

The Digital Transformation of Manufacturing Enterprises, Financing Constraints, and Innovation Resilience

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Abstract

With the continuous advancement of economic and social development, China has entered a new stage of high-quality development. The digital transformation of enterprises has become a focal point of attention in both domestic and international academic circles. Leveraging the enabling effects of digital transformation serves as a critical support for promoting high-quality innovation and development in the manufacturing sector. This paper uses China's A-share manufacturing companies from 2014 to 2023 as the research sample to systematically analyze the impact of digital transformation on corporate innovation resilience and further explores the underlying mechanism of this impact. The main findings are as follows: (1) Through baseline regression and a series of robustness checks, it is found that digital transformation positively contributes to the innovation resilience of manufacturing enterprises in China. (2) Financing constraints play a mediating role in this process. Digital transformation effectively enhances the efficiency of information and resource utilization, improves corporate financing conditions, and thereby provides strategic and resource support for innovation. Based on these findings, this paper proposes the following recommendations: At the enterprise level, first, align with the trends of the times, deepen the understanding of digital transformation, and fully leverage its enabling effects. Second, formulate digital transformation strategies tailored to the specific development characteristics and environment of manufacturing enterprises. At the government level, first, strengthen the construction of digital infrastructure to enhance the level of digital transformation in manufacturing enterprises. Second, improve the innovation ecosystem and policies, enhance corporate motivation for innovation, and prioritize the development of a robust innovation resilience system.

Keywords

Digital transformation; Innovation resilience; Financing constraints

1. Introduction

In recent years, the rapid development of digital technologies has propelled the global economy into the era of the digital economy. China attaches great importance to the

development of the digital economy, emphasizing in both the 19th and 20th National Congress reports the need to deepen the integration of digital technologies with the real economy and to expand and strengthen the digital economy. Against this backdrop, the scale of China's digital economy continues to expand, and it has become a significant engine for economic growth. As the main actors in the market economy, the digital transformation of enterprises is not only an inevitable choice to adapt to technological changes and market demands but also a critical pathway to achieving high-quality development and enhancing core competitiveness.

Meanwhile, innovation serves as the fundamental driving force for the sustainable development of enterprises. In the current complex and ever-changing environment, the innovation process faces numerous uncertainties. The concept of "innovation resilience," which emphasizes the ability to sustain and adapt innovation activities in the face of internal and external pressures, has garnered increasing attention from both academia and practitioners. This concept is of significant practical importance for China's pursuit of high-level technological self-reliance and self-improvement. Manufacturing forms the foundation of the national economy; however, it still faces challenges such as insufficient innovation capacity and relative lag in research and development in key areas. The integration of digital technologies with manufacturing provides new directions for industrial upgrading, yet existing research remains insufficient on how digital transformation affects corporate innovation resilience. Therefore, this paper focuses on China's listed manufacturing companies, delving into the mechanisms through which digital transformation influences corporate innovation resilience, with the aim of providing theoretical insights and practical implications for promoting high-quality development in the manufacturing sector and refining related support policies.

2. Theoretical Analysis and Research Hypotheses

The digital transformation of enterprises is, in essence, a profound business revolution driven by digital technologies, involving systematic changes in operational models, management structures, and innovation pathways. For manufacturing enterprises, innovation resilience has become a critical capability for coping with external uncertainties. Its core can be summarized across three dimensions: resistance, recovery, and enhancement. This paper will next analyze the impact of digital transformation on the innovation resilience of manufacturing enterprises from these three perspectives.

From the perspective of resistance, innovation resistance refers to the ability of enterprises to avoid or mitigate negative impacts when facing external shocks. Digital transformation significantly enhances the stability of business processes by deeply integrating digital technologies into areas such as R&D, production, and supply chains. The application of technologies such as the Internet of Things and industrial internet enables real-time monitoring and predictive maintenance of

experimental equipment, production lines, and pilot platforms, thereby preventing disruptions in R&D activities due to unexpected failures. Meanwhile, drawing on dynamic capability theory, digital transformation greatly enhances enterprises' ability to perceive the external environment. Traditional manufacturing enterprises are often constrained by incomplete information and insufficient processing capacity. In contrast, digital technologies enable the efficient acquisition and processing of vast amounts of data, improving enterprises' sensitivity in identifying market changes and risk signals [1]. Enterprises can more accurately predict and assess various risks [2] and adjust their innovation strategies accordingly. Furthermore, digital transformation improves enterprises' efficiency in identifying and utilizing redundant resources. Leveraging the "integration of virtual and physical" characteristic of digital technologies, enterprises can optimize resource allocation, directing limited resources precisely to key R&D stages, thereby increasing the success rate of innovation and risk resilience.

From the perspective of recovery, innovation recovery emphasizes the ability of enterprises to swiftly restore normal innovation activities after a shock. Digital transformation enhances enterprises' capacity to seize opportunities and mobilize resources. On one hand, by improving internal management quality and information transmission efficiency [3][4], enterprises can quickly coordinate resources across different departments and processes, enabling dynamic deployment [5] to effectively respond to unexpected situations. On the other hand, digital technologies help enterprises build collaborative networks with external stakeholders such as suppliers, customers, and research institutions. Through cross-organizational integration of resources and information [6], a mutually beneficial "community of interests" is formed, making it easier to obtain external support during shocks and accelerate the recovery of innovation activities. Digital transformation also enhances enterprises' flexibility—the ability to adjust innovation strategies in response to environmental changes. By reducing information asymmetry and improving information transparency [7], stakeholders can participate more effectively in enterprise decision-making, bringing additional external resources and information to the enterprise, further strengthening its adaptability and recovery capabilities.

From the perspective of enhancement, enhancement not only implies recovery but also emphasizes the ability of enterprises to learn from shocks and achieve breakthroughs. Digital transformation provides continuous momentum for innovation enhancement through knowledge management and organizational learning. Enterprises can systematically record data on successes and failures during the R&D process, analyze key factors using artificial intelligence technologies [8], and form an "organizational memory," thereby transforming crisis management experiences into innovation capabilities. At the same time,

digital transformation fosters the development of enterprises' capacity for change and restructuring, internalizing new technologies and knowledge to achieve technological innovation [9] and enabling business model innovation. Shocks expose the vulnerabilities of traditional models but also give rise to new digital-based business models, organizational forms, and management processes [10]. Furthermore, digital transformation ensures the continuity and creativity of innovation. By introducing applications such as artificial intelligence and big data, enterprises continuously distill knowledge required for innovation [11]. On the basis of improved management quality and reduced costs [12], they ensure the sustainability of R&D investments, ultimately enhancing innovation resilience and competitive advantage comprehensively.

In summary, digital transformation enhances the innovation resilience of manufacturing enterprises across all three dimensions of resistance, recovery, and enhancement. Accordingly, the following research hypothesis is proposed:

H1: The digital transformation of listed manufacturing enterprises has a positive impact on corporate innovation resilience.

By deeply integrating digital technologies with business processes, the digital transformation of enterprises significantly reduces information asymmetry, both internal and external, and enhances operational transparency and digitalization [13]. This process not only reshapes enterprises' endogenous financing capabilities and exogenous financing environment but also, through alleviating financing constraints as a core mediating mechanism, effectively strengthens their resistance, recovery, and enhancement capabilities during the innovation process. This paper explores the impact mechanism of digital transformation on corporate innovation resilience from two dimensions: alleviating external and internal financing constraints.

External financing constraints primarily stem from information asymmetry between investors and enterprises. Digital transformation makes operational information such as production, sales, and inventory traceable and verifiable, greatly enhancing the transparency and credibility of enterprise information. On one hand, this helps external investors more accurately assess the actual operational status and future development potential of enterprises, reducing information evaluation costs and investment risks [14]. On the other hand, digital transformation also gives rise to new forms of credit credentials, such as data assets and digital supply chains, broadening enterprises' channels for collateralized financing. Additionally, enterprises aligned with national digital strategies are more likely to receive government subsidies and preferential financing from financial institutions [15], thereby improving their external financing environment and providing critical support for innovation resilience. When enterprises face external shocks (e.g., supply chain disruptions, sudden market demand drops), smooth external financing channels can serve as an

important financial backup (resistance), ensuring that innovation projects are not interrupted due to short-term liquidity shortages. More importantly, stable external financial support enables enterprises to sustain R&D investments and retain key talent, laying the foundation for the recovery and leapfrogging of innovation activities (recovery and enhancement).

Internal financing constraints mainly manifest as insufficient internal cash flow and inefficient resource allocation. Digital transformation directly enhances enterprises' profitability and cash flow generation by optimizing production processes, improving operational efficiency, and enhancing product quality [16], providing more abundant and stable internal funding for innovation activities. Simultaneously, digital management systems such as ERP and BI improve the flow of internal information and the scientific basis of decision-making, enabling management to accurately identify high-potential innovation projects, optimize capital allocation, and reduce resource waste due to management issues. The alleviation of internal financing constraints further strengthens corporate innovation resilience. Ample cash flow ensures the day-to-day progress of R&D activities, enabling enterprises to cope with uncertainties in the innovation process and sustain technological iteration and product development (resistance). When subjected to external shocks, healthy financial conditions and efficient resource mobilization capabilities help enterprises quickly adjust innovation strategies and restart R&D processes (recovery). In the long run, sustained internal funding supports enterprises in pursuing higher-risk, higher-return breakthrough innovations, ultimately achieving a leap in innovation capabilities (enhancement). Digital transformation, by alleviating external financing constraints (improving financing environments and reducing financing costs) and internal financing constraints (enhancing cash flow and optimizing resource allocation), respectively, builds a stable financial support system and agile resource mobilization capabilities for corporate innovation resilience.

H2: The digital transformation of listed manufacturing enterprises improves corporate innovation resilience by alleviating financing constraints.

3. Research Design

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3.1. Data Sources

This study primarily utilizes A-share listed manufacturing enterprises as the research sample, based on the China Securities Regulatory Commission (CSRC) 2012 industry

classification standards. Data on enterprise digital transformation, fundamental enterprise information, and a series of control variables are sourced from the China Stock Market & Accounting Research (CSMAR) database. Data related to enterprise innovation are primarily obtained from the Chinese Research Data Services (CNRDS) platform, as well as the CSMAR and Wind databases. To ensure the reliability of regression results and minimize the influence of outliers, the following data processing steps are applied to the sample:

- (1) Enterprises classified as ST or *ST exhibit abnormal and highly unstable data, thus all such firms are excluded;
- (2) Observations with missing key research variables or control variables are removed;
- (3) All continuous variables are winsorized at the 1st and 99th percentiles on both tails by year.

After applying the above screening procedures, a final sample of 14,420 firm-year observations is obtained. Subsequent analysis and empirical testing are conducted using Stata 17.0.

3.2. Variable Measurement and Explanation

Dependent Variable: Currently, there is no unified standard for measuring corporate digital transformation, and scholars employ various measurement methods. These can primarily be categorized into two approaches: dummy variable methods and text analysis methods. This study measures the degree of corporate digital transformation by the total frequency of digital transformation-related keywords appearing in corporate annual reports. The keywords are classified into five major categories: artificial intelligence, blockchain, cloud computing, big data, and digital technology applications.

Explanatory Variable: Existing measurements related to innovation resilience mainly rely on single-variable indicators, such as sensitivity coefficients, to assess corporate innovation resilience. However, single indicators cannot comprehensively capture the characteristics of innovation resilience. Therefore, drawing on the approach of some scholars, this study constructs a multi-indicator system to measure innovation resilience from three dimensions: resistance, recovery, and enhancement, as shown in the table below.

Table 1. Measurement Indicators of Enterprise Innovation Resilience

Primary Indicator	Secondary Indicator	Indicator Measurement
Resistance	R&D Intensity	Ratio of R&D expenditure to operating revenue ^[17]
	Proportion of R&D Personnel	Ratio of R&D personnel to total employees ^[18]
	Innovation Quality	Natural logarithm of the citation count of patent applications in the following year ^[19]
	Number of Patent Applications	Natural logarithm of (total number of invention, utility model, and design patent applications + 1) ^[20]
Recovery	Proportion of Employees with Bachelor's Degree or Above	Ratio of employees with a bachelor's degree or higher to total employees ^[17]
	R&D Capitalization Rate	Ratio of capitalized R&D expenditure to total R&D expenditure in the current period ^[17]
	Innovation Efficiency	Ratio of the natural logarithm of (number of patent applications + 1) to the natural logarithm of (R&D expenditure + 1) ^[21]
Enhancement	R&D Fund Growth Rate	(Current period R&D expenditure / Prior period R&D expenditure) - 1 ^[17]
	R&D Personnel Growth Rate	(Current period proportion of R&D personnel / Prior period proportion of R&D personnel) - 1 ^[17]

Based on the measurement indicators of corporate innovation resilience outlined in Table 1-1 above, this study employs the entropy method, an objective weighting approach, to assign weights and calculate scores for corporate innovation resilience. Additionally, the scores are multiplied by 100 to facilitate the presentation and comparison of subsequent empirical results.

Mediating Variable: Financing Constraints (Fc): Currently, research on corporate financing constraints both domestically and internationally primarily utilizes four comprehensive indicator methods, each with its distinct characteristics. Considering that the KZ index and WW index incorporate a relatively high number of endogenous indicators, which may introduce certain endogeneity issues among variables, and while the SA index effectively mitigates endogeneity concerns, its comprehensiveness as a measurement indicator is relatively limited. Therefore, this study follows the approach of Gu Leilei et al. [22] by selecting the FC index.

Control Variables: Drawing on the research of Liang Jingshu (2024), Lu Zhengwen et al. [23], and others, this study employs the following control variables:

- **Shareholder Balance (Shrs):** The proportion of shares held by the 2nd to 5th largest shareholders relative to the proportion held by the largest shareholder.
- **Government Subsidy (Sub):** The natural logarithm of the government subsidy amount after adding one.
- **Management Age (Tmtage):** The natural logarithm of the average age of the enterprise's management team after adding one.
- **CEO Duality (Dual):** A value of 1 if the chairman and general manager are the

same person, and 0 otherwise.

- Cash Flow Ratio (Cashflow): (Net cash flow from operating activities / Total assets) $\times 100\%$.
- Enterprise Growth (Growth): (Increase in operating revenue / Total operating revenue of the previous year).
- Nature of Property Rights (Soe): A value of 1 for state-owned enterprises, and 0 otherwise.
- Return on Total Assets (Roa): Net profit / Total assets.

3.3. Figures and Tables

Based on the theoretical analysis presented earlier, this paper constructs the following benchmark regression model to examine the impact of digital transformation on the innovation resilience of manufacturing enterprises:

$$Ir_{i,t} = \beta_0 + \beta_1 Dig_{i,t} + \sum \beta_2 control_{i,t} + \sum Id + \sum Year + \varepsilon_{i,t} \quad (3-1)$$

Where: Ir represents innovation resilience; Dig represents digital transformation; Controls denote the control variables; ε is the random error term; i denotes the enterprise; t denotes time.

To account for potential influences from time trends and individual characteristics, year fixed effects ($Year$) and individual fixed effects (Id) are included in the equation. ε represents the random disturbance term. The focus is on the sign and significance level of the coefficient β_1 . If β_1 is significantly positive, it indicates that digital transformation promotes corporate innovation resilience.

Building on the benchmark regression model, this paper further examines the mechanism through which digital transformation affects corporate innovation. Following the mediation effect testing procedure proposed by Wen Zhonglin et al. [195], the stepwise regression method is adopted to construct the following models for mechanism testing:

$$Fc_{i,t} = \beta_0 + \beta_1 Dig_{i,t} + \beta_2 control_{i,t} + \sum Id + \sum Year + \varepsilon_{i,t} \quad (3-2)$$

$$Ir_{i,t} = \beta_0 + \beta_1 Dig_{i,t} + \beta_2 Fc_{i,t} + \beta_3 control_{i,t} + \sum Id + \sum Year + \varepsilon_{i,t} \quad (3-3)$$

In the above testing models, Fc represents the relevant mediating variable indicator. Based on the discussions related to the research hypotheses of this paper, the measurement is conducted from the perspective of financing constraints (Fc).

4. Empirical Analysis

4.1. Regression Analysis

Based on the analysis above, the results are shown in the following table. The coefficient of the explanatory variable digital transformation (Dig) is 0.691 and is statistically significant at the 1% level, preliminarily indicating that digital

transformation can significantly enhance corporate innovation resilience. Subsequently, to account for potential interference from other factors, relevant control variables were included for further regression, with the results displayed in column (2). The influence of individual and time factors was further considered, with the results presented in column (3). Across the regression results in all three columns, the significance of the digital transformation (Dig) coefficient shows no substantial changes, and all coefficients are greater than zero, which aligns with the conclusion of Hypothesis H1 mentioned earlier. From an economic perspective, for every 1 percentage point increase in digital transformation, the innovation resilience of manufacturing enterprises increases by 0.142 percentage points. The analysis above demonstrates a significant positive correlation between digital transformation and the innovation resilience of manufacturing enterprises. In other words, digital transformation can enhance the innovation resilience of manufacturing enterprises, thus validating Hypothesis H1.

Table 2. Regression Results of Digital Transformation on Innovation Resilience in Manufacturing Enterprises

	(1)	(2)	(3)
	Ir	Ir	Ir
	0.691***	0.620***	0.142***
(Dig)	(50.421)	(46.439)	(11.078)
		0.212***	0.172***
(Tmtage)		(4.939)	(1.243)
_cons	36.346***	30.158***	34.464***
	(1368.793)	(26.409)	(30.579)
Control	No	Yes	Yes
Year	No	No	Yes
Id	No	No	Yes
N	14420	14420	14420
Adj.R2	0.1498	0.2353	0.8430
F	2542.282	493.873	189.898

4.2. Analysis of Influence Mechanisms

The test results are shown in Table 4-6 below. Dig (digital transformation) has a significant mitigating effect on Fc (financing constraints), with a coefficient of -0.009, which is significant at the 1% level. Column (2) presents the empirical results of model (4-5). It can be observed from the table that the coefficient for Fc (financing constraints) is -0.300 and is negatively significant at the 1% level. This indicates that as financing constraints for manufacturing enterprises are alleviated, corporate innovation resilience also improves. In summary, the results confirm that digital transformation can alleviate corporate financing constraints, thereby enhancing the innovation resilience of manufacturing enterprises.

Table 3. Regression Results of the Financing Constraint Mechanism Test

	(1)	(2)
	Fc	Ir
	-0.009***	0.139***
Dig	(-5.543)	(10.856)
		-0.300***
Fc		(-4.269)
_cons	1.226***	34.832***
	(8.385)	(30.837)
Control	Yes	
Year	Yes	Yes
Id	Yes	Yes
N	14420	14420
Adj.R2	0.8210	0.8432
F	179.013	181.573

4.3. Robustness Analysis

To further verify the reliability of the empirical results in this study, the measurement paradigm of Martin et al. and Lu Zhengwen and Xu Kang is adopted to assess the innovation resilience indicator of manufacturing enterprises. Specifically, a core variable sensitive to external shocks—the number of corporate patent applications—is selected to measure corporate innovation resilience (Res) [23][24]. While keeping other control variables unchanged, the benchmark regression model is re-estimated. The results show that the coefficient for digital transformation is 0.064, which is positively significant at the 1% level. This indicates that digital transformation continues to significantly and positively promote innovation resilience in manufacturing enterprises, consistent with the original hypothesis of this study.

Considering potential interference from specific time points, the outbreak of the COVID-19 pandemic in 2020 had a significant impact on the Chinese and global economies, severely disrupting market order. Enterprises faced risks such as declining orders and supply chain disruptions. Furthermore, the quarantine measures implemented in China may have led to interruptions or stagnation in corporate digital transformation. Therefore, following the approach of Lu Zhengwen et al. [24], this study excludes samples from specific years (2020–2021, the period of the COVID-19 pandemic) and re-estimates the regression. The results indicate that the coefficient for digital transformation (Dig) is 0.165, which is positively significant at the 1% level. Through the above validation, the findings remain consistent with Hypothesis H1 of this study.

5. Conclusion

Against the backdrop of the digital economy and innovation-driven development, this study focuses on China's manufacturing sector to explore the relationship between digital transformation and corporate innovation resilience, along with its underlying mechanisms. The main conclusions are as follows:

Various empirical tests, including variable substitution, sample adjustments, and endogeneity treatment, consistently confirm a significant positive relationship between digital transformation and innovation resilience in manufacturing enterprises. Digitalization drives business transformation and strengthens environmental awareness and predictive capabilities. This enables enterprises to acquire information more effectively, respond to crises, adjust decision-making, and reconfigure resources, thereby ensuring the continuity and adaptability of innovation activities. It also promotes the iteration of business models and the enhancement of innovation capabilities.

The research indicates that digital transformation enhances innovation resilience by alleviating both internal and external financing constraints. Specifically, digitalization improves corporate information transparency and operational efficiency. On the one hand, it helps external investors reduce assessment risks, improves the corporate financing environment, and facilitates access to policy support. On the other hand, it optimizes internal resource allocation and cash flow generation capabilities. The alleviation of financing constraints provides stable financial and resource support for enterprises to cope with shocks and sustain innovation, thereby strengthening innovation resilience.

In summary, digital transformation in manufacturing enterprises serves as an effective pathway to enhance innovation resilience, primarily through the core mechanism of alleviating financing constraints. This study offers empirical evidence for understanding the internal logic of how digitalization empowers corporate innovation and provides insights for formulating relevant policies.

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