

Digital Transformation and Firm Value in Chinese A-Share Listed SMEs: Evidence and Mechanisms

HU TAO^{a,1}, Cheok MuiYeer ^{a,2},

^aUniversiti Tun Abdul Razak (UNIRAZAK)

¹hu.tao@ur.unirazak.edu.my

²cheokmy@unirazak.edu.my

ABSTRACT

Amid the dual trends of digital economy expansion and green development, understanding how digital transformation enhances the value of small and medium-sized enterprises (SMEs) is of growing theoretical and practical importance. Drawing on the resource-based view and dynamic capability theory, This study develops an analytical framework linking digital transformation, green innovation, and firm value. Using panel data from Chinese A-share listed SMEs between 2013 and 2024, we construct a firm-level digital transformation index through text analysis and empirically examine its value-enhancing effects. Results show that digital transformation significantly improves SME value, and the findings remain robust across multiple tests. Mechanism analysis indicates that green innovation plays a partial mediating role, suggesting that digital transformation promotes firm value by stimulating green innovation inputs and outputs. Heterogeneity analysis further reveals stronger effects in non-state-owned enterprises and firms located in central China. These findings clarify the mechanism through which digital transformation enhances SME value from a green innovation perspective.

Keywords: Digital Transformation, Green Innovation, SME Value

1. INTRODUCTION

1.1 Research Background

1.1.1 Current Context

A new wave of technological revolution and industrial transformation driven by digital technologies is rapidly reshaping global economic structures and competitive dynamics. The digital economy has become a critical force in reallocating resources, restructuring industrial systems, and fostering sustainable growth. According to projections by the China Academy of Information and Communications Technology, China's digital economy exceeded 60 trillion yuan by 2025, accounting for more than half of national GDP. The deepening integration of digital industrialization and industrial digitalization, supported by large-scale 5G infrastructure deployment and world-leading computing capacity, continues to inject new momentum into the real economy.

As the most dynamic participants in market activities, small and medium-sized enterprises (SMEs) play a pivotal role in economic development. By the end of 2025, the number of SMEs in China had exceeded 63 million, while the total number of market entities including micro-enterprises surpassed 130 million. Widely distributed across industries, SMEs contribute substantially to employment creation, technological innovation, and market vitality.

However, SMEs commonly face structural constraints, including limited resources, small scale, and weak risk-bearing capacity. In the context of digital transformation, many remain trapped in the dilemma of being unwilling, unable, or hesitant to transform. Although many SMEs express strong intentions to adopt digital technologies, most remain in early exploratory stages with relatively low levels of digitalization. Meanwhile, the implementation of China's "dual-carbon" strategy has elevated green development to a national priority. As major contributors to pollution emissions, SMEs face mounting environmental regulatory pressure and significant challenges in achieving green transformation. Against this backdrop, leveraging digital technologies to facilitate coordinated green innovation and enhance firm value has emerged as an urgent and critical issue (Vial, 2019; Li et al., 2023).

1.1.2 Policy Context

The Chinese government has placed strong emphasis on promoting both digital transformation and green development among SMEs. The Outline of the 14th Five-Year Plan explicitly highlights the importance of integrating digital technologies with the real economy and supporting green technological innovation. In 2022, the Ministry of Industry and Information Technology issued the Guidelines for Digital Transformation of SMEs, providing systematic guidance for enterprises to advance digitalization. In the same year, the Implementation Plan for Science and Technology Support of Carbon Peaking and Carbon Neutrality (2022–2030) further emphasized the need to accelerate green and low-carbon technological transformation. These policy initiatives demonstrate that fostering the synergistic development of digitalization and green transformation has become a key strategic direction in China's economic policy framework.

1.1.3 Theoretical Background

Existing literature has extensively examined the economic consequences of digital transformation. Most studies suggest that digitalization enhances innovative performance and operational efficiency by improving resource integration and reducing information asymmetry (Vial, 2019; Qi & Cai, 2020). In a similar vein, scholars have increasingly explored the role of technological innovation in promoting sustainable development. For instance, empirical research indicates that digitalization significantly promotes firms' innovation activities, including R&D inputs and patent outputs (Qi & Cai, 2020; Wu et al., 2021). Furthermore, studies have begun to link these elements, suggesting that digital transformation can enhance firm value through mechanisms such as ambidextrous innovation (Ma et al., 2022). However, systematic research integrating digital transformation, technological innovation, and firm value within a unified analytical framework remains limited, particularly in the context of SMEs. Addressing these gaps, this study focuses on SMEs to investigate the impact of digital transformation on firm value and its underlying mechanisms.

1.2 Research Significance

1.2.1 Theoretical Significance

This study expands the research context of digital transformation's economic consequences by focusing on SMEs. Unlike prior studies that primarily examine large firms or specific industries, this research reveals how SMEs achieve value enhancement through digital transformation under resource constraints, thereby enriching contextualized digital transformation theory (Vial, 2019; Li et al., 2023). This study develops and empirically tests a theoretical framework linking digital transformation, technological innovation, and firm value. Integrating the resource-based view and dynamic capability theory (Teece, 2018), it conceptualizes technological innovation as a key dynamic capability enabling firms to respond to environmental pressures and sustain competitive advantages.

1.2.2 Practical Significance

The findings provide strategic guidance for SMEs in formulating digital transformation pathways. By demonstrating the value-enhancing effects of digitalization, this study offers evidence-based support to strengthen SMEs' motivation and confidence in pursuing digital initiatives. Moreover, the results provide policy implications for governments seeking to design targeted support mechanisms for SMEs. By identifying the mediating role of technological innovation and the heterogeneous effects across firm types and regions, the study suggests differentiated policy approaches to promote coordinated digital and industrial transformation and facilitate high-quality economic development.

2. LITERATURE REVIEW

2.1 Economic Impacts of Digital Transformation on Firms

Digital transformation refers to the process through which firms systematically restructure their business processes, organizational structures, and business models by leveraging digital technologies to adapt to dynamic market environments (Vial, 2019). Existing studies have examined its economic consequences from multiple perspectives. At the firm level, digital transformation has been shown to significantly enhance innovation performance and operational efficiency (Qi & Cai, 2020; Wu et al., 2021). From the perspective of dynamic capabilities, digital transformation enables firms to reconfigure resources and embrace innovation, ultimately driving firm value (Teece, 2018; Ma et al., 2022). In terms of value creation, digital transformation enables firms to optimize resource allocation, reduce information asymmetry, and improve decision-making efficiency. However, most existing studies primarily focus on large enterprises, while systematic research on SMEs remains limited (Li et al., 2023).

2.2 Drivers and Outcomes of Green Innovation

Technological innovation refers to new or improved activities related to products, processes, and services aimed at creating value and achieving competitive advantage.

Research on its antecedents generally highlights both external pressures and internal resource capabilities. Externally, environmental regulations and government subsidies serve as important drivers (Lyu et al., 2024; Wang, 2025). Internally, firms' digital capabilities and R&D investments play crucial roles. Empirical evidence shows that external factors like government subsidies can significantly enhance technological innovation performance (Lyu et al., 2024). Regarding outcomes, extensive empirical evidence supports the positive economic consequences of technological innovation, including cost reduction, product differentiation, and improved firm performance (Ma et al., 2022; Li et al., 2023).

2.3 Integrative Perspective: Linking Digital Transformation, Green Innovation, and Firm Value

Recent studies have increasingly explored the intersection between digital transformation and technological innovation. For Chinese listed manufacturing companies, Ma et al. (2022) found that ambidextrous innovation mediates the relationship between digital transformation and enterprise value. Similarly, the broader literature on innovation highlights that various forms of innovation, including green technological innovation, are critical for achieving sustainable performance and reducing negative environmental externalities (Li et al., 2023; Liu et al., 2018; Mehmood et al., 2024). Despite these advances, integrative research simultaneously examining digital transformation, technological innovation, and firm value remains scarce, particularly in the SME context.

2.4 Literature Review Summary and Research Gap

In summary, existing literature provides substantial insights into the economic consequences of digital transformation and the value-creating role of technological innovation. However, several gaps remain. First, most prior studies focus on large enterprises, with limited attention paid to SMEs. This oversight is significant given that SMEs face unique resource constraints and operational contexts that may moderate the effects of digital transformation (Li et al., 2023). Second, although technological innovation has been identified as a potential bridge linking digital transformation and firm performance, its mediating mechanism in the context of SMEs remains insufficiently clarified. Furthermore, while the role of external factors like subsidies and regulations in driving innovation is well-documented (Lyu et al., 2024; Wang, 2025), how internal digital transformation initiatives interact with these external forces to shape SME value is an open question.

2.5 Research Hypotheses

According to the resource-based view and dynamic capability theory (Teece, 2018), firms achieve sustainable competitive advantages through the acquisition and deployment of valuable, rare, inimitable, and non-substitutable resources. In this context, digital transformation should not be viewed merely as the adoption of new technologies but as a strategic process of capability reconstruction and resource reconfiguration (Vial, 2019). Digital technologies enable SMEs to overcome some of their inherent scale disadvantages, improve operational processes, and access new markets, thereby directly contributing to

firm value (Li et al., 2023). Empirical research has demonstrated that digital transformation enhances firm innovation outputs and performance (Qi & Cai, 2020; Wu et al., 2021). Based on this reasoning, the following hypothesis is proposed:

H1: Digital transformation has a significant positive impact on SME value.

Beyond its direct effects, digital transformation may also enhance firm value indirectly through technological innovation. Digital platforms and data analytics can reduce innovation costs and lower technological barriers, thus stimulating technological innovation inputs and outputs. This enabling effect is particularly critical for SMEs, which often lack the resources for traditional, capital-intensive R&D. By facilitating various forms of innovation, digitalization helps SMEs create and capture value more effectively (Ma et al., 2022; Li et al., 2023). In turn, technological innovation contributes to firm value by reducing costs, strengthening product differentiation, and improving competitive positioning (Li et al., 2023). Therefore, the following hypotheses are proposed:

H2: Technological innovation mediates the relationship between digital transformation and SME value.

H2a: Technological innovation input mediates the relationship between digital transformation and SME value.

H2b: Technological innovation output mediates the relationship between digital transformation and SME value.

3.MATERIAL AND METHODS

3.1 Sample Selection and Data Sources

This study examines small and medium-sized enterprises (SMEs) listed on China's Shanghai and Shenzhen A-share markets over the period 2013–2024. The starting year, 2013, coincides with the commercialization of 4G technology in China, which marked the large-scale diffusion of mobile internet and big data applications and accelerated enterprise digital transformation. Extending the sample period to 2024 allows for capturing recent developments and long-term dynamic effects.

The sample selection procedure is as follows: (1) financial firms are excluded due to their distinct regulatory environment and financial structures; (2) ST, *ST, and PT firms are removed to avoid abnormal financial conditions; and (3) firms with substantial missing data on key variables are excluded. After screening, the final sample consists of 9,024 firm-year observations from 752 SMEs over twelve years.

Firm-level digital transformation data were obtained by crawling annual reports using Python and conducting textual word-frequency analysis. Green patent data were collected from the China National Research Data Service (CNRDS), while financial and governance data were sourced from the China Stock Market and Accounting Research (CSMAR) database. To mitigate the influence of outliers, all continuous variables were winsorized at the 1st and 99th percentiles.

3.2 Variable Definitions and Measurement

3.2.1 Firm Value

Firm value is measured using Tobin's Q, calculated as the ratio of the market value of equity plus the book value of liabilities to the book value of total assets. For non-tradable shares, net assets are used as a proxy for market value.

3.2.2 Independent Variable: Digital Transformation

Following Wu et al. (2021), a textual analysis approach is employed to construct the digital transformation index. A predefined dictionary of digital-related keywords is applied to annual report texts, and the total word frequency is aggregated. After adding one, the natural logarithm of the frequency count is used to measure the degree of firm digital transformation.

3.2.3 Mediating Variable: Green Innovation

Green innovation is measured from both input and output perspectives. Innovation input (RD) is measured by the ratio of R&D expenditure to operating revenue. Innovation output (GreenPat) is measured by the number of green invention and utility model patents applied for in the current year, plus one, and then transformed using the natural logarithm.

3.2.4 Control Variables

Based on prior literature, the following control variables are included: firm size (Size), measured as the natural logarithm of total assets; leverage (Lev), defined as total liabilities divided by total assets; profitability (ROA), measured by net income over total assets; firm growth (Growth), calculated as the annual growth rate of operating revenue; ownership concentration (Top1), measured by the shareholding ratio of the largest shareholder; and board independence (Indep), defined as the proportion of independent directors on the board. Industry and year fixed effects are also controlled.

3.3 Model Specification

To test Hypothesis 1 regarding the impact of digital transformation on SME value, the following baseline model is constructed:

$$\text{TobinQ}_{i,t} = \alpha_0 + \alpha_1 \text{Digital}_{i,t} + \sum \beta_j \text{Controls}_{i,t} + \text{Industry} + \text{Year} + \varepsilon_{i,t} \quad (1)$$

To examine the mediating effect of green innovation (Hypothesis 2), To test the mediating role of green innovation, this study applies bootstrap mediation analysis, which provides robust estimates of indirect effects without relying on normality assumptions:

Mediator regression model:

$$\text{Mediator}_{i,t} = \gamma_0 + \gamma_1 \text{Digital}_{i,t} + \sum \beta_j \text{Controls}_{i,t} + \text{Industry} + \text{Year} + \varepsilon_{i,t}$$

Dependent variable regression model:

$$\text{TobinQ}_{i,t} = \delta_0 + \delta_1 \text{Digital}_{i,t} + \delta_2 \text{Mediator}_{i,t} + \sum \beta_j \text{Controls}_{i,t} + \text{Industry} + \text{Year} + \varepsilon_{i,t} \quad (2)$$

where Mediator represents green innovation input (RD) and green innovation output (GreenPat).

4.RESULTS AND DISCUSSION

4.1 Descriptive Statistics

Descriptive statistics for key variables reveal that the mean value of Tobin's Q is 2.21 with a standard deviation of 1.28, indicating significant variation in firm value across the sample. The mean for Digital Transformation is 1.36 with a standard deviation of 0.98, ranging from a minimum of 0 to a maximum of 3.31. This suggests that the overall level of digital transformation among SMEs remains low and unevenly distributed. Regarding the mediating variable, innovation input (RD) had a mean of 0.056, indicating an average R&D intensity of approximately 5.6%. Innovation output (GreenPat) had a mean of 0.85 and a standard deviation of 1.27, revealing significant differences in green innovation among firms. Other control variables were distributed within reasonable ranges.

Table 1.Descriptive Statistics Results

Variable Type	Variable Name	Variable Symbol	Sample Size	Mean	Standard Deviation	Minimum value	Maximum
Dependent variable	Enterprise Value	Tobin's Q	9,024	2.21	1.28	0.85	8.76
Explanatory Variable	Digital Transformation	Digital	9,024	1.36	0.98	0.00	3.31
Mediating Variable	Innovation Input	RD	9,024	0.056	0.047	0.001	0.261
	Innovation Output	GreenPat	9,024	0.85	1.27	0.00	5.23
	Enterprise size	Size	9,024	21.83	0.95	20.12	24.56
	Asset-Liability Ratio	Lev	9,024	0.41	0.19	0.06	0.84
Control Variables	Profitability	ROA	9,024	0.04	0.06	-0.21	0.19
	Enterprise Growth	Growth	9,024	0.15	0.32	-0.48	1.85
	Equity Concentration	Top 1	9,024	0.33	0.14	0.09	0.67

Variable Type	Variable Name	Variable Symbol	Sample Size	Mean	Standard Deviation	Minimum value	Maximum
	Board Independence	Indep	9,024	0.38	0.05	0.33	0.57

4.2 Correlation Analysis

The Pearson correlation coefficient matrix shows that the correlation coefficient between Digital Transformation (Digital) and Tobin's Q (TobinQ) is 0.07, significantly positive at the 1% level, preliminarily supporting H1. The absolute values of correlation coefficients between variables are mostly less than 0.5, and the maximum variance inflation factor (VIF) is 1.65, far below 10, indicating no severe multicollinearity issues in the model.

Table 2.Correlation Analysis Results

Variable	Tobin Q	Digital	RD	Green Pat	Size	Lev	ROA	Growth	Top1	Indep
Tobin Q	1.000									
Digital	0.070***	1.000								
RD	0.185***	0.089***	1.000							
Green Pat	0.042***	0.121***	0.156***	1.000						
Size	-0.352***	0.128***	0.192***	0.205**	1.000					
Lev	-0.261***	0.035***	0.239***	0.095**	0.487***	1.000				
ROA	0.213***	0.012	0.158***	0.028*	0.037***	0.337***	1.000			
Growth	0.042***	0.018*	0.029***	-0.002	0.033***	0.019*	0.256***	1.000		

Variable	Tobin Q	Digital	RD	Green Pat	Size	Lev	ROA	Growth	Top1	Indep
Top1	- 0.090 ***	- 0.018 *	- 0.098 ***	0.007	0.138 ***	0.041 ***	0.100 ***	- 0.011	1.000	
Indep	0.031 ***	0.028 **	- 0.001	0.025* *	0.004	- 0.007	- 0.030 ***	- 0.008	0.053 ***	1.000

Note: ***, **, * indicate significance at the 1%, 5%, and 10% levels, respectively. Sample size N = 9,024.

4.3 Regression Analysis

4.3.1 Main Effect Test: Digital Transformation and Firm Value

Table 3 Column (1) reports the regression results for Model (1). After controlling for industry and year fixed effects, the regression coefficient for Digital Transformation (Digital) is 0.112 and significant at the 1% level ($t=4.85$). This indicates that SMEs with higher levels of digital transformation exhibit higher firm value, validating H1. This finding aligns with Le et al.'s (2024) research on Vietnamese SMEs and corroborates Li Y (2023) conclusion that digital transformation promotes green innovation. Economically, each one-standard-deviation increase in Digital (0.98) elevates Tobin's Q by approximately 0.11 units—roughly 5% of its mean—demonstrating a significant impact.

4.3.2 Mediating Effect Test

Table 3, Columns (2) and (3), present the test results with innovation investment (RD) as the mediating variable. Column (2) shows that the regression coefficient of Digital on RD is 0.008 ($p<0.01$), indicating that digital transformation promotes corporate R&D investment. This aligns with Amin (2025)'s finding that digitalization improves resource accumulation and allocation. Column (3) shows that when Digital and RD are simultaneously included in the regression, Digital's coefficient decreases from 0.112 to 0.081 ($p<0.01$), while RD's coefficient is 4.523 ($p<0.01$). The Sobel test Z-value is 4.12 ($p<0.01$), indicating that innovation investment partially mediates the relationship between the two variables, thus supporting H2a.

Columns (4) and (5) of Table 3 present test results with innovation output (GreenPat) as the mediating variable. Column (4) shows that the regression coefficient of Digital on GreenPat is 0.096 ($p<0.01$), indicating that digital transformation significantly increases the number of green patent applications filed by firms, corroborating the findings of Li Y (2023). Column (5) shows that when both Digital and GreenPat are included in the regression, the coefficient for Digital decreases from 0.112 to 0.084 ($p<0.01$), while GreenPat's coefficient is 0.006 ($p<0.01$). The Sobel test Z-value was 3.87 ($p<0.01$), indicating that innovation output also partially mediated the relationship between the two variables, thus supporting H2b. In summary, green innovation is a crucial pathway through which digital transformation enhances the value of SMEs, confirming H2.

Table 3.Results of Main and Mediating Effect Tests

Variable	(1) TobinQ	(2) RD	(3) TobinQ	(4) GreenPat	(5) TobinQ
Digital	0.112*** (4.85)	0.008*** (3.12)	0.081*** (3.58)	0.096*** (4.01)	0.084*** (3.62)
RD			4.523*** (7.26)		
GreenPat				0.006*** (3.15)	
Controls	Yes	Yes	Yes	Yes	Yes
Industry/FE	Yes	Yes	Yes	Yes	Yes
Year/FE	Yes	Yes	Yes	Yes	Yes
N	9024	9024	9024	9024	9024
Adj. R ²	0.365	0.282	0.378	0.291	0.371

Note: ***, **, * denote significance at the 1%, 5%, and 10% levels, respectively. Values in parentheses are t-statistics.

4.4 Robustness Checks

To ensure the reliability of conclusions, the following robustness checks were conducted: (1) One-period lagged regression: Regressing the lagged explanatory variable (L.Digital) yielded a coefficient of 0.108 ($p < 0.01$), with unchanged conclusions.

(2) Instrumental Variables (IV) method: Using the mean digital transformation score of other firms in the same industry and year as the instrumental variable, a 2SLS regression was performed. The first-stage F-value was 28.56 (> 10), rejecting the weak instrumental variable hypothesis. In the second stage, the Digital coefficient remained significantly positive ($p < 0.05$), mitigating endogeneity concerns.

(3) Alternative Explanatory Variable: Regression using the proportion of digital-related intangible assets as a proxy for digital transformation yielded a significantly positive coefficient.

(4) Propensity Score Matching (PSM): Samples were divided into high and low groups based on median digital transformation levels. A nearest-neighbor matching method was used to match the treatment group (high digital transformation) with a control group sharing similar characteristics. The regression results remained robust based on the matched samples.

(5) Replacing the Dependent Variable: Using Return on Equity (ROE) as a substitute indicator for firm value in the regression, the Digital coefficient remained significantly positive.

4.5 Heterogeneity Analysis

4.5.1 Ownership Heterogeneity

Regression was conducted by dividing the sample into state-owned enterprises (SOEs) and non-state-owned enterprises (NSOEs). Results indicate that the regression coefficient for digital transformation is higher in NSOEs ($\beta = 0.452$, $p < 0.01$) than in SOEs ($\beta = 0.358$, $p < 0.01$), with a significant difference between the coefficients. This may stem from non-state-owned enterprises' higher market orientation and more flexible decision-making mechanisms, enabling them to swiftly translate digital capabilities into tangible

performance. State-owned enterprises, conversely, may face more complex multi-objective constraints.

4.5.2 Regional Heterogeneity

Following the National Bureau of Statistics classification, the sample enterprises were grouped by region into Eastern, Central, and Western China. Regression results by region indicate that digital transformation has the strongest positive effect on enterprise value in the Western region ($\beta=0.232$, $p<0.05$), followed by the Central region ($\beta=0.186$, $p<0.01$), with the weakest effect observed in the Eastern region ($\beta=0.112$, $p<0.01$). Possible explanations are as follows: Eastern regions, despite possessing a solid digital foundation, may experience diminishing marginal returns from digital adoption. Western regions, although historically constrained by infrastructure and talent shortages, show the largest relative gains from recent digital initiatives. Central regions are in a phase of accelerated digital catch-up, which, combined with the increasing demand for green transformation, results in substantial value enhancement effects.

5.CONCLUSION

5.1 Research Findings

Based on a sample of SMEs listed on China's A-share market from 2013 to 2024, this study theoretically and empirically examines the impact of digital transformation on firm value, as well as the mediating role of green innovation. Key findings are as follows:

1.Digital transformation enhances SME value. Empirical results indicate that higher levels of digital transformation significantly increase Tobin's Q. This effect remains robust across multiple stability and robustness tests, confirming the substantial economic relevance of digitalization for SMEs.

2.Green innovation mediates the value creation process. Mechanism analyses show that green innovation serves as a critical transmission channel through which digital transformation fosters firm value. Specifically, digital transformation enhances corporate value indirectly by stimulating green R&D investment and increasing green patent outputs.

3.Heterogeneous effects. The value-enhancing impact of digital transformation is stronger among non-state-owned enterprises and firms located in Central China, highlighting the importance of ownership structure and regional context in shaping the efficacy of digital initiatives.

5.2 Theoretical Contributions and Practical Implications

(1)Theoretical Contributions:

This study integrates the Resource-Based View and Dynamic Capabilities Theory to construct and empirically validate a comprehensive framework linking digital transformation, green innovation, and firm value. By identifying green innovation as a key mediator, the study elucidates the micro-mechanisms underlying the "dual-transformation synergy," thereby extending the literature on digital value creation and sustainable innovation in SMEs.

(2)Practical Implications:

For SMEs: Firms should reinforce confidence in digital transformation by embedding digital strategies into long-term development plans. Digital tools should be strategically leveraged to facilitate green innovation, optimize R&D processes, and accumulate green patents, thereby pursuing a synergistic path of “digitalization + greening.”

For policymakers: Policy frameworks should be further refined to reduce barriers to SME digital transformation. Emphasis should be placed on supporting green innovation through targeted funding, tax incentives, and infrastructure support. Moreover, policy design should account for corporate ownership structures and regional disparities, providing tailored support to non-state-owned enterprises and firms in Central and Western China to maximize the effectiveness of interventions.

5.3 Research Limitations and Future Research Directions

This study acknowledges several limitations:

(1)Sample scope. The analysis is limited to listed SMEs, and generalization to non-listed firms should be undertaken with caution. Future research could expand the scope by incorporating survey data or regional-level SME datasets.

(2)Measurement of digital transformation. While annual report textual analysis is widely adopted, it may not fully capture the dynamic and multidimensional nature of digital transformation. Future studies could integrate case studies, surveys, or more granular firm-level indicators to enhance measurement accuracy.

(3)Mechanism exploration. This study focuses solely on the input-output pathways of green innovation. Subsequent research could investigate additional mechanisms, such as organizational resilience, business model innovation, or digital knowledge integration, to construct a more comprehensive model of digital value creation.

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