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The Impact of Digital Transformation on Innovation Capability in Manufacturing Enterprises: An Empirical Study Based on Structural Equation Modelling

Jiaxin Cheng

School of Nanjing University of Science and Technology University, Nanjing, China

Abstract. Amidst the global surge in digital economic development, advancing digital transformation has become pivotal to corporate innovation and growth. Building upon a review of existing literature, this study employs Structural Equation Modelling (SEM) to conduct reliability and validity testing, correlation analysis, regression analysis, and mediation effect testing on a sample dataset from manufacturing enterprises. It explores the influence mechanism of digital transformation on innovation capabilities within manufacturing firms and examines the mediating role of innovation climate between these two variables. Findings reveal that digital transformation exerts a direct positive effect on innovation capability, while also exerting an indirect positive influence through the mediating variable of innovation climate. These conclusions provide crucial evidence for managers to advance digital transformation strategies and enhance corporate innovation capability.

Keywords: digital transformation; structural equation modelling; corporate innovation capability; innovation climate.

1. Introduction

1.1. Research Context

The vigorous development of next-generation digital technologies such as big data, cloud computing, and artificial intelligence has actively propelled innovation levels, transformed the flow mechanisms of traditional factors, and significantly enhanced innovation efficiency. We are now in the era of the digital economy, where corporate development must inevitably align with this trend. Driven by the digital economy wave and underpinned by the "Digital China" policy framework, accelerating digital economy development and comprehensively advancing corporate digital transformation hold critical significance for sustainable enterprise growth.

Currently, China's manufacturing sector is accelerating its digital transformation, with the scope of application continually expanding. The integration and innovation of next-generation information technologies with manufacturing industries—particularly in petrochemicals, automotive, and electronics—is intensifying. Presently, China has over 2,000 "5G + Industrial Internet" construction projects, with the level of digital transformation steadily advancing. However, despite the accelerating pace of digital transformation among enterprises, the overall progress remains at an early stage. Data indicates that only 16% of enterprises have successfully implemented digital transformation and are now in the phase of promotion and deepening, while 40% have achieved preliminary results. This means that enterprises yet to undertake digital transformation still constitute the majority of the economic market, with those that have initiated such transformation representing only a small portion of the market.

This study focuses on manufacturing enterprises undergoing digital transformation. Using structural equation modelling, it examines the relationship between digital transformation and innovation capability, with innovation climate serving as a mediating variable to explore the causal pathways between the two. This research enriches empirical studies on digital transformation in Chinese enterprises and offers significant implications for future strategic planning.([8])

1.2. Research Significance

(1) Theoretical Significance

This paper enriches empirical research on the impact of digital transformation on innovation capabilities, offering new perspectives on how digital transformation enhances corporate innovation. By comprehensively examining the practical relevance and research necessity of digital transformation and its effects on innovation capabilities, it explores effective pathways for digital transformation to boost innovation, holding significant academic value.

(2) Practical Significance

This study enhances managers' understanding of corporate digital transformation, thereby laying a foundation for strategic planning and execution. Digital transformation optimises organisational structures, transforms operational models, and expands profit margins. The findings also provide policy references for governments seeking to promote corporate digital transformation and enhance innovation capabilities, fostering an optimised policy environment for digital transformation and advancing digital government development.

2. Literature Review

2.1. Digital Transformation

Regarding digital transformation, international scholar Mergel (2019) defines it as the integration of an enterprise's online and offline products and services. This integration employs internet-based digital information technology to stimulate market demand in a multidimensional manner, accelerate the sharing of enterprise resources and factors, thereby reducing operational costs and enhancing sustainable competitiveness.[1] Niu Sijia and Shen Lei (2020) note that digital transformation relies upon and is underpinned by IT technologies to foster the convergence of corporate technology and operations, thereby unlocking greater value· . Conversely, Zou Bangshan and Wang Chengli (2002) contend that the essence of a digital enterprise lies in leveraging the internet, network technologies, communications technologies, and artificial intelligence to position customers at the centre of operations and management, actively engaging in global economic activities.[3] .

2.2. Innovation Capability

Academic circles frequently employ innovation performance to gauge innovation outcomes. Regarding innovation performance, international scholar Drucker (1993) noted that for corporate R&D innovation activities, innovation performance serves as the key indicator concentrating the reflection of an enterprise's innovation achievements[4] ; Chinese scholars Niu Sijia and Shen Lei (2020) note that digital transformation relies on IT technology as its foundation, facilitating the integration of corporate technology and operations to unlock greater value[2] ; Chen Jin and Chen Yufen (2006) suggest that metrics such as the number of significantly improved products, new product sales rate, number of new products, and scientific publications serve as crucial indicators for assessing innovation capability[5] .

2.3. Indirect Effects of Digital Transformation on Innovation Capability

2.3.1. Direct Impact of Digital Transformation on Innovation Capability

Existing research indicates a positive correlation between the two. Foreign scholars Sébastien and Georges (2019), based on survey samples from multiple SMEs, concluded that digital transformation exhibits a significant positive correlation with corporate performance[6] . Domestic scholars Xiong Xianqing and Ma Qingru (2020) et al. noted that intelligent manufacturing enables furniture enterprises to reduce production costs, effectively shorten production cycles, and enhance production efficiency[7]; Hu Qing (2020), based on survey data from private enterprises in Zhejiang Province, found that corporate digital transformation positively promotes company performance. The study

further indicates that the effectiveness of digital transformation also benefits from an open learning atmosphere and mindset within the enterprise, strengthened external internet collaboration, and a shared corporate vision. Therefore, this project aims to explore how digital transformation influences corporate innovation performance.

2.3.2. Indirect Effects of Digital Transformation on Innovation Capability

Existing research suggests that the impact of digital technologies on corporate performance is mediated through multiple variables, each operating through distinct mechanisms. International scholars Mikalef and Pateli (2017), drawing on survey data from 274 multinational corporations, confirmed that information technology-enabled dynamic capabilities enhance organisational performance by improving agility in market and operational adjustments[9] ; Wang Cai (2020) examined data from 173 manufacturing enterprises in the Yangtze River Delta and Pearl River Delta regions, finding that corporate digital transformation exerts a significant positive effect on dynamic capabilities and innovation performance, with dynamic capabilities serving as the mediating variable[10] ; Zhang Caifeng et al. (2019) conducted an empirical analysis of questionnaire data from 254 enterprises in Guangdong Province. Based on the resource-based view and dynamic capability theory, they demonstrated that big data capability exerts a significant positive effect on corporate performance, and identified exploratory learning capability as a partial mediator between the two.

3. Research Hypotheses and Research Design

3.1. Formulation of Research Hypotheses

3.1.1. Digital Transformation and Corporate Innovation Capability

Digital transformation, underpinned by advancements in digital technologies, involves integrating business operations with digital technologies to drive innovation, thereby fostering sustained growth in corporate performance. Digitalisation not only enhances data collection and utilisation but also enables multidimensional categorisation and interpretation of such data, thereby elevating business insights to a higher level. Furthermore, digital transformation facilitates more effective management of corporate resources by organising information and services into comprehensive business solutions. Ultimately, it enhances organisational agility, resulting in faster response times and greater flexibility. Based on this, Hypothesis 1 is proposed:

H1: Digital transformation exerts a direct positive influence on an organisation's innovation capacity.

3.1.2. Digital Transformation, Innovation Climate, and Innovation Capability

Fostering a relaxed, inclusive, and harmonious innovation environment is essential for cultivating innovative talent. The key to stimulating. Only by establishing a positive innovation atmosphere both within and outside the enterprise can breakthrough innovations in products be achieved. During an enterprise's digital transformation, the innovation environment plays a crucial role in stimulating the vitality of innovative talent and enhancing the enterprise's innovation capability. Accordingly, Hypothesis 2 is proposed:

H2: Digital transformation indirectly influences an organisation's innovation capability by positively affecting its innovation atmosphere.

3.2. Definition and Measurement of Variables in the Model

The questionnaire encompasses three dimensions: digital transformation, innovation climate, and innovation capability. Each dimension is measured using established scales developed by domestic and international scholars, with all items scored on a five-point Likert scale.

The digital transformation scale draws upon the scale developed and validated by Chi, Mao Mao (2022)[12] , comprising six items as detailed in Appendix Table 1. The innovation climate scale adopts the scale developed by Lee (2001)[13]and is detailed in Appendix Table 2. The Innovation

Capability Scale draws upon scales developed in the research of Calantone (2002)[14] and Zhao Hongxia (2021)[15] , comprising nine items in total, as detailed in Appendix Table 3.

3.3. Questionnaire Survey

This empirical study employed a questionnaire survey method to collect relevant sample data. The survey design questionnaire is detailed in the appendix. Employing an electronic questionnaire format, the survey targeted manufacturing enterprises nationwide that were aware of or undergoing digital transformation. A total of 280 questionnaires were distributed. After excluding incomplete or carelessly completed invalid responses, 215 valid responses were recovered, yielding an overall valid response rate of 76.79%. The recovered valid data will be analysed using SPSS 26.0 and Amos 24.0 software.

3.4. Descriptive Statistics of the Sample

Table 3.1. Variable Frequency Analysis

Variable	Option	Frequency	Percentage	Mean	Standard Deviation
Gender	Male	100	46.5%	1.53	0.5
	Female	115	53.5%		
Age	18–25 years	45	20.9%	3.3	0.895
	26–30 years old	78	36.3%		
	31–40 years old	74	34.4%		
	41–50 years old	18	8.4%		
Educational attainment	Secondary school or technical college	9	4.2%	4.04	0.814
	College	31	14.4%		
	Bachelor's degree	127	59.1%		
	Postgraduate	39	18.1%		
	Doctoral	9	4.2%		
Year Established	1-5 years	36	16.7%	2.14	0.679
	6–10 years	112	52.1%		
	Over 10 years	67	31.2%		
Company size	1-50 employees	20	9.3%	2.89	0.958
	51-100 employees	51	23.7%		
	101-200 employees	76	35.3%		
	Over 200 employees	68	31.6%		

Table 3.1 reveals the sample characteristics of the digital transformation in manufacturing sector, indicating a relatively balanced distribution that largely meets the requirements of this sampling survey and possesses good reliability.

4. Data Analysis and Model Validation

4.1. Reliability Analysis

Reliability testing examines the dependability and consistency of measurement outcomes. This study employed SPSS 26.0 software to conduct reliability analysis on the scales.

1. Reliability Tests for Each Dimension

Table 4.1. Reliability Tests for Each Dimension

Variable	Number of Items	Cronbach's Alpha Coefficient
Digital Transformation	6	0.961
Innovation climate	8	0.967
Innovation Capacity	9	0.975

Based on the reliability analysis results for the three dimensions of digital transformation, innovation climate, and innovation capability in Table 4.1, the overall standardised reliability coefficients were 0.961, 0.967, and 0.975 respectively, all exceeding 0.9. Consequently, the questionnaire scales employed in this study demonstrate sound reliability.

2. Overall Reliability Testing

Table 4.2 Reliability Statistics

Cronbach's Alpha	Cronbach's Alpha Based on Standardised Items	Number of Items
.990	.990	23

As indicated by the overall reliability coefficient in Table 4.2, the standardised Cronbach's alpha coefficient is 0.990, exceeding 0.9. This demonstrates that the questionnaire exhibits high overall reliability and a high level of internal consistency.

4.2. Validity Analysis

Following satisfactory reliability testing, validity assessment of the measurement results is required. Construct validity refers to the ability to test theoretical concepts and traits, with test results capable of confirming or explaining theoretical hypotheses or constructs. This encompasses Exploratory Factor Analysis (EFA) and Confirmatory Factor Analysis (CFA). This study primarily employed SPSS 26.0 and Amos 24.0 software for validity testing of the scales.

4.2.1. KMO and Sphericity Tests

Table 4.3 KMO and Bartlett's Test

KMO Sample Adequacy Measure		.976
Burtlett's Sphericity Test	Approximate Chi-Square	7354.126
	Degrees of freedom	253
	Significance	.000

The KMO coefficient in Table 4.3 is 0.976, exceeding 0.9, demonstrating excellent construct validity and suitability for factor analysis. The Bartlett's sphericity test yielded a significance level of 0.000, passing the 1% significance test. This indicates the questionnaire scale is ideal for factor analysis and possesses sound validity.

4.2.2. Total Variance Explained

Table 4.4 Explained Total Variance

Component	Initial Eigenvalue			Extracted Loadings		
	Total	Percentage of Variance Explained	Cumulative %	Total	Percentage of variance	Cumulative %
1	18.72	81.391	81.391	18.72	81.391	81.391
2	0.384	1.669	83.06			
3	0.348	1.513	84.574			
4	0.331	1.44	86.014			
5	0.306	1.329	87.343			
6	0.282	1.226	88.568			
7	0.26	1.131	89.7			
8	0.244	1.062	90.762			
9	0.233	1.013	91.774			
10	0.209	0.908	92.682			
11	0.19	0.825	93.508			
12	0.181	0.786	94.294			
13	0.174	0.755	95.048			
14	0.17	0.74	95.788			
15	0.154	0.67	96.458			
16	0.138	0.601	97.06			
17	0.131	0.568	97.628			
18	0.118	0.515	98.143			
19	0.112	0.486	98.629			
20	0.098	0.424	99.053			
21	0.09	0.39	99.443			
22	0.075	0.328	99.771			
23	0.053	0.229	100			
Extraction method: Principal Component Analysis.						

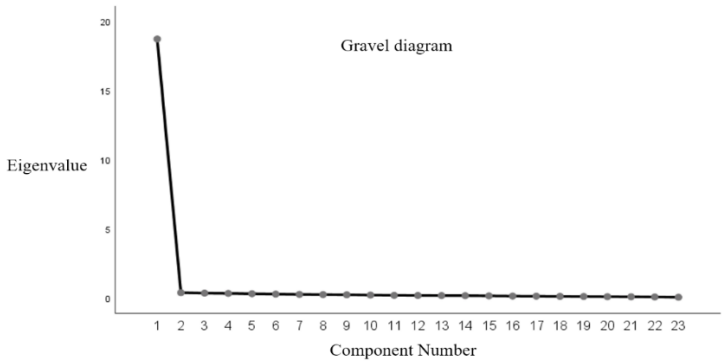

Fig. 4.1 Gravel diagram

The principal component extraction results are shown in Table 4.4. One factor with an initial eigenvalue greater than 1 indicates that extracting one factor provides an ideal level of explanatory power for the original data. The cumulative variance explained is 81.391%, exceeding the critical value of 60%. This demonstrates that the common factor extracted from the questionnaire is highly representative of the original variables, indicating good overall measurement effectiveness for the scale, which can proceed to subsequent analysis.

4.2.3. Overall Fit Indices

Table 4.5 Overall Fit Indices

Indicator	Reference Standard	Actual Results
CMIN/DF	1–3: Excellent; 3–5: Good	2.245
RMSEA	<0.05 is excellent, <0.08 is good (acceptable)	0.076
NFI	>0.9 indicates excellent fit, >0.8 indicates good fit	0.933
RFI	>0.9 is excellent, >0.8 is good	0.926
IFI	>0.9 is excellent, >0.8 is good	0.962
TLI	>0.9 is excellent, >0.8 is good	0.957
CFI	>0.9 is excellent, >0.8 is good	0.962

The overall model fit indices obtained via Amos analysis were: CMIN/DF=2.245, falling within the 1-3 range; RMSEA=0.076, below 0.08. Additionally, NFI, RFI, IFI, TLI, and CFI all exceeded 0.9, indicating overall good model fit.

4.2.4. Convergent Validity Testing

Table 4.6 Convergent Validity Tests

Path Relationships			Estimate	AVE	CR
szh6	<---	Digital Transformation	0.875		
szh5	<---	Digital Transformation	0.897		
szh4	<---	Digital Transformation	0.906	0.8032	0.9608
szh3	<---	Digital Transformation	0.901		
szh2	<---	Digital Transformation	0.898		
szh1	<---	Digital Transformation	0.9		
fw1	<---	Innovation Culture	0.909		
fw2	<---	Innovation Atmosphere	0.899		
fw3	<---	Innovation Atmosphere	0.873		
fw4	<---	Innovation Atmosphere	0.907	0.8081	0.9711
fw5	<---	Innovation Atmosphere	0.876		
fw6	<---	Innovation Climate	0.843		
fw7	<---	Innovation Atmosphere	0.88		
fw8	<---	Innovation Atmosphere	0.899		
nl1	<---	Innovation Capacity	0.899		
nl2	<---	Innovation capacity	0.912		
nl3	<---	Innovation Capacity	0.907		
nl4	<---	Innovation Capacity	0.898		
nl5	<---	Innovation Capacity	0.872	0.8113	0.9748
nl6	<---	Innovation Capacity	0.896		
nl7	<---	Innovation Capacity	0.901		
nl8	<---	Innovation Capacity	0.904		
nl9	<---	Innovation Capacity	0.917		

As shown in Table 4.6, the factor loadings for items corresponding to latent variables across all dimensions exceed 0.7, indicating high representativeness of items for each variable. Furthermore, the AVE values for all dimensions exceed 0.5, while CR values exceed 0.7, demonstrating satisfactory convergent validity of the model.

4.2.5. Discrimination Validity Testing

Table 4.7 Discriminant Validity Test

Variable	Digital Transformation	Innovation Climate	Innovation Capability
Digital Transformation	0.803		
Innovation Environment	1.010	0.808	
Innovation Capacity	0.313	0.692	0.813
Square root of AVE	0.896	0.899	0.902

As shown in Table 4.7, in this discriminant validity test, significant correlations exist among digital transformation, innovation climate, and innovation capability. Moreover, most correlation coefficients are smaller than the square root of the corresponding dimension's AVE value, indicating relatively satisfactory discriminant validity.

4.2.6. SEM Path Relationship Hypothesis Test Results

Table 4.8 SEM Path Relationship Test Results

Path Relationship			Estimate	S.E.	C.R.	P
Innovation Atmosphere	<---	Digital Transformation	1.01	0.051	20.646	***
Innovation Capacity	<---	Innovation Environment	0.692	0.156	4.39	***
Innovation Capacity	<---	Digital Transformation	0.313	0.162	2.006	0.045

Note: *** denotes p-value less than 0.001

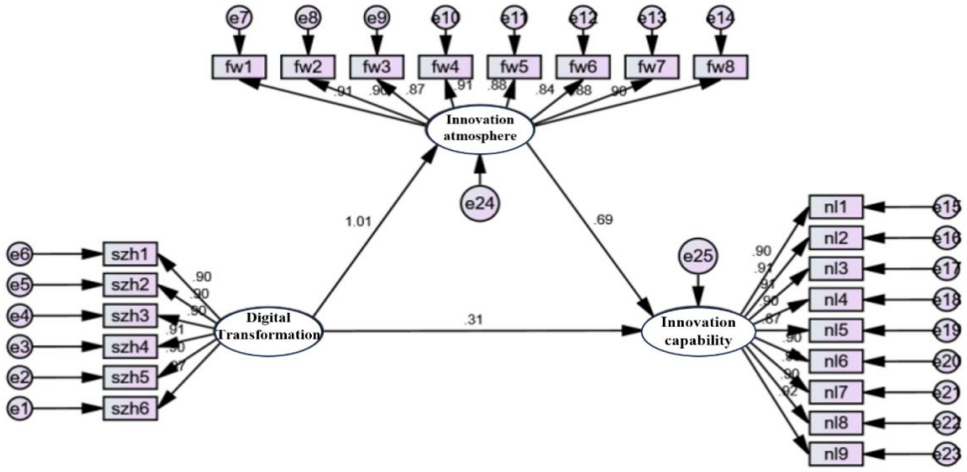

Fig.4.2 SEM Analysis Diagram of Influencing Factors

4.3. Correlation Analysis

Table 4.9 Correlation Analysis Among Dimensions

Variable	Correlation	Digital Transformation	Innovation Atmosphere	Innovation Capability	Years in operation	Company size
Digital Transformation	Pearson Correlation	1				
Innovation culture	Pearson Correlation	.973**	1			
Innovation Capacity	Pearson Correlation	.979**	.979**	1		
Years since company establishment	Pearson Correlation	.340**	.353**	.359**	1	
Company size	Pearson Correlation	.494**	.490**	.486**	.786**	1

Note: **Significant at the 0.01 level (two-tailed).

The study employed Pearson correlation analysis to examine relationships between variables, with results presented in Table 4.9. Digital transformation exhibits significant positive correlations with both innovation climate and innovation capability, yielding Pearson correlation coefficients of 0.973 ($p < 0.01$) and 0.979 ($p < 0.01$) respectively. Innovation climate and innovation capability also exhibit a significant positive correlation, with a Pearson correlation coefficient of 0.979 ($p < 0.01$).

4.4. Regression Analysis

Regression analysis was conducted on the collected enterprise sample data using SPSS 26.0, with results presented in Table 4.10.

Table 4.10 Regression Analysis Table

Variable	Innovation Capability		Innovation Climate		Innovation Capability	
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Years in operation	-0.887	0.943**	-1.043*	0.49*	0.312	0.663*
Company size	5.56***	-0.516*	4.915***	-0.176*	-0.094	-0.415*
Digital transformation		1.485***		1.244***		0.776***
Innovation Climate					1.15***	0.57***
R^2	0.238	0.96	0.243	0.948	0.959	0.972
Adjusted R^2	0.238	0.722	0.243	0.705	0.721	0.972
F value	33.055***	1695.395***	34.027***	1273.377***	1634.421***	1849.132***

Note: * denotes p-value < 0.05, ** denotes p-value < 0.01, *** denotes p-value < 0.001

In the regression model, variables potentially influencing innovation capability—such as the enterprise's years in operation and scale—were treated as control variables. The independent variable was set as digital transformation, and the dependent variable as enterprise innovation capability. Results, as shown in Model 2 of Table 4.10, indicate that digital transformation exerts a significant positive effect on enhancing innovation capability ($r=1.485$, $p<0.001$), thereby validating Hypothesis H1.

In Model 6 of Table 4.10, incorporating all three dimensions—digital transformation, innovation climate, and innovation capability—simultaneously into the regression model reveals that digital transformation positively influences corporate innovation climate, with a regression coefficient of 0.776, significant at the 0.1% level. Concurrently, corporate innovation climate exerts a significant positive effect on innovation capability, with a regression coefficient of 0.57, also significant at the 0.1% level. This confirms the partial existence of a mediating effect.

4.5. Testing the Mediating Effect

To verify the accuracy of the mediation effect conclusions, a bootstrap test was conducted using the Process macro plugin. The test results are presented in Table 4.11.

Table 4.11 Mediation Effect Test

	Effect	BootSE	BootLLCI	BootULCI	Effect Proportion
Mediation Effect	0.7086	0.1121	0.491	0.9351	47.73%
Direct effect	0.776	0.1192	0.5371	1.0093	52.27%
Total Effect	1.4846	0.024	1.4373	1.5319	100%

Table 4.11 data indicates that the total effect coefficient between digital transformation and corporate innovation climate is 1.4846, with a direct effect coefficient of 0.776 and a mediating effect coefficient for innovation climate of 0.7086. The direct effect accounts for 52.27% while the mediating effect accounts for 47.73%. The mediating effect of corporate innovation climate is significant, validating H2.

5. Research Findings and Implications

5.1. Research Findings

Through theoretical analysis, literature review, and empirical investigation, this study draws the following conclusions:

Firstly, the degree of digital transformation in manufacturing enterprises exerts a significant direct positive influence on enhancing innovation capability. The application of digital technologies advances the coordinated development of internal processes such as R&D, design, production, storage, and sales, thereby increasing innovation opportunities, expanding innovation space, and elevating the enterprise's innovation capacity.

Second, within the context of digital transformation, the mediating effect of innovation climate on enhancing innovation capability is significant. Stimulating innovation vitality hinges on fostering a favourable innovation climate, which can invigorate employees' innovative drive and enhance the efficiency and enthusiasm of organisational innovation.

5.2. Management Implications

Empirical analysis indicates that digital transformation positively promotes the enhancement of corporate innovation capabilities, offering the following implications for managerial practice:

First, strengthen the digital infrastructure foundation. Throughout digital transformation, enterprises must continuously enhance their information systems to underpin further transformation. Concurrently, they should adopt technologies such as remote collaboration with specialist departments and virtual reality, tailored to operational needs, to digitise routine business processes and provide technical support for advancing digital transformation.

Second, cultivate a positive and open innovation environment. Achieving high-level innovation performance requires fostering an open, tolerant, and diverse workplace, providing innovation resources, and nurturing high-calibre innovative talent. Therefore, managers should prioritise creating a conducive innovation atmosphere, promoting internal innovation activities and the development of an innovation culture, thereby enhancing the enterprise's innovation capacity and enabling sustained innovation.

Thirdly, the government must continuously optimise the policy environment for corporate digital transformation. Firstly, it should increase investment in public digital infrastructure (such as 5G networks, data centres, and artificial intelligence) to provide critical foundational support for manufacturing enterprises undergoing digital transformation. Secondly, it is imperative to strengthen the development of digital government systems, enhance governmental operational efficiency, and drive the advancement of Digital China through the construction of digital government frameworks.

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