1000 resamples to improve the precision of parameter estimation. Second, we apply generalized least squares (GLS), which helps account for potential heteroskedasticity and serial correlation in panel data. Third, we use the generalized method of moments (GMM), with lagged variables as instruments, to alleviate possible endogeneity and omitted-variable bias. The results are reported in Table 6. Columns (1) and (2) show that the coefficient of difin remains significantly positive. Column (3) presents the GMM estimates, and the coefficient remains positive and significant after considering potential endogeneity. These results confirm that the baseline conclusion is robust to changes in estimation methods.

Table 5. Robustness: Alternative digital finance measures.

Variables	(1) Tough	(2) Tough	(3) Tough
difinrb1	0.0071 *** (0.0020)		
difinrb2		0.0065 *** (0.0016)	
difinrb3			0.0045 *** (0.0013)
Constant	−0.3551 *** (0.0090)	−0.3490 *** (0.0096)	−0.3608 *** (0.0085)
Controls	Yes	Yes	Yes
Observations	21,060	21,060	21,060
Adjusted R2	0.4159	0.4160	0.4159
Year FE	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes

Notes: Robust standard errors are in parentheses. *** denotes the significance at a 1% level.

Table 6. Robustness: Alternative estimation methods.

Variables	(1) Bootstrap	(2) GLS	(3) GMM
L.Tough			0.4182 *** (0.0126)
difin	0.0063 *** (0.0007)	0.0042 *** (0.0006)	0.0010 ** (0.0004)
Constant	−0.3298 *** (0.0094)	−0.3959 *** (0.0081)	−0.2428 *** (0.0074)
Controls	Yes	Yes	Yes
Observations	21,060	21,060	17,820
Year FE	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes

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

We perform a series of additional robustness checks. First, we exclude firms headquartered in the four municipalities directly under the central government, Beijing, Shanghai, Tianjin, and Chongqing, as these cities exhibit stark disparities relative to other prefectures in economic development, policy incentives, and institutional environments. As Column (1) of Table 7 demonstrates, the coefficient on digital finance is significantly positive, verifying that our baseline findings are not biased by observations from the four municipalities. Second, we cluster standard errors at the firm level to control for within-firm correlation across years. Column (2) shows that the main result remains unchanged. Third, we adjust the fixed-effects specification. Beyond year and industry fixed effects, we further incorporate province fixed effects to absorb time-invariant cross-provincial disparities in institutional frameworks, resource endowments, and economic fundamentals. Column (3) shows that the positive effect of digital finance remains significant. We further include year-by-province and year-by-industry fixed effects to control for time-varying regional and industry heterogeneity. As displayed in Column (4), the positive coefficient retains statistical significance. Overall, these tests confirm the robustness of the main finding that digital finance improves manufacturing firms' supply chain resilience.

Table 7. Robustness: Sample and fixed-effect structures.

Variables	(1) Tough	(2) Tough	(3) Tough	(4) Tough
difin	0.0072 *** (0.0010)	0.0063 *** (0.0016)	0.0046 *** (0.0010)	0.0061 *** (0.0013)
Constant	−0.3230 *** (0.0098)	−0.3298 *** (0.0211)	−0.3268 *** (0.0108)	−0.3202 *** (0.0121)
Controls	Yes	Yes	Yes	Yes
Observations	17,537	21,060	21,060	21,060
Adjusted R ²	0.4024	0.4181	0.4294	0.4290
Year FE	Yes	Yes	Yes	No
Industry FE	Yes	Yes	Yes	No
Province FE	No	No	Yes	No
Year-province FE	No	No	No	Yes
Year-industry FE	No	No	No	Yes

Notes: Robust standard errors are in parentheses. *** denotes the significance at a 1% level.

5.3. Endogeneity Treatment

Table 8 uses the approach of an instrumental variable to deal with the issue of endogeneity. The chosen instrument is regional search popularity for intelligent finance, which is denoted by IntelPopularity. This instrumental variable selection follows a clear logical rationale: regional search volume of smart financial services has a tight correlation with the rollout of digital finance. However, this indicator exerts no direct influence on individual manufacturers' supply chain resilience. After controlling for city-level fixed effects, year fixed effects, and a complete array of covariates, the results verify that the focal influence functions exclusively through the digital finance channel. The first-stage regression yields a coefficient of 0.0168 for IntelPopularity, which is significant at the 1% statistical level. The Kleibergen–Paap rk LM statistic presents statistical significance, whereas the Kleibergen–Paap Wald F statistic far exceeds the conventional critical value. This result rules out the concern of weak instrument bias in the empirical setting. In the second-stage estimation, digital finance generates a coefficient value of 0.0107, also significant at the 1% level.

Table 8. Instrumental variable estimation.

Variables	First Stage: Difin	Second Stage: Tough
IntelPopularity	0.0168 *** (0.003)	
difin		0.0107 *** (0.0022)
KP rk LM		1030.098 ***
KP rk Wald F		2262.159
CD Wald F		1550.402
Controls	Yes	Yes
Industry FE	Yes	Yes
Year FE	Yes	Yes
R ²	0.5101	
Observations	21,060	21,060

Notes: Robust standard errors are in parentheses. *** denotes the significance at a 1% level.

5.4. Mechanism Tests

The two-step mechanism channel analysis framework is used in this paper to determine the mechanism of digital finance. In contrast to the conventional three-step effect testing framework, the two-step method aims to determine whether the independent variable has a significant effect on the mediator and whether the mediator has an impact on

the dependent variable. It is widely adopted by researchers because it helps to determine the presence of the mechanism without imposing many restrictions. Table 9 provides the mechanism tests on how digital finance could contribute to the supply chain resilience of manufacturing companies. On the basis of the theoretical framework, this part analyzes the impacts through three channels: information transparency, investment–financing maturity mismatch, and financial risk.

Table 9. Mechanism test results.

Variables	(1) Opacity	(2) IFMM	(3) Z-Score
difin	−0.0052 ** (0.0024)	−0.0695 *** (0.0042)	0.0500 *** (0.0076)
Constant	0.4470 *** (0.0334)	0.0853 (0.0569)	3.8511 *** (0.1031)
Controls	Yes	Yes	Yes
Observations	14,820	21,060	21,060
Adjusted R ²	0.0621	0.1580	0.7040
Year FE	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes

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

First, Column (1) examines the information transparency channel. Corporate opacity is the dependent variable, denoted as Opacity. Opacity is proxied by the aggregated absolute value of discretionary accruals over three consecutive fiscal years, reflecting a firm's earnings management level and external information disclosure quality. A larger value indicates more earnings manipulation, poor quality of earnings, and a lack of information transparency. The coefficient on digital finance is −0.0052, being statistically significant at the 5% level. This result implies that digital finance greatly reduces corporate opacity and improves information transparency, thereby supporting H2. Due to artificial intelligence, cloud computing, big data, and blockchain, digital finance lowers the cost of information collection, verification, and analysis [47]. Digital finance allows banks to have better monitoring of the operational conditions, transaction records, order flow, and credit risk of the firm. In addition, the information disclosure makes it easier for the partner to evaluate the reliability and stability of the firm. With the decrease of information asymmetry, the trust costs and transaction costs in supply chain collaboration become lower, and hence the firms will obtain more stable financing and establish more reliable supply chain connections with the suppliers and customers.

Second, Column (2) tests the investment–financing maturity mismatch channel, denoted as IFMM. The cash-flow matching method is adopted to measure the maturity mismatch. The indicator equals the amount of cash outflow from long-term investments (including fixed asset purchases and construction), the amount of current increase in long-term borrowings, the current increase in equity, the net cash flow from operating activities, and the cash flow from fixed asset dispositions, all divided by lagged total assets. A larger value indicates higher dependence on short-term financing for long-term investments, thereby indicating a higher maturity mismatch. Digital finance greatly decreases maturity mismatch, with its estimated coefficient standing at −0.0695 at the 1% significance level, indicating that this result supports H3. The investments in capacity, technology, and other aspects usually need a stable funding source. The dependence on short-term debt for long-term projects increases the refinancing risk and liquidity risk, especially when there is disruption in the supply chain and the simultaneous requirement for production maintenance, inventory adjustment, payment to suppliers, and receivables financing. The maturity mismatch is solved by improving the credit assessment and widening the fi-

nancing channels through digital finance. The digital platform is able to make a better evaluation of the true condition of the firms and provide corresponding financing products. At the same time, the transaction cost is lowered, and dependence on short-term loans becomes lower. With the decrease in maturity mismatch, firms obtain more stable cash flow arrangements and become more flexible to cope with shocks in the supply chain.

Third, Column (3) examines the financial risk channel. Financial health is measured by the Z-score as the dependent variable, which reflects the profitability, solvency, operational efficiency, and growth potential of the firm. A larger Z-score indicates stronger financial stability and a lower probability of financial distress. The coefficient on digital finance is 0.0500 and statistically significant at the 1% level, implying that digital finance greatly improves the Z-scores of the firms, which supports H4. Due to data-driven risk management and online credit evaluation, the dependence on collateral and relationship-based credit of lenders is decreased by digital finance. Digital finance can provide loans to firms that have good performance but little collateral. Also, digital finance improves the convenience and timeliness of external financing, lowering the short-term payment pressure and cash flow instability. Declining financial risk enables enterprises to gain superior credit credentials and enhanced bargaining power, thereby fostering stable cooperative relationships with supply chain partners, allowing the firm to mobilize resources and maintain key supplier–customer relationships and business continuity under external shocks.

5.5. Heterogeneity Analysis

Table 10 presents the empirical findings regarding regional heterogeneous effects. To capture regional financial development, this study adopts the aggregate year-end deposit and loan balances of provincial financial institutions as the proxy indicator. Based on the annual average value of this index, the full sample is split into two subsamples: high and low regional financial development groups. The regression outcomes show that digital finance carries a positive coefficient in both subgroups, yet the effect size varies substantially across the two groups. Specifically, the estimated coefficient equals 0.0031 for regions with advanced financial development, whereas the figure reaches 0.0201 for areas with underdeveloped financial systems. This finding is expected, as it is consistent with the compensating nature of digital finance: the larger the share of the market served by traditional finance, the lower the marginal benefit of digital finance, and vice versa. It means that digital finance can help compensate for some part of regional inequality in the resilience of supply chains among manufacturing firms.

Table 10. Heterogeneity by regional financial development.

Variables	(1) High Financial Development	(2) Low Financial Development
difin	0.0031 ** (0.0015)	0.0201 *** (0.0019)
Constant	−0.3810 *** (0.0227)	−0.2898 *** (0.0108)
Controls	Yes	Yes
Observations	7280	13,780
Adjusted R2	0.4664	0.4041
Year FE	Yes	Yes
Industry FE	Yes	Yes

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

Table 11 reports the estimation results concerning corporate governance heterogeneity. This study develops a composite index to quantify firms' overall governance quality. This aggregated indicator is synthesized based on seven dimensional attributes: managerial compensation, executive shareholding ratio, independent director proportion, board size, institutional ownership, equity balance degree, and CEO duality. We adopt principal component analysis to generate the integrated corporate governance score. Using the annual mean value of this index as the grouping threshold, the full sample is further categorized into two subsamples featuring high and low corporate governance levels, respectively. For the stronger-governance firms, the coefficient on digital finance is 0.0056, and for weaker-governance firms, the coefficient is 0.0071. The higher effect of digital finance on the resilience of supply chains in weaker-governance firms can be explained by two reasons. On the one hand, weaker-governance firms experience higher information asymmetry and higher external financing costs; therefore, digital finance provides a larger marginal improvement through using data and information about transactions. On the other hand, digital financial platforms can exert strengthened external monitoring on enterprises with poor corporate governance. It does not mean that governance does not matter; instead, digital finance can help to mitigate problems of information caused by poor governance to some extent.

Table 11. Heterogeneity by corporate governance.

Variables	(1) Better Governance	(2) Weaker Governance
difin	0.0056 *** (0.0010)	0.0071 *** (0.0009)
Constant	−0.3006 *** (0.0140)	−0.3505 *** (0.0123)
Controls	Yes	Yes
Observations	9490	11,570
Adjusted R2	0.3743	0.4482
Year FE	Yes	Yes
Industry FE	Yes	Yes

Notes: Robust standard errors are in parentheses. *** denotes the significance at a 1% level.

Table 12 presents the heterogeneous impacts of digital finance across different corporate life cycle stages. In particular, firms in the growth stage are characterized by positive operating cash flows, negative investment cash flows, and positive financing cash flows. This cash flow structure indicates that such firms enjoy steadily improving profitability, yet they still require substantial capital injection to support business and project expansion. Based on the above criteria, this paper identifies the enterprise samples that are in the growth stage and those that are not. The coefficient on digital finance for growth-stage firms is 0.0100, and the coefficient on digital finance for non-growth-stage firms is 0.0054. Growth-stage firms tend to increase sales, invest in additional capacity, develop new products, and expand supply chains. Therefore, they have greater liquidity demands and face higher risks because of fluctuations in demand. Such firms have relatively short credit histories and low collateral, whereas traditional finance does not meet all of their needs. Digital finance allows assessing transactions based on a wider range of data and estimating future cash flow. It can explain the greater effect of digital finance on growth-stage firms.

Table 12. Heterogeneity by firm life cycle.

Variables	(1) Growth-Stage Firms	(2) Non-Growth-Stage Firms
difin	0.0100 *** (0.0014)	0.0054 *** (0.0008)
Constant	−0.3138 *** (0.0195)	−0.3334 *** (0.0104)
Controls	Yes	Yes
Observations	4771	16,289
Adjusted R2	0.3907	0.4265
Year FE	Yes	Yes
Industry FE	Yes	Yes

Notes: Robust standard errors are in parentheses. *** denotes the significance at a 1% level.

6. Conclusions and Policy Implications

6.1. Conclusions

This research examines whether digital finance enhances manufacturing sustainability by improving supply chain resilience among Chinese manufacturing firms. Using A-share listed manufacturing firms from 2011 to 2023, the paper constructs a city-level Baidu Search Index measure of digital finance and a firm-level entropy-weighted supply chain resilience index. Empirical findings confirm a positive association between digital finance and supply chain resilience. In accordance with the baseline specification, a one-unit rise in the digital finance index contributes to a 0.0063-unit increase in the resilience score. This result remains significant after using alternative digital finance measures, bootstrap, GLS, GMM estimators, more demanding fixed effects, and an instrumental variable approach. The mechanism tests show that digital finance improves resilience by reducing information opacity, lowering investment–financing maturity mismatch, and improving financial health. The heterogeneity tests reveal stronger effects in regions with weaker financial development, in firms with weaker governance, and in growth-stage firms.

6.2. Policy Implications

Several policy implications can be drawn to facilitate the sustainable development of manufacturing supply chains. First, financial institutions need to create and promote inclusive digital supply chain finance adjusted to the operational peculiarities of manufacturing companies, especially in regions where traditional finance mechanisms are underdeveloped. As the effect of digital finance is significantly higher in these regions, making it accessible via digital financial products is crucial. Financial products need to be developed according to operational data, including orders, tax data, inventory, and logistics records. Simultaneously, the institutions need to design credit instruments that will not be limited by a standard one-year duration but will last for at least five years so that manufacturing companies will have an opportunity to finance their capital-intensive improvements, keep inventory, and change suppliers.

In turn, manufacturing firms need to integrate digital finance into the processes of resilience-building of their supply chain. Improving digital record keeping of financial information and integrating it into the supply chain can increase credit visibility and financial flexibility. However, it is important for these firms to avoid financing long-term development projects with short-term credit. According to this study, companies with bad corporate governance structures experience bigger benefits from digital finance. It means that external digital credit mechanisms can replace the internal capital allocation constraints. Thus, improving governance structures is necessary when working with digital finance mechanisms.

Also, it is important to create a secure data-sharing infrastructure for the entire supply chain. As information transparency is one of the channels for building resilience through digital finance, regulators should facilitate the creation of a system of shared credit databases, secured communication, and data format standardization of supply chains. At the same time, there should be safeguards against the risks of using digital platforms, including data authorization, algorithmic transparency, and cybersecurity.

Moreover, it is also necessary to enhance financial risk monitoring and warning systems within supply chains. As shown, digital finance decreases the financial fragility of the supply chain. Thus, it will be helpful for public–private partnerships to create analytic systems that will monitor financial stress indicators among supply chain actors and will help to identify any risks of core enterprises and financial institutions.

Lastly, policies related to digital finance must be in close coordination with broader plans on industry and supply chain development. The results show that the growth of the firm is positively correlated with access to digital finance. As such, digital finance solutions must be integrated within government programs for the development of small and medium-sized businesses, for upgrading industries, as well as promoting sustainable and resilient supply chains. At the same time, businesses need to be encouraged to improve their financial literacy and digital skills.

6.3. Limitations and Future Research

This paper has several limitations. First, the Baidu Search Index is an indicator of localized attention and diffusion environment and not an indicator of value or the contractual terms of digital financial transactions. Second, the sample of this study contains only the listed manufacturing firms that have better disclosure and financing access compared to the smaller and less sophisticated firms. This means that the estimates derived from this study could under- or over-represent the impact of digital finance on manufacturing firms in general. Third, the measure of firm resilience is an indicator of latent capabilities in the areas of resistance, recovery, adaptation, and renewal rather than the realized recovery path following one identified disruption. Further research can employ data on bank platform transactions, networks of suppliers and customers, event-specific information about production and logistics, and rigorous quasi-experiments to investigate the effects of digital finance on the speed, cost, and distribution of recovery after a shock.

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